A RUDIMENTARY TREATISE

ON

COAL AND COAL MINING

BY THE LATE

SIR WARINGTON W. SMYTH, M.A., F.R.S.

CHIEF INSPECTOR OF THE MINES OF THE CROWN AND OF THE DUCHY OF CORNWALL, ETC. ETC.

Eighth Edition, Revised and Extended

BY

T. FORSTER BROWN

MINING AND CIVIL ENGINEER
CHIEF INSPECTOR OF THE MINES OF THE CROWN AND OF THE DUCHY OF CORNWALL, ETC. ETC.

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EXTRACTS FROM

PREFACE TO FIRST EDITION.

THE following pages have been written as an elementary account of COAL, and the modes of working and raising it from the pits. Those who are familiar with the details of this great branch of British industry may probably object to the brevity with which portions of the subject have been treated; but I must plead in reply the narrow limits allotted me. I have endeavoured as far as possible to supply a general view of the methods and appliances employed in various districts, giving the fuller prominence to a description of the principal coal-producing regions at home and abroad, and of the various precautions needed for the preservation of human life.

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I trust that this little introduction to COAL-MINING bears internal evidence of not being mere extract of books; and that—whilst intended mainly to convey sound information to the unpractised—it may, nevertheless, contain matter of interest for Viewers and Overmen, to a long list of whom I have to express my thanks for many an instructive and agreeable day underground.

W. W. S.

EDITOR'S PREFACE TO THE EIGHTH EDITION.

AT the request of Lady Smyth I have gladly undertaken—in conjunction with my son, Mr. W. Forster Brown—to edit this new edition of the work of my late friend, Sir Warington W. Smyth, on COAL AND COAL-MINING, seven large editions whereof have already been issued, as revised from time to time by the Author.

Our object has been to maintain Sir Warington Smyth's original design of an elementary account of Coal and Coal-Mining. Naturally, with such a progressive industry as Coal-Mining, various changes and improvements are from time to time adopted, and it has been our endeavour in the present edition, as far as practicable, to describe the existing modes of working and treating Coal, whilst retaining the general character of the book in other respects.

The principal additions we have made are two short Chapters on Blasting Explosives and Coke-Making, respectively. The other subjects, where required, have been added to and brought up to date.

T. FORSTER BROWN.

CARDIFF, *October*, 1899.

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COAL AND COAL-MINING.

CHAPTER I.

THE USE OF COAL: ITS COMMENCEMENT AND EXTENSION.

IN these our modern days, surrounded as we are by coal-fires, steam, and coal-products, it is somewhat difficult to imagine ourselves in the position of the early writers on natural history, who touched with uncertain pen on what they thought to be the leading characters of a rare and ambiguous mineral. Many of the passages which have been quoted from ancient authors as indicating a knowledge of the use of coal have no reference whatever to the substance to which we now give the name, but indicate simply charcoal, or even wood-fuel. The translators of the Scriptures have thus employed the word *coal* in the same sense as the Greek *anthrax*, the Latin *carbo*, and the German *kohle;* the same, in fact, as was usual in our own language, until wood and charcoal came to be supplanted as fuel by their stony relative.

Certain varieties of this mineral were noticed by the ancients, although with little idea of the probability of their receiving any extensive application. Thus Theophrastus, the pupil of Aristotle, in an oft-quoted passage, described, nearly 300 years B.C., a fossil or stone-coal of an earthy character, found in Liguria (now the province of Genoa), and in Elis, on the way to Olympias, capable of kindling and burning like charcoal, and employed by smiths. *Ampelitis*, a black stone "like bitumen," and *Gagates*, or jet, are mentioned by Pliny and others as available for medicinal or ornamental purposes; but neither the naturalists who endeavoured to describe the various products of creation, nor the historians who enumerated the sources of wealth of particular countries, leave us the impression of their having seen or heard of a generally-useful fossil-fuel. It has been attempted to show that the early Britons worked coal; and a stone axe, stated by Pennant to have been found in the outcrop of a coal-seam in Wales, has been well-nigh worn out in the service; but we have no satisfactory evidence on the subject prior to the later days of the Roman occupation, when roads had been carried through many of the coal-producing districts. Coal-cinders have been found amid the ruins of several of the Roman stations in Durham, Northumberland, and Lancashire, and more recently at Wroxeter, the ancient Uriconium, the destruction of which place dates, according to Mr. Thomas Wright, F.S.A., from the sixth century.*

It is not until the thirteenth century that we obtain clear proof that coals were systematically raised for fuel. In 1239, King Henry III. is stated to have granted a charter for this purpose to the townsmen of Newcastle-on-Tyne; and so early was the produce of their pits attracted to the devouring focus of London, that by the beginning of the next century great complaint arose on the injury done by the coal-smoke to the health of the citizens. In 1306, on

* The cinders were still on the ground adjoining the baths when the British Association excursion visited the spot in September, 1865.

petition by Parliament, King Edward I., says Stowe, "by proclamation prohibited the burneing of sea-coale in London and the suburbs, to avoid the sulferous smoke and savour of the firing; and in the same proclamation commanded all persons to make their fires of wood." Not twenty years, however, passed away before the inevitable consequence of a gradually-pressing scarcity of wood followed; the banished "sea-coale" again sailed up the Thames, landed in the capital, and actually effected a lodgment in the Royal palace.* From that time forth, with a temporary check during the civil wars, the coal trade grew with the growth of the population, especially of London and the east coast, and *pari passu* with the rapid destruction of the forests.

On the Continent the coal-basin of Zwickau, in Saxony, appears to have been the earliest known in Germany, and it is said that its working can be carried back to the time of the Sorbenwends, about the tenth century. In 1348 the metal-workers of that town were forbidden to pollute the air with the smoke of coal. In Westphalia coals seem to have been dug near Dortmund as early as 1302.

The first mention of coal-mining in Scotland occurs in a grant executed in 1291 in favour of the abbot and convent of Dunfermline. Coal was probably worked on a small scale in several of the English and Welsh districts about this time; and we have the evidence of the quaint old traveller Marco Polo to show that the Chinese were at the same epoch well acquainted with its use.

One of the earliest manufactures which depended on the use of coal was glass-making, commenced about 1619 on the banks of the Tyne. In the year 1635, a proclamation of King Charles, prohibiting the importation of foreign glass, set forth that "Sir Robert Mansell had by his

* "The History of Fossil Fuel." London, 1841.

industry and great expense perfected that manufacture with sea-coal, or pit-coal, whereby not only the woods and timber of this kingdom are greatly preserved, but the making of all kinds of glass is established here, to the saving of much treasure at home, and the employment of great numbers of our people."

Up to the end of the seventeenth century pit-coal was employed for little else than household purposes; but it is not possible to obtain statistics of the quantities raised, excepting the amounts which were shipped. London and the east and the south-east coast, as well as some Continental ports, were supplied by Newcastle and Sunderland, which, about 1704, shipped off in a year respectively :—

178,143 chaldrons, or 473,080 tons;
and
65,760 chaldrons, or 174,264 tons.

In 1750 the *vend* from both ports together amounted to 1,193,457 tons.

Dublin and the east coast of Ireland were supplied from Flintshire and Whitehaven; whilst the requirements of the rest of the country were variously contributed to by small workings in the Lancashire, Staffordshire, Warwickshire, and other coalfields. Many experiments had in the meanwhile been tried in Staffordshire and the Forest of Dean to substitute pit-coal for wood-coal in the smelting of iron; but before this great revolution in commerce could be accomplished about one hundred and twenty years were to be occupied in trials, disappointments, losses, and delays.

Meanwhile, the beginning of the eighteenth century was marked by the first wavering steps of the infant Steam, so soon to develop into the mighty giant, depending for his strength on coal, himself making possible the extraction of the fuel from amid difficulties till then insurmountable, and opening out a thousand new methods for its consumption and application. Thus far coal had been valued for the production of Heat only. It was now to enter upon a second phase of usefulness—that of the generation of Force. Already ingenious minds had pondered on the possibility of raising water from the mines by aid of the power of steam. Solomon de Caus, a French engineer, in his work, published in 1615, entitled, "Les Raisons des Forces Mouvantes," proposed the experiment in scientific terms; and the Marquis of Worcester, in his "Century of Inventions," in 1655, rather dimly foreshadowed what might be done. But it was reserved for our countryman, Captain Thomas Savery, to apply the steam practically by the introduction of the principle of a vacuum, and to erect engines for the actual unwatering of mines at Great Work, in the parish of Breage, Cornwall, and in several other localities. In his paper read to the Royal Society in 1699, and in his treatise, "The Miner's Friend," 1702, Savery describes the construction of his fire-engine, and renders it very clear that although the coals to be used were to be "of as little value as the coals commonly burned in the mouths of the coal-pits are," this ingenious invention, in which the water was first "sucked up" into a receiver by condensing the steam within it, and then forced up a stand-pipe by the direct impulse of the steam, required at least another step to fit it for general application. This step was the interposition of a piston, on the surface of which the steam should exert its power; and the application was ere long made by Newcomen. Some years, however, before this, Dr. Papin, a French refugee, had proposed an engine, in which a piston working in a cylinder should be raised by the explosive force of gunpowder, and then depressed, on the condensation of the gases, by atmospheric pressure.

Soon afterwards he endeavoured to obtain the same result, so difficult of regulation with gunpowder, by introducing the elastic power of steam.* But although experiments were made at certain mines in the Auvergne, and in Westphalia, Papin's contrivance was so far unsuccessful.

Newcomen appears to have been assisted by the suggestions of Dr. Hooke, the Secretary of the Royal Society, and to have first tried his "fire-engine" on the large scale at a colliery near Wolverhampton. His mode of condensation, by cooling the outside of the cylinder at every stroke, proved to be inefficient, and it was only when he introduced an internal jet of cold water that success became decided. In concert with his assistant, Calley, of Dartmouth, he erected near Newcastle and in Yorkshire several engines of 23 inches cylinder, and in 1720 constructed at Wheal Fortune, in Ludgvan, an engine with cylinder of 47 inches diameter, working 15-inch pumps, to be soon followed by others at Wheal Rose, near Redruth, Wheal Busy, and Polgooth mines. Coal was burnt under their clumsy dome-shaped boilers at a fearful rate; but what matter? It must be done, if the hidden treasures of tin in the west, and coal in the north, were to be followed up to depths that had been proved unattainable by aid of the water-power at the command of the mines. The convenience with which the new invention could be applied caused it again often to be used as a lifter of water to the top of water-wheels; and thus, whether applying its force directly or indirectly, it prospered, and spread through the length and breadth of the land. A few of these old Newcomens, or atmospheric engines, working the pump-rods with the intervention of a horizontal "beam," or "bob,"

* The engine with its piston (*pistillum*) is described and figured in the "Acta Eruditorum," Lipsiæ, 1707.

and more or less patched and modified, have survived even to our own times.

About the time that the miners began to employ, on a large scale, the facilities afforded them by the new fire-engine, there arose from another side an application of coal, founded upon its calorific power, and on the action of the gaseous products of its combustion. Between 1730 and 1735, Mr. Abraham Darby, of Coalbrook Dale, Shropshire, succeeded at length, through the introduction of the process of coking, in smelting iron with pit-coal. The iron trade of Great Britain had at that period sunk to a very low ebb, but was now destined to rise to a height which is one of the great marvels of all the world, and that in a chief measure by the employment of the beds of mineral fuel so wondrously stored up in close proximity to the iron ores which have formed the great staple of our manufacture. Still, during all this period, we have no general statistics of coal. More and more of it came to be consumed as wood became yearly more scarce, and as population and commerce increased. After the middle of the eighteenth century a more scientific treatment of the fuel, and of the steam to be raised by its aid, began to occupy attention, and the devices which had for their object the economisation of coal very soon, successful as they were, increased a hundredfold the consumption of the very substance they sought to spare. Foremost among these was James Watt's admirably-reasoned contrivance of a separate vessel for the condensation of the steam; and then followed, with the rapid distribution of "Boulton and Watt's" engines over the whole civilised world, a series of improvements originating in great part among the uncertain adventures of the Cornish tin and copper mines, where economy of fuel became one of the manifest elements of mining success. The names of Murdock, Woolf, Hornblower, Trevithick and Grose are household words with the miners who are conscious of the great extension of enterprise which has become possible in consequence of the successive introduction of plunger-pumps, high-pressure steam, expansive action, tubular boilers, and the clothing of steam-pipes and cylinders. True that each of these inventions has had for its aim the reduction of the cost of fuel in proportion to the work done; but the result is an enormously increased aggregate consumption of coal, with a still more greatly multiplied amount of work done directly, and a superlative increase in the general traffic and prosperity of the kingdom.

About the year 1803 there was brought into practical application another grand employment of coal—the production of Light. For upwards of a century various experiments, and latterly on a manufacturing scale, had been made on the distillation of coal in order to procure tar and oils, whilst the application of the invisible gases produced was strangely neglected, notwithstanding attention had been called to the moderately lighting properties of the fire-damp so largely evolved from many of the northern collieries. Soon after 1792, Murdock, the engineer, in charge of some of Boulton and Watt's engines, suggested that the gas might be conducted through tubes, and employed as an economical substitute for lamps and candles. To light him on his homeward way over the Cornish downs, he used to carry a bag of gas under his arm with a lighted jet before him, and tradition still tells of his frightening the superstitious miners, whom he met in the dark, by a sudden squeeze of his bag, which threw out a long flame, taken assuredly for the fiery tongue of the arch-demon himself.

The rapid extension of the gas manufacture within the last two generations need not be dwelt upon, and the vast quantities of fossil-fuel now employed for this indispensable adjunct of our modern civilisation may be imagined when it is remembered that hardly a town exists within moderate distance of a coalfield, or of the sea-coast, in which gas is not used for the lighting of the thoroughfares, as well as for that of public and private buildings.

The year 1830 witnessed the commencement of another great drain upon our coal-mines, accompanied, it is true, with enormous advantages to other trades, but also originating in what appeared to be a more economical use of coal. The application of the *hot blast*, by Neilson, to iron furnaces, begun at the Scotch Works, saved so large a proportion of the coal needed for the smelting of each ton of pig-iron, that the great majority of the ironworks were forced by competition to adopt the same method; and, in spite of a very common belief that the quality of the produce was thereby injured, the result has been an enormous increase of the total quantity of coal used for this purpose, with a much greater increase to the iron trade. If we take as an example the results in Scotland, we find that the ton of pig-iron, as made in 1829 at the Clyde Iron Works, required the coke of 8 tons 1¼ cwt. of coal, whilst in the following year the introduction of air heated to 300° Fahr. brought down the consumption per ton of pig to 5 tons 3¼ cwts. Eight cwts. of coal were consumed in heating the blast, so that the actual saving per ton of pig-iron was 2½ tons. In 1833, when raw coal had come to be used instead of coke, 1 ton of pig-iron was made with 2 tons 5½ cwts. of coal, which, with 8 cwts. for heating the blast, made a total of 2 tons 13 cwts. Hence, by the application of the hot blast, the same amount of fuel reduced three times as much iron, and the same amount of blast did twice as much work as previously.*

Now the production of pig-iron in Scotland has risen as follows:—

	Tons.
1820	20,000
1830	37,500
1839	200,000
1851	775,000
1861	950,000
1864	1,158,750

Whence, at the rates above quoted, the total consumption of coal in iron-smelting would have been, in—

	Tons.
1820	161,250
1864	2,621,671

It must not, however, be concluded that this enormous development in the Scotch trade was due to the hot blast alone. Concurrent with that great improvement was the employment of the abundant and economical mixture, the "blackband," for the discovery of which Britain is indebted to Mr. Mushet. But the main fact remains that every advance which tends to cheapen the productions of manufacture enlarges so widely the field of operations that coal, the basis of the whole of them, is always demanded in ever-increasing quantities.

In the absence of accurate data, it is estimated that in Great Britain about 10,000,000 tons of coal were raised in a year at the beginning of this century. The Continental production at the time was exceedingly small, the backwardness of many manufactures and the large expanses of forest-land having delayed the necessity for turning to subterranean fuel. Within a short time after the conclusion

* Percy's "Metallurgy of Iron," p. 398.

of the great war, steam-engines were rapidly supplanting or acting as auxiliaries to water-power, and the coalfields of our own and foreign districts became the scene of more active researches. But it was not until the facilitation of traffic by means of steamboats and railroads that the steady, absorbing march of the present epoch commenced. When, between 1829 and 1835, the locomotive engines running on wrought-iron lines, and the coasting and sea-going steamers, were proved to be a triumphant success, leading to imitation in foreign countries, and to enormous multiplication in our own, a new system of the distribution of raw material may almost be said to have been started.

Many new and striking applications of coal have, within the last few years, rewarded the exertions of chemists. The once useless and fetid products of its distillation have been made to yield sweet scents and savours. From its *naphtha* are obtained the paraffine oil and the beautiful translucent solid paraffine, which in brilliancy and purity excels wax itself; and from its *aniline* are obtained a galaxy of brilliant colours, among which need only be mentioned the popular *mauve* and *magenta* to prove the varied forms under which the products of coal have found their way into the useful arts.

The International Exhibition of 1851—possible only under these conditions of mechanical advancement to which we have referred—naturally directed the attention of inquirers more forcibly to the statistics of mineral produce. It was roughly estimated that, for 1850, the production of all the British coal-mines was 42,000,000 tons; France was raising 4,433,000 tons; Prussia and Belgium followed with smaller quantities; and then Austria, with a little above 1,000,000 tons.

In 1853, Mr. T. Y. Hall, of Newcastle, after much investigation, stated the British production to be 56,550,000 tons.

At length, in 1854, through the instrumentality of Mr. Robert Hunt, of the Government Mining Record Office, aided by the recently-appointed inspectors of coal-mines, we obtain reliable statistics; and the following table will command the attention, if it does not excite the astonishment, of every reader:—

COAL PRODUCTION OF GREAT BRITAIN.

	Tons.			Tons.
1854.	64,661,401,	of which	were exported	4,309,255*
1864.	92,787,873	,,	,,	8,063,846
1874.	125,043,257	,,	,,	13,927,205
1877.	134,610,763	,,	,,	15,420,050
1878.	132,607,866	,,	,,	15,494,633
1883.	163,737,327	,,	,,	22,775,634
1884.	160,757,779	,,	,,	23,350,230
1888.	169,935,219	,,	,,	26,970,536
1892.	181,786,871	,,	,,	30,063,808
1897.	202,119,196	,,	,,	36,984,841

The vast quantity represented by these figures may be brought before the eye by the following comparisons, supposing that we take the approximation of 1 ton being, as it lies densely packed in the earth, 1 cubic yard. If we take the area of Lincoln's Inn Fields, measured up close to the houses, at 11 acres, about the dimensions of the base of the Great Pyramid, and could stack the coal as nature has done in the seams, the British coal raised in 1865 would form, on that base, a solid block of the height of 5,229 feet, or as high as Snowdon surmounted by another mountain of half its height.

* The exports of 1854 alone are from the returns to the House of Commons; the remaining numbers are taken from the statistics compiled originally by Mr. Robert Hunt, F.R.S., Mining Record Office, now published by the Home Office.

Again, taking the distance from London to Edinburgh, 400 miles, the same quantity, similarly packed, would build a wall the whole way of 12 feet thick and 99 feet high; whilst, if put together in the broken state in which coal is commonly used, it would give a wall of more than double that thickness.

This yearly production, obtained by the labour of about 240,000 men,* is palpably a gigantic effort for so small an area as that of our united coalfields, and naturally excites apprehension for the future.

The statistics of the produce of the mines of most of the European nations are well kept up, although a few of them can only be roughly estimated, and it is interesting to compare, after intervals of fourteen years, the annual amount produced by the chief coal-bearing countries:—

	Tons.	Tons (1883).	Metric Tons (1897).
Great Britain and Ireland (1870)	110,431,192	163,737,327	205,373,631
United States of America (1871)	33,637,486	96,159,719	181,638,161
German Empire, inclusive of the two following	..	70,223,456	91,054,982
†Prussia, including Silesia, etc. (1870)	29,432,756	62,437,648	84,253,393
Saxony (1869)	3,096,231	4,736,707	4,571,685
Austria-Hungary (1870)	7,084,391	17,047,961	35,939,418
France (1869)	13,100,000	21,446,799	28,702,207
Belgium (1870)	13,607,110	18,177,754	21,492,446
Russia (1870)	800,000	3,600,000	11,207,475
Province of Nova Scotia (1871)	597,418	1,422,553	2,358,161
New South Wales (1869)	919,522	2,109,232	4,453,937

* Increased in 1897 to nearly 700,000 persons.

† Given in the official statistics in *zollcentner*, of which 20 = 1 ton English, nearly. The German *tonne* is 1,000 kilogrammes, or 2,000 pounds, equivalent to 2,204 English pounds.

It is hence evident that, although our favoured country has so long taken the lead, all civilised countries have entered into the race of competition; and it becomes a matter of anxious inquiry to learn under what circumstances the treasure is in each country developed, and where it is likely to be best expended or longest economised.

CHAPTER II.

MODE OF OCCURRENCE OF COAL.

THE substance receiving the name of true coal (in contradistinction to lignite and brown coal) is, in almost all the coal-producing countries, found in beds, or seams, divided from one another by more or less thick *strata*, or beds of shale, sandstone or grit, and indurated clay, the whole being termed collectively the coal-measures, and belonging to a still larger group of stratified rocks called the Carboniferous Formation or System (*Système houillière*, or *anthraxifère*, Fr. —*Steinkohlen-gebirge*, Ger.).

It is difficult to define exactly what constitutes a coal. Several legal trials, on a grand scale, in Edinburgh, London, and in Prussia, have only succeeded in making it more clear than ever that no suitable definition exists, and that whilst all parties may agree in recognising the characters of a typical coal, differences of opinion will soon arise when the substance to be determined approaches the boundary of the shales and of the bitumens.

It is obviously loose to assert that "anything is a coal which is dug out of the earth and will burn"; whilst, on the other hand it is inconveniently strict to demand any approach to a definite composition as indispensable to coal. We may fairly require of it that it be black or dark brown, capable of direct employment in furnaces and fireplaces for the production of heat: brittle, and not soluble—like the bitumens—in ether, oil of turpentine or benzole. The following are the chief characters of the various substances regarded as coals :—

ANTHRACITE (Stone, Kilkenny, or Crow-coal).—Black, with black streak ; fracture, conchoidal ; does not soil the fingers ; specific gravity, 1·3 to 1·75 ; less easily kindled than other kinds of coal ; often decrepitates much in burning ; composition, carbon in great proportion, generally 90 to 95 per cent. ; hydrogen, oxygen, and nitrogen in minute quantities.

BITUMINOUS COAL.—Black, of various shades, streak sometimes greyish black ; lustre, more waxy than that of anthracite, in some varieties dull ; fracture, subconchoidal to uneven, the substance often divided by cleats or joints into parallel-faced figures (*cubical coal*, *dicey*, *etc.*) ; specific gravity, 1·25 to 1·4 ; composition, generally from 73 to 90 per cent. of carbon, 8 to 22 per cent. of oxygen, hydrogen, and nitrogen, with (as in anthracite) a variable amount (3 to 30 per cent.) of earthy matter constituting the "ash."

The term *bituminous coal* is somewhat deceptive, and it must be remembered that it does not mean that any bitumen (or mineral pitch, soluble in ether, etc.) is contained in it, but that the gases, oxygen, hydrogen, and nitrogen enter more largely into its composition than in anthracite, and give it a more flaming character in burning. The varieties generally recognised are mostly named after their application or chief properties : *Free-burning*, *steam or smokeless coal*, *non-caking coal*. These, in different grades, approach towards the anthracites, and are chiefly valued for engine and smelting purposes. They often exhibit, in parts of the seams at least, a peculiar fibrous structure, passing into a singular toothed arrangement of the particles, called *cone-in-cone*, or "crystallised coal." Some of these "dry" coals will coke, but the smalls, from their not agglutinating, cannot be used for that purpose. With the addition, however, of pitch or tar to the amount of 8 or 10 per cent., the small may be made into "patent fuel," or "agglomerated coal."

Caking coals are those which tend to partially fuse when burning; emitting jets of gas, and, as a rule, giving off abundant flame and smoke. The "household coals" are generally of this variety, and are valued, in great measure, according to their freedom from ash. The "smalls" have the valuable property of fusing together into large masses when duly heated; whence they are abundantly turned into coke for iron-smelting and for burning in locomotives.

A single seam or bed often contains layers of different descriptions of coal, which may, in some cases, advantageously be divided from one another, and separately sold for divers commercial purposes.

A remarkable instance of this was noticed by me in the "Top-hard," a famous Derbyshire and Yorkshire seam, at Handsworth, where its aggregate thickness was 55 inches. The divisions were as follow:—

	Inches.	
Roof coal	2	useless, thrown away.
Batt (black shale)	2	
Brassy piece (pyritous)	5	
Rough bright	4	for house fires.
Best bright	4	good for making soft coke.
Top hard	4	"converting" coal, for steel-making.
Dead bed	8	
Bottom hard	1	
Rough bright	6	for house fires.
Soft bright	3	for soft coke.
Dirt, parting	9 to 12	
Holing coal	4	very dusty soft coal.
	55	

Cannel is commonly considered a variety of bituminous coal, with the beds of which it is not unfrequently associated in parallel layers; but it is a fair question whether it should not, in scientific nomenclature, be separated from the coals proper. It is black or brownish, dull in lustre, breaks with a flat conchoidal fracture, is not made up like ordinary coal of thin laminæ, does not soil the fingers, often contains teeth and scales of fishes, and, according to some of our best microscopists, is readily distinguishable from coal by the general absence of vegetable structure. Its name from *cannyl*, a "candle," is derived from the readiness with which it lights and gives off a steady flame. Some varieties, however—*parrot coal* (Scotland), and *rattlers* (Yorkshire)—decrepitate and crack loudly on the fire. Cannel is largely employed for gas-making.

It is by no means easy, if at all feasible, to draw a distinct line of demarcation between cannel and the black *basses*, *bats*, or crisp shales which occur in the coal-measures, but contain too much earthy matter to allow them to be of present value. And between all these and the *torbanite*, or "boghead mineral," there exists a relationship which makes the difference only one of degree. This last is a brown, tough substance, containing little more than 9 per cent. of carbon, 60 to 69 per cent. of volatile matter, and the "ash" so abundant, and so equably diffused through the mass that, when the mineral has been "burnt," or had the volatile parts extracted by distillation, it is taken out of the retort blanched in colour, but in volume looking just as when it was put in. Its great value consists in its oil and gas yielding properties—a ton of this mineral giving as much as 15,400 cubic feet of gas, whilst good cannels give but 8,000 to 10,000 feet. *Torbanite* is classed by some authors as a distinct mineral species, and by others as a bituminous shale.

Lastly we have *Brown Coal*, or Lignite, a mineral—more distinctly than any of the foregoing—formed of a mass of vegetable matter; some stems, in fact (lignite proper), presenting the appearance of undecomposed wood. Colour, brown to pitch black; lustre, sometimes resinous, sometimes dull; specific gravity, 0·5 to 1·5; fracture, various; burns easily with a smoky flame and unpleasant odour; composition, 50 to 70 per cent. of carbon, a much larger proportion of oxygen than in the bituminous coals; hydrogen and nitrogen about the same. A large amount of water generally present. Varieties of it are termed—according to their aggregation—*pitchy* coal (*pech kohle*), *slaty* coal (*schiefer kohle*), *paper* coal, or dysodil, *bast* coal, *needle* coal, and *earthy* coal.

Certain examples of the brown coal of the better sort so closely resemble the good bituminous coals as to be indistinguishable by any trenchant difference of composition in appearance. It has, however, been usual to apply this name to all the coals which occur in formations more recent than the true carboniferous period. Thus the name brown coal—not a very happy one—embraces as many qualities and varieties as does the *old* family name Coal, from which it is now held to be a distinct off-shoot.

For a general account of the geological phenomena which have to do with the occurrence of the coal-measures, we must refer the reader to some of the numerous "handbooks" and "manuals" already before the public. We have only space in the present little volume to deal with those parts of the subject which are more specially related to the finding and working of coal.

Our descriptions will almost entirely have reference to strata of the true carboniferous system, as being without comparison the most important. It is there, in the upper part of the *Palæozoic*, or "ancient life" division of the earth's crust, that the great coalfields of the world are sought out and worked. But some countries, as Italy for example, are not fortunate enough to possess any of these within the ken of man, and must content themselves with brown coal alone; others, like Hungary, have brown coal of several successive periods and of very different qualities. Much value will then attach, locally, to this minority among the coals, and the following table will show with clearness the succession of the entire series of strata in their true geological sequence, along with the different classes of coal which they have been proved to contain.

It is to be remembered that, whilst the annexed table exhibits the natural sequence where all the strata are developed, it frequently happens that some of them are missing from their places. Thus, in Belgium and North France, the coal-measures lie immediately beneath the chalk or cretaceous beds. In South Staffordshire the carboniferous limestone and other strata under the coal, down to the silurian rocks, are wanting. In South France (St. Etienne) all stratified rocks are absent, and the coal-measures rest directly upon granite.

Similarly, it has to be borne in mind that the coal itself may possibly not be present, although the group above it and the group below it may be in their places; but the order of the *superposition* is never changed.

Those who learn their practical lesson in one single coal-field are apt to acquire notions about the physical conditions which require to be corrected, by visits to other districts, to make them capable of general application. Thus, whilst the total thickness of the coal-measures in Shropshire and

Table of the Stratified Rocks.

Showing the position of Beds of Fossil Fuel.

	Group.	Chief Divisions.	Locality of Coal or Brown Coal.
TERTIARY, OR CAINOZOIC.	Pleiocene.	Norwich Crag. Red and Coralline Crag.	Surturbrand Lignite, Iceland.
	Miocene.	Faluns of Touraine. Molasse Sandstones, etc.	Austrian Alps. Germany. Leafbeds in Mull. Lignite in Antrim ? Vancouver Island. Bovey, Devon (Heer).
	Eocene.	Bagshot Sands. London Clay. Woolwich Beds, etc.	Tyrol, and the Venetian Alps. South Styria, some beds of fathoms in thickness.
SECONDARY, OR MESOZOIC.	Cretaceous.	Upper Chalk. Lower Chalk. Chalk Marl. Upper Greensand. Gault. Lower Greensand.	Austrian Alps, in the Gosau beds. Coal, up to 4 feet thick, Lettowitz, etc., in Moravia. Santa Fé de Bogota, South America.
	Wealden.	Weald Clay. Hastings Sand.	Good brown coal beds in North Germany, Utrillas, etc. N.E. Spain ?
	Oolitic or Jurassic.	Portland Oolites. Oxford do. Bath do. The Lias.	Purbeck *dirt-bed,* with Lignite. Mori, Tyrol. Kimmeridge "coal." Productive coal in Lower Oolite, Brora; Yorkshire; Pennsylvania. Excellent coal at Fünfkirchen, Steierdorf in South Hungary, and Texas.
	Trias.	Rhœtic beds. Keuper. Muschelkalk. New red Sandstone.	Keupercoal, *Lettenkohle*, S. Germany. Virginia, U.S.
PRIMARY, OR PALÆOZOIC.	Permian.	New red, in part. Magnesian Limestone. Lower red Sand.	Coalfields of India not older than this ? and *Brandschiefer* Germany and Bohemia.
	Carboniferous.	Coal-measures, often divisible into 3 groups. Millstone-grit. Carboniferous Limestone.	True coal in England, Scotland, Wales, France, Belgium, Prussia, Bohemia, Moravia, Spain, the United States, Nova Scotia. Anthracite in South Wales, Ireland, Pennsylvania. Coals in North England. Coal in Northumberland, Scotland, Russia.
	Devonian.	Old red Sandstone. Slaty rocks. *Killas*, etc.	New South Wales coals appear to belong to period from hence up to the Trias.
	Silurian.	Ludlow rocks, etc. Bala beds. Llandeilo Flags. Cambro-Silurian Slates.	Petroleum, in these three lower groups. Anthracite in Co. Cavan, and Isle of Man (Laxey mine); Norway.

South Staffordshire is only from 1,000 to 1,600 feet in thickness, in North Staffordshire it reaches 5,000 feet, in South Wales 14,000 or 15,000 feet, and in Saarbrücken, in Prussia, no less than 20,000 feet.

The great bulk of the series of rocks, termed *coal-measures*, consists of shales or indurated slaty clay, variously coloured grey, bluish or black (*clod*, *bind*, *batt*, *metal*, etc., of the colliers); of dense clays, a bed of which almost invariably underlies every seam of coal (*warrant*, *pounson*, *clunch*, etc.); and of sandstone (post, rock, or stone) of various degrees of hardness and roughness of grain, though seldom containing pebbles, except in the strata which occupy quite the lower part of the series. The actual beds of coal, then, from an inch or two thick, up to 8 or 10 feet (generally considered "workable" when above 18 inches or 2 feet in thickness) and making up in the aggregate perhaps 100 feet of coal, form but an inconsiderable part in dimensions of the great mass of rocks with which they are interstratified.

Whatever may be the form of the surface of the ground, it rarely happens that the coal-measures under it, whether deep or shallow, lie in a flat position for more than a small distance. They are found to incline (*dip* or *pitch*) more or less regularly from the moderate angles of 6° or 8° to as much as 25° or 30°, a "sharp pitching," or even, in exceptional cases, to 70° or 80° (*rearing* or *edge* seams). Whatever happens in this way to one of the beds, the others are similarly effected, because the strata throughout this system or group are all *conformable* or parallel.*

The inclined position of the beds will necessarily bring

* Certain cases have been observed in which one portion of the coal-measures is slightly unconformable to another; but this does not interfere with the doctrine of the general parallelism of the beds.

them at some point or other to the surface, unless they are overlaid by some newer formation deposited *unconformably* upon the ends of the upturned strata, known as their outcrop. This must in no way be confounded with what is known in geological phraseology as the "strike of a bed," which is a line measured at right angles to the full inclination or dip. An outcrop will be governed by the configuration of the surface, and may, or may not, coincide for a short distance with the strike. Hence it is that a great insight into the character of a coal district may be obtained by a careful study of the surface, especially in

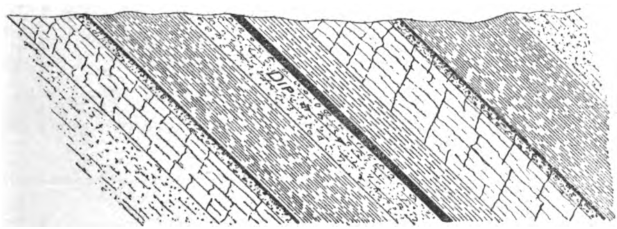


Fig. 1.—Dip of Strata.

brook-courses which run more or less in the direction of the dip and rise of the seams. If we follow out the subject over a large area, we shall find many variations to take place, and the coalfield assuming a form which may be traced as on a map if the tract be surrounded by older formations, but about which there will be uncertainty if the measures are observed to dip beneath other and newer groups of rock.

When the beds ascend or rise for a while, then dip and rise again, they form a *saddle* or *trough*, known, when very persistant over a considerable distance, by the terms

Anticlinal and *Synclinal;* and when they rise on all sides towards the surface, as in the Forest of Dean, they constitute a *basin.* The outline of the shapes into which the coalfields have been brought by the forces of elevation and depression may be studied in the geological maps; but where these forces have exercised their powers on a grander scale, the measures are often folded back, corrugated or contorted in such a manner as to present great complexity. Examples of this may be seen in Pembrokeshire, at Vobster, Somersetshire, and in the Belgian coalfield.

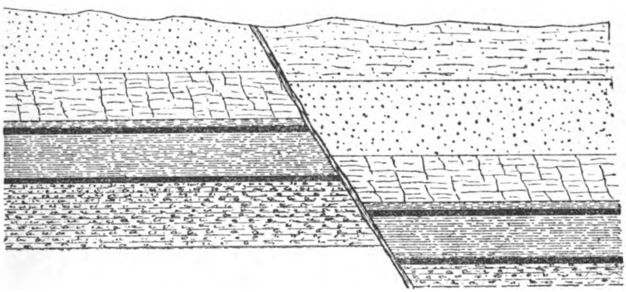


Fig. 2.—Fault.

In addition to this general disturbance from the original—more or less horizontal—position in which the beds must have been deposited, they have been cut through by inclined planes of fissure, and so dislocated that they are now lower on the one side of the line of fault than on the other.

This line of dislocation seldom takes place absolutely vertically, the horizontal distance between the position of the same bed on each side of the line of fissure being termed the *hade* of the *fault*, and, as a general rule, the direction of the *hade* may be taken as a guide as to the direction of the displacement of the strata, and whether the *fault* be an upthrow (or *riser*) or downthrow (or *dipper*).

It occasionally happens, however, that this order of things is exactly reversed. When this is the case the *fault* is

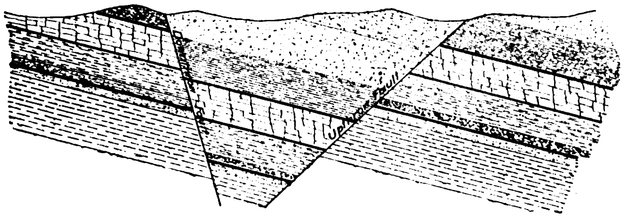


Fig. 3.—Hade.

known as a *reverse*, or *overlap fault*, and when met with is usually the source of considerable trouble and expense.

This class of *fault* is often found in districts where

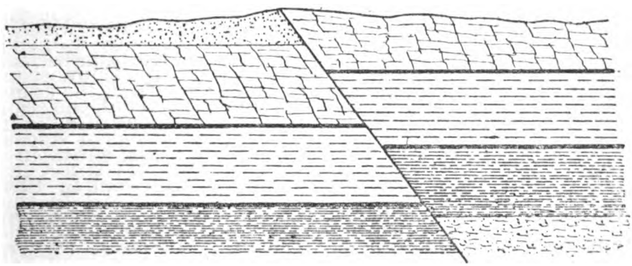


Fig. 4.—Reverse Fault.

considerable lateral thrusts have taken place, in the neighbourhood of anticlinals.

When the strata is found to be thrown down for a distance, and to be then thrown up to its original horizon, such a *fault* is termed a *trough-fault*. It may be that the strata is found to be dislocated by a series of small *faults*, throwing up or down in a series of steps; this would be generally known as a *step-fault.*

The forms and peculiarities which *faults* assume are very numerous, and it is only by actual exploration, often at a large expenditure of capital, that their several local peculiarities can be ascertained.

The amount of *throw* or *leap* of a fault may be only a few inches or feet, in which case the workings are not much affected; but the movement may in many instances be shown to have arrived at hundreds, and more rarely to thousands of feet. A great number of these *troubles* within a small space may render a seam of coal so "faulty" as to be worthless; whilst, if they are filled with clay, and suitably distant from one another, they serve a useful purpose in dividing a coalfield into water-tight compartments, and a jealous eye is thence kept on their security.

This by no means sums up the troubles that coal-mining adventurers have sometimes met with. In some coalfields, more especially in this country, those of Northumberland and Durham, South Staffordshire and in Scotland, the seams of coal are found to be intersected by intrusions of volcanic rocks, which have been forced up through the strata in a molten state, and burnt to a cinder the coal in their proximity. These intrusions, known as *whin dykes* in Northumberland and Durham, are generally composed of very hard rock, which renders the driving of underground roadways through them an expensive matter. In some cases, these upheavals of volcanic matter are found to have spread out in the seam, and in some coalfields many acres of valuable coal have been rendered utterly worthless.

A curious example of the effect of some of these *dykes* may be quoted from the Bulli Colliery, near Sydney, New

South Wales, where a fringe of what may be termed *natural* coke was found surrounding a considerable area over which the coal had been burnt and rendered worthless.

If we now turn back from the larger view of the whole group of strata, and look at the seam itself, we shall note first its thickness—an amount varying generally from 18 inches to 8 feet. In Somersetshire they contrive to work seams with only 11 inches of coal. At Whitehaven, and in the upper measures in Flintshire, seams of 10 and 12 feet thick are worked. In South Staffordshire, 30 to 36 feet; at Pictou, Nova Scotia, 36 feet; and at Pottsville, U.S., 40 feet are the thicknesses of exceptional seams, put together by the superposition of several of ordinary dimensions. A very thick one will rarely be of clean coal throughout. Partingswill occur, of clod or various earthy material, which, if of a few inches, may not occasion much inconvenience, but if they get to be more than 18 inches or 2 feet, may practically interfere with the possibility of working advantageously. Iron pyrites, or *brasses*, will sometimes run with a line parting, and needs to be carefully picked out. The partings are often mere planes of division, and are then sometimes smooth surfaces, *slicks*, requiring caution in undercutting; but are more generally films of black, soft and fibrous coaly matter, apparently made up of small fragments of carbonised wood. Then comes the physical condition of the coal, to whichever of the kinds above enumerated it may belong. Is it dense, hard and unjointed, it will be expensive to cut, but more valuable from giving a large proportion of "round" or massive coal. Is it divided like the Derbyshire, by one set of *backs* or *faces*, running most regularly parallel, it will need a special direction of the working faces. Is it, on the contrary, divided by two sets of divisional *cleat*, as in some of the northern coal, the direction is not so important. These divisional planes are generally almost vertical, but in South Wales (Pontypool, Merthyr, etc.) they dip at a considerable angle; and when they here and there meet a "rider" inclined the other way, they form a loose mass of coal, very dangerous to unwary colliers.

The *floor*, *thill* or *seat* (*pavement*, Scot.) of the coal is an underclay, generally good for fire-brick. If soft it is apt to heave, under the pressure from above, into the open roads, and greatly to multiply expenses. Here and there a quartzose silt forms the seat, especially in some of the lowest seams (Yorkshire, Lancashire, etc.). It is so hard as to make a capital road-stone, known as *ganister*, but bears the black rootlets thick in it, which we see in the ordinary bottom-clay, *spaven*, or *warrant*. The *ganister* is commonly a foot or 20 inches in thickness, and has clay again beneath it.

Lastly, the *roof* or *top* of the seam is one of the most important items in the economy of its working. A good tenacious shale or bind is the most favourable. But rock or sandstone roofs there are, which will hold up for a very great breadth of ground, and come down pretty manageably, whilst others can hardly be trusted. It is most fortunate that the frequent planes of division, which almost invariably split up the coal, do not pass up into the roofs. If the immediate cover of the coal be too short, or soft, or cracky to stand well, it may be necessary to leave some inches of coal as a roof, or again (depending on the strata overhead), it may be better to rip down a foot or two (or even 4 or 5 feet sometimes) to afford security to the roads.

It must not be forgotten that although the coal-seams are, as a rule, more persistent and regular than any of the beds of rock which accompany them, they are subject to variations which may influence their value, and often within a small area. The thinning by a gradual depression of the roof till sometimes the entire coal is gone, but for a certain width only, is a kind of fault (*nip* or *want*) that has often been noticed, and is confined to one seam, not affecting, or only slightly, those above it or below it. An interesting example of this kind occurs at Denby Colliery, Derbyshire, where a channel of 320 yards wide was found eroded in the "deep hard" coal for half a mile in length, whilst the next seam above it, the "upper soft coal," has proved continuous, and been worked over the entire area. Another sort of thinning is where the floor rises, if sharply, in a "hog-back" or saddle; if gently, like a swelling undulation, which subsides again in 10, 20, or 40 yards, and is succeeded sometimes not merely by the usual normal thickness of the coal, but by an exceptional amount, to make up, as it were, for the thinness to which it had before been reduced.

One of the most notable examples of this kind is in the fine colliery of Seaton Delaval, where, throughout a depression of 1,000 yards in length between the old and the new, or Forster pits, and for 120 yards wide, the seam is from 6 to 7 feet thick, whilst on both sides it dwindles rapidly till much of it is but 2 feet 6 inches, and has been unworkable.

In the Forest of Dean the Coleford High Delf seam, averaging 4½ feet thick, is here and there reduced to much less, and then rapidly expands till (Miles' Level Colliery) it attains 9 and even 11 feet thickness. Variations so considerable are more frequent in the lower than the upper coals, and, coupled with the smoothly-polished under-surface, which may occasionally be noticed, lead me to think that the coal must have remained in a plastic condition long after it was covered up with sediment, and that it has been much squeezed and moulded by the various movements to which the strata have been subjected.

The introduction of bands of foreign matter, as partings, between the laminæ of the coal, has already been described; and these, so apt in particular districts to multiply as well as to increase in bulk, are frequently to be added to the other elements of uncertainty, which, in some regions more than others, render coal-mining a more speculative undertaking than it at first sight would appear to be.

CHAPTER III.

ORGANIC REMAINS AND ORIGIN OF COAL.

NOT a doubt can exist in the minds of those who have either observed for themselves, or fairly examined the description of others, that the coal has been produced from an accumulation of the remains of various kinds of plants. The bed of fire-clay, or *clunch*, which lies beneath each seam is full of roots and rootlets; the shale overhead is often so charged with the brightly-preserved fronds of ferns, flattened trunks, and various strange forms of leaf, as to rival all that can be shown in a princely conservatory. The sandstones contain fragmentary trunks and branches, and the coal itself may often be seen, on carefully dividing its laminæ, to show the impressions of numerous vegetables, with, at intervals, a film of soft, silky "mineral charcoal"; whilst occasionally the structure of the plants has been preserved by mineralisation, revealing in their slices, under the microscope, the flora of the primeval world.

These appearances vary much in different coalfields, and in the different seams of a single field. Certain authors, especially Dr. Göppert, of Breslau, are of opinion that many seams can be safely distinguished by the difference of the plants associated with them. Mr. Salter, following Mr. Binney and Professor Phillips, has recently endeavoured to show, for certain seams of our own country, that there are useful distinguishing characters in the animal remains (mollusca, fish, etc.), which often occur in the roof shales. But the subject, noble, and every way interesting, has, strangely, been left to the handling of occasional visitors of collieries, and needs much further inquiry.

We will endeavour to put together a brief synopsis of the principal forms of vegetation which are met with in the coal-measures, premising only that, whilst some 500 different plants derived from this source have been described, a short sketch like the present will be mainly useful if it lead the inquirer to study the works of some of the authors who have contributed to this branch of knowledge—Witham, Lindley and Hutton, Brongniart, Göppert, Binney, Sternberg, Corda, Dawson, Williamson, Hooker and Schimper.

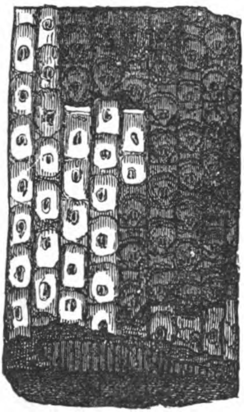


Fig. 5.—Sigillaria Elegans, Forest of Dean. (Half the natural size.)

SIGILLARIA.—A great proportion of the actual coal appears to have been formed of this plant, which is often represented in the shale by the bark alone. They are sometimes as much as 3 to 5 feet in diameter, and 30 to 60 feet in length. Their beautifully fluted and symmetrically-scarred patterns may often be seen crossing one another in luxuriant confusion in the roof from under which the coal has been removed. I had, on one occasion, an excellent opportunity, in conjunction with Mr. Beete Jukes, of observing the bared upper surfaces of successive steps of the Dudley thick coal when it was being worked open to the daylight, and when they all showed fine impressions of Sigillaria.

Eighty-three species are described by Schimper in his great work. They are allied to the humble club mosses of the present world. *Sigillaria* stems of full thickness and a few feet in height are frequently found erect, sometimes hundreds together, in a very small area. Often they stand

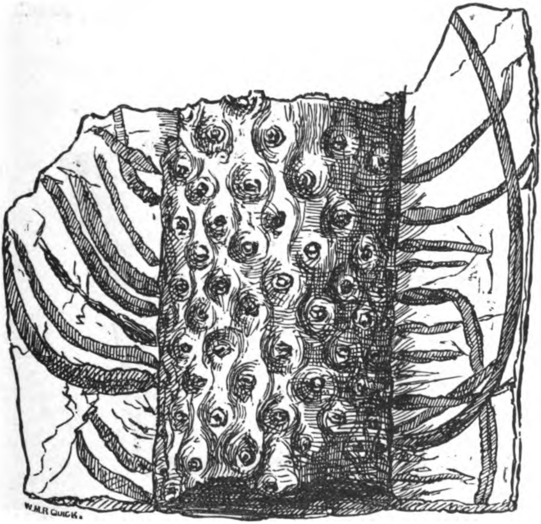


Fig. 6.—Stigmaria Ficoides. (Half natural size.)

based close upon the seam of coal, and most unfortunately for the safety of our colliers, since the film of coal representing the bark which surrounds them separates them from the surrounding matrix, and they are apt to drop out without warning, in masses weighing from a few hundredweights to a ton. They are thus commonly known as bell-moulds, coal-pipes, or cauldron-bottoms, and may be traced by a slight circular outline, often formed of bright coal.

STIGMARIA.—The curious fossil, found so universally in the clays or indurated silts beneath the coal, was long supposed to belong to a distinct family, but the researches of Mr. Binney, in Lancashire, and Mr. Richard Brown, in Nova Scotia, have proved it to be the root of *Sigillaria.* From the central boss great cylindrical arms extend in every direction, branching oftentimes into two, and the smaller ones into two again, and thus occupying an area of many yards. From

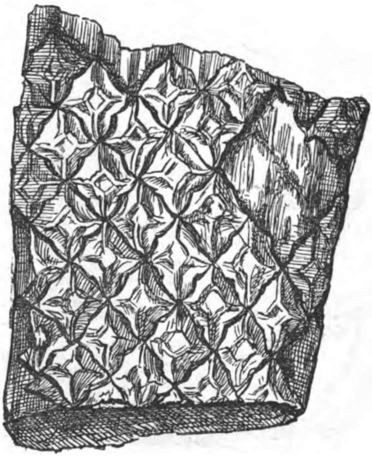


Fig. 7.—Lepidodendron Obovatum. (Half natural size.)
(Le Botwood Colliery, Shropshire.)

the little tubercles regularly arranged on the root were given off innumerable rootlets, which we now find squeezed into narrow carbonised ribands, confusedly interlaced with the clay, and stretching for many feet away. These are found retaining their original form when they have been preserved by being embedded in a quartzose silt, like the *ganister* bed of some of the lower coals, when it becomes evident that each was attached by a curious rounded base resembling a ball-and-socket joint.

LEPIDODENDRON.—The trees of this beautifully-marked family also attained a length of upwards of 40 feet, and are referred to some 60 species.

The size is the more extraordinary when we realise that, like the *Sigillaria*, they belong to the Lycopodiaceæ, or club mosses, the largest of which now living in tropical climates attains a height of only a few feet.

An elegant cone, often found well preserved in ironstone among the coal shales, and termed *Lepidostrobos*, is the fruit or catkin of the *Lepidodendron*.

HALONIA, a stem from 2 to 4 inches thick, looking in outline like a knotty blackthorn, is a branch of a *Lepidodendron* on which were borne sessile cones.

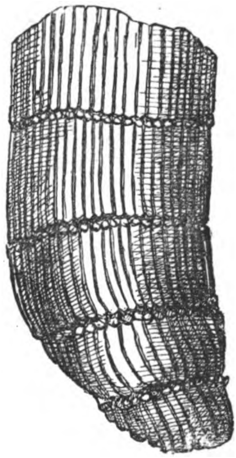


Fig. 8.—Calamites Decoratus, Derbyshire. (Half natural size.)

CALAMITES.—Jointed and striated stems, occurring abundantly in some of the shales, have been compared by the unlearned with bamboo, but belong to the *Equisetaceæ*. The fruits have been discovered beautifully preserved, and have been described by Carruthers, Schimper, and Williamson, and their affinities with *Equisetium* established. The views of Brongniart—that two groups of plants, one Cryptogamus and the other Phanerogamous, are included in the plants generally called Calamites—though still held by some French authors, cannot be maintained. These paleozoic *Equisetaceæ* do not differ more from their living allies than the *Sigillaria* and *Lepidodendra* from living *Lycopodiaceæ*.

The Calamites have also been found in their original erect position, the root-end tapering and curved towards the main axis.* They seemed to have formed a dense brake of perhaps half the height of the *Sigillariæ*.

ASTEROPHYLLITES, *Annularia* and *Sphenophyllum*.—These consist of branches with leaves arranged in whorls or stars.

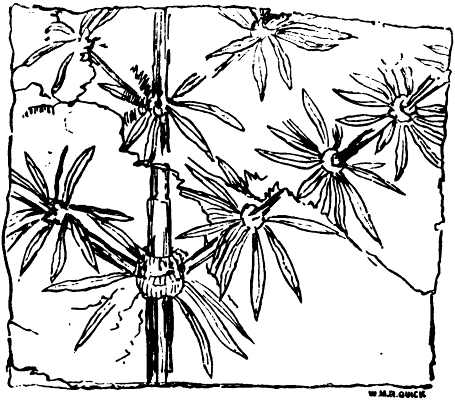


Fig. 9.—Asterophyllites Equesetiformis, Forest of Dean. (Natural size.)

They are the foliage of the Calamites, and perhaps represent as many distinct *genera*. Various fruits have been described which may be co-related with these leaves, and thus supply good generic characters.

* The conical end used to be taken for the top of the stem, and sometimes by collectors for a fish's snout.

CONIFERÆ, OR FIRS.—Among the trunks found petrified in the sandstones, many exhibit under the miscroscope a structure which appears to indicate their relation to the Araucarias, of which the species brought from Norfolk Island is a well-known modern representative. The coal-pines were peculiar from containing a very large pith, which, found separately as a ringed cylinder, used to be described as an independent plant, under the name *Sternbergia.* Angular nut-looking fruits, called Trigonocarpum, are referred to this class of trees, and these would imply an affinity rather with the Taxineous group of Conifers, but there have not yet been obtained specimens to show the relation of the fruits to the stems.

Again, in the films of soft mineral charcoal, or "mother-of-coal," which, of the thickness of a knife-blade to a quarter of an inch (rarely), run evenly between the brighter laminæ of the coal, frequent in some, absent in other seams, the angular fragments of woody-looking substance, all mashed up together, present, in many instances, this Araucarian structure. Other portions exhibit a *bast* tissue, or elongated cells from the bark of the *Sigillaria* and *Lepidodendron.*

Of this highly-organised class of trees, the most abundant remains are referred to one genus called *Araucarioxylon.*

FERNS, OR FILICITES.—These graceful relics of a former world of vegetation adorn the shaly roofs of many of the coal-seams, sometimes clearly spread with their black tracery on a grey ground, a true specimen of nature-printing; at others, tossed and tumbled in wild profusion throughout several feet in thickness of the roof-stone. A careful eye, and still better if aided by a microscope, may often see their traces in the coal itself, and in some of its dull unpromising parts may descry innumerable spiculæ or hair-like needles, which Dr. Dawson refers to the vascular bundles of decomposed plants of this tribe.

Certain botanists have named and described hundreds of species; others, more cautious, remind us that considerable difference of appearance may be seen on the several fronds of one plant, or even on the *pinnæ* of the same frond, and that the number of species may thence have to be reduced.

A general resemblance to ferns of the present day must not be confounded with identity of species or even genus.

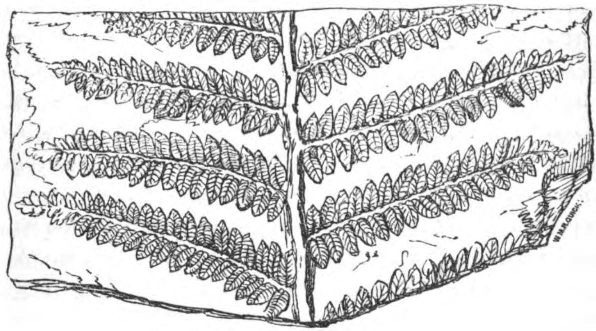


Fig. 10.—Pecopteris Pteroides, Forest of Dean. (Half natural size.)

It is to be remembered that the whole of the coal-measure ferns are utterly extinct, and their place in nature is supplied by fresh races.

PECOPTERIS (adherent fern).—The name ALETHOPTERIS is given to those species in which the pinnules are long and narrow. The leaflets adhere by their base to the rachis or stem, and are traversed by a strong mid-rib, from which veins branch off almost perpendicularly, some of them simple, some bifurcating, but never intersecting. Sometimes found with fruit patches (sori) in the back of the fronds.

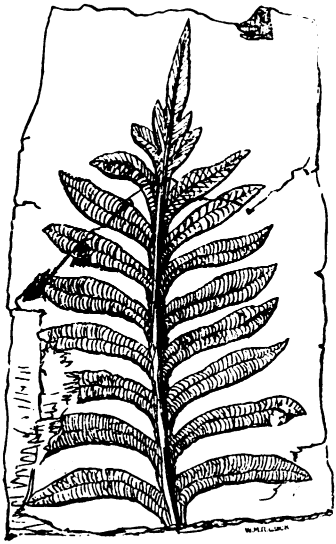


Fig. 11.—Pecopteris (Alethopteris), Berlin.
(Half natural size.)

NEUROPTERIS (nerved fern).—Leaves more or less heart-shaped and entire, not adhering by their base or to one another; veins very fine, dichotomous, arched as they rise obliquely from the base of the leaflet; bears a general resemblance to the recent *Osmunda regalis*, or royal fern. The leaflets are sometimes so long as to suggest comparison with examples of Glossopteris, an oolitic species, and with the recent Hart's-tongue.

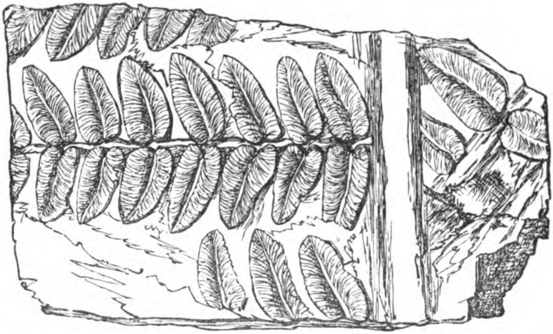


Fig. 12.—Neuropteris Gigantea, Cwn Avon. (Half natural size.)

SPHENOPTERIS (wedge-fern).—Very variable general aspect, leaflets contracted at their base, lobed, and the

Fig. 13.—Sphenopteris Latifolia, Felling Colliery, Newcastle. (Half natural size.)

lower lobes largest, reminding the observer of our recent *Adiantum;* veins on the leaflets radiating from the base.

The ODONTOPTERIS, or tooth-fern, and LONCHOPTERIS, or spear-fern, are genera which occur less frequently than the above.

Some of these fronds appear to have belonged to low plants, others to have grown on large and lofty trees; and certain trunks, called *Caulopteris* and *Palæopteris*, exhibiting clear and frequent scars left after the fall of the fronds, represent the tree-ferns of the carboniferous period.

Lastly, we must not omit to mention a kind of plant-remains which have engaged the attention of but few, but which have played an important part in the making up of certain coals.

These are broad, parallel-veined, elongated leaves, referred by authors to very different plants. The most frequent, which were described by Corda as *Flabellaria*, have been since termed *Cordaites*, and have been referred by Schimper to *Cycadeæ;* but they may belong to a lost type of Cryptogams. The vast numbers of them, layer upon layer, visible in certain cases, testify to their having accumulated in thick banks.

No single circumstance about the coal-vegetation is more remarkable than its uniformity over a large portion of the world. It has long been known that a great part of the plants of this epoch are alike all over Europe, and even North America. In South America, South Africa, and Australia many of them occur, and at Melville Island, in lat. 76°, and in other boreal spots described by Arctic navigators similar genera are found.

It has hence been argued that the climate of the globe was at that period more equable; and, advancing another step from this basis, the earlier geologists supposed that it was owing to a generally diffused higher temperature—an intermediate stage between the original globe of fused matter and our own times of a cooler crust. But more accurate investigations have set aside this hypothesis, and shown that the general type of the coal-flora is that due to a warm—not hot—climate, in which moisture was very abundant. To account further for the inordinately luxuriant growth of the plants which made up the fossil-fuel, Brongniart suggested the hypothesis that the atmosphere must at that period have contained a much larger percentage of carbonic acid (poison to animals, but nutriment to plants) than it does now. And when we consider the enormous volume of carbon in the coal and carbonaceous beds which *must* have been obtained from carbonic acid, and add to it all that which has been locked up since in making the thousands of feet thick of limestone, or carbonate of lime, we certainly have a cause which must have played its part. What were the animals which at this time tenanted the globe, is an interesting but difficult inquiry, when we consider the accidents on which it depends that the remains of land animals should be reserved for our study. The *Archægosaurus* was the first coal-reptile found (in Bavaria, 1844): one probably intermediate between the batrachians and the saurians. But the last few years have added several to the list; one of them, the *Dendrerpeton Acadianum*, having been curiously found by Sir C. Lyell and Dr. Dawson in the hollow stump of an erect Sigillaria.

In 1865, Professor Huxley was able to determine, in a collection of specimens obtained from the Jarrow Colliery, Kilkenny, no less than four, if not five, *genera* of amphibian labyrinthodont reptiles.

Among the other vertebrate animals, fishes were common enough, their teeth, scales, and spines being abundant in many of the roof-shales. Agassiz described above 154 species from the coal-measures, a great part of them predaceous, and stated to be more highly organised than any living fish.

Of the *Mollusca*, vast quantities are found, best preserved by being embedded, petrified, in nodules of ironstone, or flattened in the shales.

In association with the lower seams of coal, in most of our British fields, shells of a decidedly marine character occur. Sometimes one seam, sometimes several, will exhibit in its roof of black shale, and commonly within a few inches of thickness, multitudes of a pecten or comb-shell (*Aviculopecten papyraceus*), and of a curled-chambered shell, somewhat like a nautilus (*Goniatites Listeri*), with rarer examples of *Productus*, *Orthoceratites*, *Lingula*, etc. The bivalve *Anthracosia*, much resembling the Unio, or Horse-mussel of our fresh waters, is sometimes found in the same group of denizens of the sea.

Throughout all the middle and upper measures, the great bulk, in fact, of the coal-producing strata, *Anthracosia* alone, with some rare exceptions, out of all the above, continues its existence; but this sometimes in such quantities that entire strata ("mussel-bands") of several inches thick are made up of them. To these may be added Mr. Salter's genus *Anthracomya*, a mud-burrowing shell, occurring also in dense beds like those of the modern mussel. The black band ironstones of North Staffordshire are literally crowded with them.

And lastly, through the whole range of the coal strata there may be noticed, either attached to other fossils or embedded in the stone, the minute spiral case of a sea annelid, termed *Spirorbis carbonarius*, and the seed-like valve of a little crustacean, *Cypris*, or *Cythere*. The tracks of large worms (probably marine) occur in great abundance in the clay ironstones which so often diversify the coal-shales, and the latter sometimes exhibit the remains of crickets and other insects.

When we pass downwards to the great foundation-stone on which our coalfields rest, and with which the lower seams of Scotland and those of Russia are associated, we find, in the carboniferous limestone, a series of strata bearing the most evident traces of marine origin. In part, nothing but banks of coral and encrinites; in others, filled with the well-preserved shells of *Terebratula*, *Spirifera*, and *Productus*, they tell us plainly of deposits formed in a sea of moderate depth; and since the thickness of these beds varies from 500 to nearly 2,000 feet, it seems probable that the floor of that sea must have been more and more, though not uniformly, depressed. In the period that succeeded—that in which the millstone grit was deposited—there is evidence of much disturbance by sea and land: granite and other rocks broken into bits, or rolled into pebbles, and wafted and dragged about by currents and eddies, whilst an occasional bed of quietly-settled shale reveals the shells of *Goniatites*, *Bellerophon*, *Lingula*, and other denizens of the sea, who had found a lull, either in place or time, amid the turbulence of the period. And throughout these strata we find the preparatory symptoms, as it were, of the great coal-making epoch that was approaching, in stems and impressions of several of the genera of plants that were soon afterwards so multiplied.

Some years ago there were authors of weight who inclined to the opinion that coal had been formed by the drifting of large masses of vegetable matter into bays or estuaries, and they pointed to the "rafts" of the lower Mississippi as examples of a similar process still in action. But since due attention has been paid to the constant presence of the roots in the floor of the seams, to the upright trunks—often one series above another—and to the high state of preservation of the most delicate remains, it has been generally agreed that most of the appearances are explained by assuming that the vegetation grew on the spot where we now find it.* Some writers there are, still, who have a hankering after the old aquatic origin, and, supported by the evidence of fishes and marine shells, would assign salt water as a habitat for some of the coal plants. But with others, the doubtful point is whether the trees and undergrowth flourished on dry land or swampy sea-margins. We can no longer doubt that the under-clay was a true soil, in which the great Sigillaroid trees were fixed by their tap-roots, their spreading radical branches, and filamentous rootlets. How many generations of these trees may have risen to maturity and died away before the conditions were favourable to their being preserved, it is hard to surmise; but at length, when a mingled matting of vegetable matter, stems, roots, leaves, etc., had accumulated, like the pulpy mass of a modern peat-bog, the surface of the area was, with much uniformity, depressed. Then would flow back the waters, fresh or salt, over their ancient domain, and, according to the sediment they were able to carry, would deposit sand or mud to be one day known as the rock, or the shale-roof. The *Mollusca* above enumerated then burrowed in the soft ooze, close upon the top of the buried vegetation; in many cases the stumps of the old forest remained standing, whilst mud or silt was deposited around them until the central portion of the trunk would rot away, serve for a time as an asylum for

* Franz von Beroldingen appears to deserve the credit of first suggesting the view that the coal-beds are the peat-bogs of a former age, converted first into brown coal and afterwards into stone coal. ("Beobachtungen, etc., die Mineralogie betreffend," 1778.) In this theory he was supported by De Luc, and after many years by Schlotheim, Nöggerath, and Lindley and Hutton.

some of the lizards or land-shells of the period, and then get filled in with petrifying matter. As the water deepened it was haunted by fish of many kinds, whose exuviæ fell to the bottom and were there buried up, and thus bed after bed of sediment accumulated, sometimes to the depth of a few feet, sometimes to hundreds of yards—if the continuous depression of the land was maintained—until circumstances favoured again the formation of a proper soil (the under-clay), and of a growth of trees and plants, when we should have a recurrence of the same phenomena.

An enormous bulk of vegetable matter would be needed thus to form one of our thicker seams of coals; but we have seen how the latter are generally divisible into several beds, and these again into thin laminæ, whilst we know that peat-bogs of the present day, without the special advantages of the coal-jungle, attain depths of 30 or 40 feet. It has been estimated that 8 feet thick of packed woody substance would be needed to make 1 foot of coal; but we may take it for granted that such an amount would represent only a fraction of the total amount of vegetation that flourished at the time, since much of it must doubtless have escaped from the preservative process of interment.

We cannot afford space to dwell on the chemical argument by which this derivation of the different kinds of coal is shown to be probable; but the following table, borrowed from Dr. Percy's "Metallurgy," supplies at a glance an illustration of the successive steps in the change from woody tissue to anthracite. The proportions of carbon in each substance being taken at the constant amount of 100, the hydrogen and oxygen will be found to have been more and more eliminated.

	Carbon.	Hydrogen.	Oxygen.
1. Wood (mean of 26 analyses) . .	100	12·18	83·07
2. Peat	100	9·85	55·67
3. Lignite (average of 15 varieties) .	100	8·37	42·42
4. Ten-yard coal, South Staffordshire	100	6·12	21·23
5. Steam coal from the Tyne . . .	100	5·91	18·32
6. Pentrefelin coal, South Wales .	100	4·75	5·28
7. Anthracite, Pennsylvania . . .	100	2·84	1·74

When the buried forest had once been fairly covered up by hundreds, and, as the land sank, by thousands of feet of rock, we may conceive it subjected to those conditions of pressure, temperature, and moisture which were needed to change it into that condensed form of fuel now so necessary to mankind.

And when at length, after ages of due preparation, portions of the coal-formation were upheaved into the islands and continents, the seams of coal were brought into a position to be accessible to man, and the forces of the sunbeams which fell upon the jungles of the primeval world are again unlocked and made subservient to our use, when we now decompose by burning those compounds which had been called into existence by the solar light and heat.

CHAPTER IV.

COALFIELDS OF THE NORTH.

In order to enable us to form a due estimate of the coal resources of the various countries, we must glance at the extent and character of the coal-measures as they are developed in the different districts; and, since the history and commercial importance of the coalfield of Newcastle give it the pre-eminence, we may conveniently start from that focus of activity.

It must be premised that the limits of a coalfield are not to be confounded with the area coloured as "coal-measures" in a geological map; for, although in some regions (as in South Wales) it is one and the same thing, the coal-seams are often well known and largely worked beneath other newer formations, which in a map are represented by their proper colour, whether they overlie coal-measures or any other older rocks. We shall, therefore, in many instances, have to speak of a coalfield as such, where it signifies the extent of proved coal-producing ground, whatever the mere covering may be composed of.

Durham and Northumberland.—On examination of a geological map, it will be seen that, coming southward from the Durham coalfield on one side of the central chain of North English hill-country, and from that of Cumberland on the other, a large interval separates them from those of Yorkshire and Lancashire respectively. It will be seen, too, that there are certain features of connection in each case between the east and the west which it is not so easy to establish between north and south, and we may, therefore, take one division for this chapter as including the coal regions north of a line drawn from the mouth of the Tees, westward through Kendal, and the south side of the Lake country.

About equi-distant from the Irish Sea on the west and the North Sea on the east rises the broad backbone of the hill country, composed of the carboniferous limestone, with all its numerous subdivisions so carefully studied by the lead-miners of those breezy fells, and bearing on its culminating points, and on the high ground extending for many miles breadth on the east, a capping of millstone grit. On the west side, or towards Penrith, this main chain has been greatly disturbed and abruptly broken at an early geological period, whilst on the other side the land slopes more uniformly from the high ground. The strata here inclining gently eastward, partake of the same regularity, and as we proceed towards the coast succeed in ever ascending order till the various coal-seams "put in," one after the other, and are at length similarly capped by the magnesian limestone, and soon afterwards—not cut off, but surmounted—by the sea. The field of the Blythe, Tyne, and Wear, so called after its rivers, extends from the Coquet on the north to near the Tees on the south for about 50 miles in length, with a breadth of about 20 miles for a great part of the way, till it narrows to a point when it passes north of the Blythe, an area in all of 705 miles. For some miles in breadth along the western side only a few of the lower seams are worked; then in a line ranging through Newcastle and Durham we get the full number of the workable seams; and again, following a sinuous course from Tynemouth, past Houghton-le-Spring to near Bishop Auckland, the overlying permian formation succeeds, represented by a generally bold outline of magnesian limestone resting on the irregular lower red sand, which, from its water-bearing and loose properties, presents great difficulties to the sinking of shafts eastward of this line.

In former days this upper was confounded with the lower (carboniferous) limestone, and it was supposed that a limit was thus formed to the coalfield on either side. It was, therefore, a bold step when the Messrs. Pemberton, relying on true geological reasoning, determined to pierce downward from the coast near Sunderland, and search for the hidden coal-measures below. Their famous Monkwearmouth pit was commenced in 1826, and had to pass through 330 feet of this newer formation, towards the bottom of which no less than 3,000 gallons of water per minute had to be raised by pumping power, until it was successfully tubbed off. At 285 fathoms depth they cut the Hutton seam, having previously intersected the Maudlin or Bensham seam 20 fathoms higher. And these results appear to establish a curious point in the configuration of the coalfield. The seams which thus lie nearly 1,700 feet below the sea at Sunderland occur at a less depth as they pass to the north and to the south, whilst westward they rise to their outcrop at Howes Gill—an elevation of 740 feet *above* the sea, giving a difference in level of 2,440 feet. It would appear, then, that this is the deepest part, or a sort of transverse trough in the stratification; but as the measures have generally a gentle inclination eastward, where they have been sunk to along the coast, it yet remains to be proved whether the deeper part of the entire basin does not lie further seaward, and the probability remains of a large area of this productive coalfield extending beneath the German Ocean. At these deep pits, and those of Ryhope and Seaham, at a small distance from the coast-line, the deeper seams of the field have not yet been reached; but from sections obtained in the shallower pits in the west the succession is perfectly well known.

The total thickness of the measures from the lowest known seam upwards may be taken at little more than 2,000 feet. The upper half contains only a few unworkable beds, the lower half all the valuable seams. In this field, as in all others, the thickness and character of a particular band of coal will be found to vary, and that to such an extent as to occasion much difficulty in identifying the seams of distant pits. A coal which is suitable for steam purposes in one part of the area will be more fitted for household use in another; and that which is the mainstay of a colliery in one locality may be barely traceable in another.

The chiefly important seams are the following :—

	Feet.	Inches.
Monkton and Hebburn Fell seam	2	10
High main	6	0
Metal coal	3	0
Yard coal (Main coal of Hutton, 6 feet) . . .	3	8
Bensham or Maudlin, 4 feet 8 inches at Monkwearmouth	6	0
Six-quarter	2	6
Five-quarter (Low main at Monkwearmouth) .	4	1
Low main (Hutton seam, 4 feet on the Wear) .	6	0
Crow coal, generally thin, at Ryton	2	3
Five-quarter	3	8
Ruler	1	6
Townley main	3	10
Stone coal, or five-quarter (Busty Bank) . .	3	9
Six-quarter (Busty Bank)	3	4
Three-quarter	2	8
Brockwell	3	2

The average number of seams found to be workable in any one section may, I believe, fairly be taken as 12, with about 50 feet of coal in the aggregate.

Great advantages exist in the district: first, in the general regularity of the measures, dipping at a very moderate angle, commonly about 1 in 20; the convenient thickness of the seams, from 3 to 6 feet; the excellent qualities of the coals, and the usual goodness of the roof, which allows of wide working places and roads, with a very small expenditure of timber The difficulties are the considerable depths of the sinkings in the newer pits, the watery strata to be pierced, and the large amount of fire-damp given off by many of the seams.

Faults or slip-dykes are few and far between as compared with most coalfields, and the *whins*, or basaltic dykes, which traverse the district in an east-south-east direction—although they injure the coal on both sides of them to a distance of some yards—are not found to derange and interfere with them as they do in Scotland and South Staffordshire. Among the ordinary faults, the most remarkable is the great 90-fathom dyke, which—appearing on the coast near Cullercoats, where it displaces the strata to that amount—ranges past Gosforth to Blaydon, and then, entering on the more hilly ground, may be traced westward through the limestone range to the new red sandstone in the neighbourhood of Carlisle. Along this part of its course the *throw*, though variable, is sufficient to inlay, as it were, on its north side a long strip of coal-measures, and thus to give rise to the collieries of Stublick, Midgholm, Tyndal Fell, etc.

The occurrence of the Butter Knowle Dyke, ranging west-south-west and east-south-east, in the southern portion of the coalfield in the neighbourhood of Leasingthorne, throws down the strata to the south some 700 feet, and has the effect of extending the coalfield in this direction, where the coal-measures rise up to the newer formations overlying them. The faults generally do not pass through the newer overlying formations, and they were evidently formed previous to these depositions.

The variations in quality of the seams as they range through this extensive field give rise to different commercial applications. The best "household coal," commonly called after the well-known Wallsend pits, extends from the Tyne to the Wear, and from the last-named river to Castle Eden, and occupies another area about Bishop Auckland. The denser white-ash steam coal characterises the district beginning some five miles north of the Tyne; whilst the tender coals, which afford an admirable coke, are largely worked all along the line of the outcrops on the west, from Wylam and Ryton down to the outskirts of Raby Park.

In the northern portion of the field a further series of coal-seams are met with, the carboniferous limestone series underlying the Millstone Grit being the first example, travelling northwards, of workable coal-seams being found in this formation, which, on reaching the Scotch coalfields, become prolific of valuable coals. The extent to which this coalfield will be workable under the North Sea is a point still open to speculation. Coal workings have been carried on to a distance of three-quarters of a mile below low-water mark in the northern portion of the field in the Low Main Seam, but there would appear to be a considerable thinning and splitting of the coal-seam in this direction, and the question as to whether this may be deemed peculiar to this seam, or portend a general deterioration of the coalfield in this direction, has yet to be seen.

The resources of coal in this coalfield, including the carboniferous limestone series, in seams of 18 inches in thickness and upwards, were estimated by Professor Hull in 1877 at

	8,032,000,000 tons.
Worked since that date . .	785,109,312 „
Quantity available	7,246,890,688 tons.

The total production of the Durham and Northumberland field, which in 1854 was 15,420,615 tons, was for the year 1864 no less than 23,284,367 tons; increased in 1870 to 27,613,539 tons, and in 1897 to 43,587,527 tons. This enormous increase is in great part due to the rapid development of the Cleveland iron district in North Yorkshire. The iron furnaces in the three districts fed with the coal from this field were in 1854 as many as 58; in 1865 they were augmented to 105 actually in blast; and as huge quantities of Durham coke are now conveyed to the western coast for the smelting of the hematite ores, the total quantity of coal thus consumed is probably much more than doubled in one decennium.

Cumberland Coalfield.—In the mountain limestone district about Alston two or three small seams of anthracite (*crow coal*), mostly of but a few inches thick, have been worked for lime-burning, etc., yet are of little commercial importance. But a remarkable change occurs on their passing the great dyke or fault above described, for on the line of the Newcastle and Carlisle Railway one of them has been worked, at Blenkinsop, of good bituminous character, and no less than 6 feet thick, surmounted by a limestone roof. As these seams pass northward they increase in number and importance till, in the farther parts of Northumberland, they are described by Mr. Boyd as being 12 in number, from 2 to 4 feet each; and thus it is that they form an intro duction to the series of limestone coals so valuable in Scotland.*

On the western side of the great limestone chain slight indications of much-disturbed coal-seams occur near the base of the great Cross Fell escarpment; but the important part of the Cumberland coalfield only appears distinctly on emerging from beneath the red sandstone cover south of Wigton, whence it laps round the older rocks of the Lake district, by Maryport, Workington, and Whitehaven, to its termination near St. Bees.

The total thickness of the measures, as well as the number of seams, is notably less than in the Durham field, whilst its length is under 30 miles, and its proved breadth about 6 miles. The quality is also inferior for household coal, and very much so for coking. Certain of the seams are, however, remarkable for thickness and regularity, as well as the peculiar circumstances under which they have been worked. These are best exhibited at Whitehaven, where, along a coast-line of nearly 2 miles, extensive operations have been carried on by Lord Lonsdale, to the distance of 2 to 3 miles under the sea. The strata here dip slightly seaward, but are intercepted by a numerous succession of faults which have rendered their exploration unusually difficult and expensive. Fortunately, the dislocations have been of such a character as to allow of this large area being mainly worked by horizontal roads driven off from the William, Wellington, Croft, and Saltom pits, at depths of from 100 to 150 fathoms. The principal seams (omitting two or three thin beds above and below) are as follow :—

* See Mr. Boyd's paper in the "Transactions of the Institute of Mining Engineers."

Bannock band, 6 ft. 4 ins. to 10 ft. 11 ins., including 14 ins. to 3 ft. 6 ins. of "metal" partings.
Strata, 20 fathoms.
Main band, 9 ft. to 11 ft. 9 ins., with occasional partings of 2 ins. to 1 ft. 3 ins.
Strata, 40 fathoms.
Six-quarter band, 4 ft.

In the year 1765 M. Jars stated that operations had already been extended to the distance of a quarter of a mile under the sea; that three seams were in work, an upper, rather stony, 5 feet coal, used for salt-making; the second 75 fathoms deeper, the Bannock band; and the Main band of 10 feet thick. Wooden rails were in use, and the drainage was effected by four fire-engines, two of which stood on the sea-shore. Fire-damp appears to have been very troublesome, and it is a remarkable fact that the manager of the mine had at that early date proposed to the authorities of Whitehaven to lead pipes through all the streets of the town to light them at night with the natural gas.

At Workington the seams were also wrought beneath the sea, but as they rose towards the bottom of the sea, they were followed up too far, and as due precaution was strangely disregarded, the sea burst in in 1837, and the lamentable result was the loss of 36 human lives, and the entire destruction of the colliery. The same seams are extensively worked on their rise at the Clifton and other collieries in the valley of the Derwent, and again towards Maryport and Wigton.

The total production of this county increased from 887,000 tons in 1854 to 1,408,935 tons in 1870, and the amount had reached 1,986,536 tons in 1897.

COALFIELDS OF SCOTLAND.—In tracing northwards the great calcareous mass which forms the mountain limestone of Derbyshire and Yorkshire, we have seen above that when it enters Cumberland and Northumberland it has already greatly changed its character. Divisional strata of shale (*plate*) and sandstone (*hazel*) separate the bands of limestone, and coal-seams make their appearance, which, beyond the great 90-fathom dyke, attain considerable technical importance. And when at length we cross the border and enter upon the Scottish area we find this formation—lapping round the great upheaved districts of older rocks, ranging from Kirkcudbrightshire to Berwick—to contain a valuable and largely-worked series of coal-seams.

The range of the carboniferous formation in Scotland extends from the coast of Ayr to the mouth of the Firth of Forth, and over an irregular width of from 20 to 30 miles; but as regards the workable portions it is broken up into several distinct fields, partly by the uprising of the lower coalless strata, and partly by the interference of vast masses of igneous or trap rocks (the whin of north England), sometimes bedded, and at others injected as dykes.

These various coalfields are known under the following names:—"Ayrshire," stretching from Ardressan on the north to the River Doon on the south, a distance of about 20 miles, and stretching eastward until cut off by a ridge of Devonian rocks, which separates it from the important coalfield of the Clyde basin. This latter stretches through portions of Renfrewshire, Dumbartonshire, Stirlingshire, and Lanarkshire. Passing eastward still further, we come to the Fife and Midlothian coalfields, lying on opposite sides of the Firth of Forth.

The full thickness of the coal-bearing strata is well shown in the coalfield of Midlothian, east of Edinburgh, where a district of about 9 miles long by 2 or 3 miles wide is occupied by "measures" perfectly analogous in character and contents to the English coalfields.*

In the northern portion of this field, extending from the Firth of Forth at Musselburgh southwards to the neighbourhood of Dalkeith, the upper coal-measures are met with, in addition to the carboniferous limestone coals. The Sheriffhall fault, crossing the coalfield from east to west-north of Dalkeith, an upthrow to the south, of 480 feet, throws these measures out south of this line.

In a total thickness of about 1,200 feet, including a middle band of 200 feet of unproductive rock, are developed some 12 seams, mostly from 2 to 5 feet thick, although one of them, the "great seam," attains a thickness of 8 to 10 feet.

Below these comes the millstone grit of 340 feet thick, and then, in descending order, the carboniferous limestone, with a total thickness of 1,590 feet, but containing, along with only some 40 feet of limestone in many thin bands, a series of about 17 beds of coal of from 2 to 5 feet each (Howell), below which come a series of oil shales. Along the western outcrop of this field the seams dip at high angles from 50 degrees up to the vertical, whilst the centre of the basin is comparatively flat, rising at a moderate inclination to the eastern outcrop. The seams in the carboniferous limestone series are found generally too thin to be workable. The lower limestone is without coal.

Mr. Matthias Dunn, writing in 1830, gave an interesting description of the working of the outcrop or edge coals, which, in a measured section at Niddrie Colliery, he states

* See Mr. Milnes's account of this coalfield in the "Transactions of the Royal Society, Edinburgh," and Mr. Howell's description in the "Memoirs of the Geological Survey," 1861.

to be 24 in number, workable seams, with a total thickness of 95 feet of coal in 4,344 feet of measures, included between the "gramacham" or "diamond" above and the "north greem" seam below, which rests nearly upon the thick encrinital limestone.

The Fifeshire coalfield, as described by Mr. Landale, presents a valuable array of seams, one of which—the Dysart main seam—attains the unusual thickness of 21 feet; but this region is much dislocated by faults and interfered with by igneous rocks.

The seams of this coalfield produce good gas, smithy, smelting, and steam coals, and are found to dip southward at moderate inclinations under the Firth of Forth, so far as they have yet been traced.

Passing westward, through Clackmannan, Stirling, and Linlithgowshire, we come to the important fields of Lanarkshire and Ayrshire, where the chief features are the admirable gas or parrot coals, the moderately thick splint coals, used for iron-smelting, and the black bands or beds of carbonaceous ironstone, which have for many years been the mainstay of the surprising production of Scotch pig-iron. Mr. Ralph Moore, adopting a similar threefold division to that above cited, states the general character of the section to be:—

1. The true coal-measures, 840 feet from the upper 4-foot coal down to the slaty-band ironstone, including 10 seams of 2 to 5 (and in one case 8) feet in thickness.
2. The millstone grit, 960 feet.
3. The limestone series, 2,200 feet, with 3 beds of black-band ironstone, and several seams of good coal.

The importance of the coalfields of Scotland may be inferred from the fact that in 1854 the production of coal was 7,448,000 tons, from 367 collieries; in 1870, 14,934,553 tons, from 411 collieries. In 1888 Scotland produced 22,319,104 tons of coal besides over 2,000,000 tons of oil shales, which was in 1897 increased to 29,082,996 and 2,211,617 tons respectively.

CHAPTER V.

COALFIELDS OF CENTRAL ENGLAND.

If the reader will take in hand a geological map of England,* and fix upon the curious rugged hill of Mow-Cop, near Congleton, as his centre, he may draw a circle with a radius of 60 miles which will embrace 16 patches of coal-measures, being fields and basins more or less separated from one another. Geologically, we have very good reasons for assigning a common origin to the whole of them, and considering them to be the separately visible portions of one vast deposit, which, in the course of ages, has variously been depressed and covered up by newer strata, then upraised and denuded in part, so that—after the fashion of Virgil's famous oak-tree—whilst the higher portions may have stood 8,000 feet above the crests of the Peak of Derbyshire, the lower beds approximate to Tartarus by dipping down from off the Buxton moorlands to a depth of some 12,000 feet beneath the plains of Cheshire. And the inductions of geology in this respect will, at no distant day, be required to solve a question of national

* It has been thought unnecessary to insert a map in this little volume, when so many good geological maps on a useful scale are before the public. As a series arranged according to increasing size, may be recommended Sir R. Murchison's little map, prepared for the Society for the Diffusion of Useful Knowledge; Prof. Ramsay's "England and Wales;" Knipe's "British Isles;" and Greenough's large map, edited by the Geological Society.

moment—the continuity and position of the coal-measures between these apparently disjointed fragments.

YORKSHIRE AND DERBYSHIRE.—From Leeds to Nottingham there extends an unbroken range of coalfield, 65 miles long by from 8 to 20 miles wide, inclining on the whole gently to the east, where it is covered in succession by the lower red sand, the magnesian limestone, and the new red sandstone. Whilst, therefore, bounded on the west by the outcrop of the beds, it is on the east only overlaid by newer formations, and in all probability extends far beneath them.

The thickness of the measures, where fully developed (which is not the case until some miles away from the outcrop), is about 3,000 feet, out of which the lower several hundred feet are chiefly noticeable for the occurrence of flagstones, and of coals with ganister floor, whilst the shales contain the marine shells, already enumerated at page 44. The chief seams of coal and ironstone are found, for the most part, towards the bottom of the measures, and the former may be taken on the average at 16 in number, with 45 feet total thickness of coal, of which the following are the principal, taken in the Barnsley district, near the centre of the exposed coalfield:—

	Feet.	Inches.
Shafton coal	5	0
Muck coal	3	6
Woodmoor coal	3	0
Timber coal	4	0
Beamshaw coal	3	0
Barnsley coal	9	0
Swallow wood coal	3	0
Joan coal	2	0
Flockton top coal	3	0
Park Gate coal	5	0
Thorncliff thin coal	2	6

		Feet.	Inches.
Four-feet coal		2	6
Silkstone coal		5	0
Whinmoor or Low Moor coal		2	6
Ganister series	Halifax coal	1	9
	Halifax soft coal	1	6

The most remarkable of these is the Barnsley thick bed, or the "Top-hard" of Derbyshire. Another seam well known in the London market is the "Silkstone," or black shale, of Derbyshire. In the south of this latter county one of the purest house coals ever seen, the "Kilburn coal," occurs.

In these counties, then, with the adjoining Nottinghamshire, we have the largest continuous coalfield in England; for we may estimate that it occupies about 800 square miles. But one of its most welcome features is its prolongation eastward, first proved on a large scale by the Duke of Newcastle's spirited sinking at Shireoaks, where —commencing in the red sandstones at the distance of 5 miles from the visible coalfield, and cutting the top-hard coal at 510 yards deep—it is not only shown that all the measures are in their proper place, but that they may be expected to lie at moderate depth and an easy inclination. It may be roundly said that this success assures us of half as much again to be added to the resources of the coalfield, and a speculative mind will reckon on a still larger augmentation.

Different opinions are held by eminent authorities as to the extent to which this fine coalfield will be found to extend eastward under these newer formations, some maintaining that the coalfield is a basin and that the coal-measures will be found to gradually rise from the axis of the trough, which is assumed to lie a little east of the Shireoaks Colliery, and to run N.N.W., and S.S.E. and outcrop against the overlying formation in the neighbourhood of Lincoln; whilst others consider that the field will be found to stretch eastward in a succession of undulations, one of which is known to exist in the portion of the coal-field already proved.

Future explorations only can decide which of these theories is correct.

The presence of coal-measures underlying the newer formations has now been proved still further eastward, at South Carr, south-east of Doncaster, where the Barnsley thick coal was proved by boring to lie at a depth of 1,015 yards from the surface, and the coal-measures at this point to be overlain by 600 yards of newer formations. The coal-measures appear to lie fairly flat at this point, and would indicate the approach of the lowest part of this basin.

LANCASHIRE.—More irregular in form, and much intersected by great faults, which dislocate the strata to the amount of hundreds of yards, this coalfield is one of our noblest. Crossing to the westward the ridge of lower rocks which separate it from Yorkshire, a watchful eye will recognise the re-entry into the ground of the various seams which had been seen to pass out on the opposite side of the hills. Especially is this to be noted with the ganister coals, and the peculiar fossils in their roofs, and with the Arley *mine* or seam, which occupies the place of the black shale or silkstone.

As a general feature, although much interfered with by the great dislocations, the analogous arrangement to that of Yorkshire is observable, viz., that the seams incline off from the high country of the moorlands, and are succeeded, after occupying a variable breadth of surface, by the newer beds of the Permian and Trias formations. But the total thickness of carboniferous strata, as well as the number of coals, is much greater than on the eastern side of the chain of hills.

Mr. Binney, the assiduous explorer of this field, has long since found it convenient to divide its thickness of above 7,000 feet into three portions, as follows :—

1. Upper coalfield, including the peculiar Ardwick limestones, with numerous fish-remains, and several thin beds of coals.
2. Middle coalfield, 3,500 feet, containing all the more important seams from the Worsley 4 ft. downwards.
3. Lower coalfield, or ganister series.

The chief centres of activity are St. Helens, Wigan, Chorley, Bolton, Manchester, and the outlying tract of Burnley.

The names and thicknesses of the principal seams, taken at Wigan, are as follows:—

	Feet.	Inches.
Four-feet coal	4	0
Ince Yard coal	3	0
Ince four-feet coal	3	7
Ince seven-feet coal	7	0
Furnace Mine	4	7
Pemberton five-feet	5	2
Pemberton four-feet	4	6
Wigan five-feet	4	6
Wigan four-feet	4	0
Cannel	3	0
King coal	3	10
Yard coal	3	0
Bone coal	2	3
Smith coal	3	6
Arley Mine	4	0

And here, as at Pendleton, Patricroft, etc., near Manchester, very extensive collieries are worked at depths of from 400 to 900 yards. The Rose Bridge is 815 yards deep; the Ashton Moss 950.

The total number of seams above 2 feet in thickness is on the average 16 to 20, with about 70 feet of coal in the aggregate, whilst the entire area is given by Mr. Hull, who has examined it for the Geological Survey, as being 217 square miles.

The principal faults may be enumerated as follows:—The western boundary fault, which terminates the proved coalfield at the present day, is a downthrow to the west which brings the lower beds of the New Red sandstone down to the level of the lower coal measures.

Between Rainford and Wigan the lower coal-measures are met with thrown up to the east by the Great Up Holland Fault of 650 yards throw. Three main faults, the Shevington, Cannel Fault of Ince, and the Great Haigh Fault, are recognised in the immediate neighbourhood of Wigan, whilst towards Manchester the New Red sandstone is brought in by the Great Pendleton or Irwell Valley Fault, throwing down to the north-east 1,000 yards.

CHESHIRE.—The Lancashire is continuous on the south and east with the Cheshire coalfield, so that a narrow strip belonging to this latter county exhibits a very similar succession of strata. A special interest has been given to its mining by the fine shaft (the deepest in England but three) sunk by Mr. Astley, at Dukinfield, to the "Black Mine" at the depth of 686 yards, and pierced through no less than 22 workable coals. Towards Congleton this coalfield fines off and is divided by a very narrow interval from that of—

North Staffordshire.—Here a very singular plication, or folding of the strata, brings in a most valuable succession of coal-measures, amounting in the whole to about 5,000 feet in thickness.

1. *The upper portion* of 1,000 feet contains a quantity of red and purple clays, much used in the potteries for bricks, etc., and only a few thin coals.
2. *Pottery coals and ironstone measures*, 1,000 to 1,420 feet, with 8 to 13 seams of coal of above 2 feet thick, most inferior; and 10 to 12 measures of ironstone.
3. *Lower thick measures*, containing the chief furnace-coals from the Ash to the Winpenny inclusive, 17 or 18 seams above 2 feet. Ironstone scarce or absent.
4. *Lowest measures*, 800 feet, with from 2 to 4 thin coal-seams.

Neglecting the seams under 2 feet in thickness, we have in certain measured portions of this field no less than 40 seams, with a total thickness of 140 feet of coal; in another case 24 seams with 109 feet. Among its more remarkable beds are the courses of carbonaceous ironstone, or black-band, which occur three or four in number, with a variable thickness, but amounting in some cases to 3, 4, and even 6 feet, often crowded with shells of the bivalve *Anthracomya*. Near these also comes in a thin band of fresh water (?) limestone, containing *spirobis carbonarius* and analogous to the Ardwick limestones near Manchester, and to a bed with the same fossils in the coalfield south of Shrewsbury, and in that of Warwickshire.

With the exception of a few large faults—one of which bounds the coalfield to the west by bringing in the New Red sandstone, and another running north-west and south-east past Newcastle, under Lyme and Hanchurch, with a parallel one passing Hanford, throwing down the strata 350 and 200 yards respectively to the east—the coalfield is fairly free from faults.

The boundary on the eastern side of the tract is the outcrop, against the bleak hills of millstone grit; on the west the New Red sandstone, under which its beds plunge; and on the south an irregular line, occasioned by dislocations and the inletting of the overlying Permian strata.

A small outlying field, named after the town of Cheadle, with seven or eight seams, is of very limited importance.

Taking your stand on the high ground on the west of the Potteries coalfield, you may on a clear day descry the Shropshire field on the south, and the Welsh Hills on the west, with the coal area of Denbighshire at their base. The plain of New Red sandstone and marl extends almost like the sea from one hill range to the other, and the idea involuntarily suggests itself to the mind of the geologist that the coal-measures are continuous beneath those broad intervals, even though the depth may be such as to render them, in part at least, unattainable to man.

DENBIGHSHIRE AND FLINTSHIRE.—Commencing suddenly with a bold promontory of the carboniferous limestone near Oswestry, a band of coal-measures reposes against the chain of hills which course by way of Ruabon and Mold to Mostyn at the mouth of the Dee. The seams are not numerous, but some of them, as the 3-yard and 5-yard coals, are remarkable for their thickness; and a bed of cannel, found near Mold, is no less noted for its excellent quality. Moreover, the boundary of the field being on the east and north-east, the overlying New Red formations, leaves it very probable that a large amount of coal, continuous with that already worked, may be found at moderate depths.

SHROPSHIRE.—Omitting some small unimportant patches of coal around Shrewsbury, we arrive—in the Coalbrookdale district—at a focus of colliery working intimately connected with the development of the British iron trade. The total thickness of the measures is but 1,000 to 1,200 feet, and the number of seams of coal, with their height, also diminish rapidly in going south, so that the 55 feet of coal at Donnington dwindles to 40 feet at Lightmoor, and to 16 feet at Amies, near Broseley, south of which town all the ironstone measures—so valuable north of the Severn—are represented by a single bed, the Crawstone. The especially interesting geological characters of the district have been excellently described by Prestwich ("Geol. Trans." Second series, vol. V.), and further details on the ironstones are given in "The Iron Ores of Great Britain" ("Memoirs of Geological Survey," 1862).

The whole of the old or hitherto-known coalfield will, in a very few years hence, be entirely exhausted; but already successful workings have been put through the Permian rocks which border its eastern margin, and the geologist has little doubt that, were he possessed of physical penetrating power, enough to enable him to dip with the coal-seams as they incline eastward, he would, after a deep underground passage of some 14 miles, emerge again in the coalfield of—

SOUTH STAFFORDSHIRE AND WORCESTERSHIRE.—The "Black Country," as it has been popularly called, exhibits the most amazing focus in the world of the various manufactures which depend on a plentiful supply of coal. Its mingled forges, pit-heaps, engines, canals, railways, and blast-furnaces, and the roar of activity which pervades the district, create in the visitor a feeling of confusion which only gradually subsides into admiration of the great natural advantages conferred by the contents of the substrata—advantages which have been the means of attracting a dense population, and of raising upon and around it a vast assemblage of various and prosperous branches of industry. The total area is not large—about 90 square miles—and the total thickness of measures moderate, say 1,800 feet; but the presence in the southern part of the field, about Dudley, Bilston, and Wolverhampton of the 10-yard coal (from 24 to 36 feet thick) has been a feature of importance without a parallel. The roughness of the surface has been repeated below ground, and the mode of working this admirable deposit of fossil-fuel has been a model of which we have no reason to be proud: sad loss of life and great waste of coal having characterised it almost throughout, and the rapid exhaustion of the present pits renders it probable that in a few years the workings of the "thick coal" will be a matter of history.* Meanwhile the lower seams of the "Heathern" and "New Mine" coals are coming into great employ, and a comparatively new field of many different seams—the separated representatives of the 10-yard coal—has been rapidly opened out in Cannock Chase. For the details of this coalfield we must refer the reader to the excellent description by Mr. Jukes ("Mem. Geol. Survey," 2nd ed., 1859).

The number of seams may be given as averaging six, with a total thickness of 50 feet of coal.

Two peculiarities of this coalfield require to be mentioned, even in a brief sketch like the present: 1st, the prevalence of intrusive dykes and bands of igneous rock, the *white* and *green rock* of the miners; 2ndly, the absence of the mill-

* The discovery, which was made at Sandwell Park, of a new area under the Red sandstone, is highly important (1880).

stone grit and carboniferous limestone, the coal-measures reposing directly upon the silurian shales and limestone.

The glory of South Staffordshire as an independent district is past; but the iron-masters make a gallant fight of it in competing with other districts by the introduction from great distances of cheaper iron-ores as well as coals, and by strict attention to the quality of their products.

WARWICKSHIRE.—On the south-east of Tamworth, the clearing away of the red marls reveals a coalfield which runs for some 15 miles in length by Nuneaton and Atherstone, in the same south-easterly direction as the Trent Valley Railway. The total thickness of its constituent rocks is nearly 3,000 feet, but the lower half is unproductive, and the upper half contains only five seams, with an aggregate of 26 feet of coal. The area, too, being only 30 square miles, leaves this a very unimportant tract at present; but its significance as an indication is not to be overlooked, seeing that, like the last and next following coalfields, it is surrounded for the most part by the New Red formations, and may, therefore, with confidence be expected at a future day to be greatly extended.

LEICESTERSHIRE.—In this county—again after an interval of a few miles of the covering of red rocks—a coal-producing tract presents itself. With a total amount of strata a little less than the last, it exhibits more seams, generally 10 of workable thickness, with 45 feet aggregate of coal. The Moira Colliery, near Ashby-de-la-Zouch, is very largely opened on the fine "main seam" of 12 feet thick, of which only the upper 6 feet, the *over coal*, is taken out in the present operations; the *nether coal*, of rather inferior quality, remaining for a future day.

The actual area of the denuded coalfield is only 15 square miles; but several pits have already been sunk with success beyond its boundaries through the overlying strata.

COAL PRODUCTION IN CENTRAL ENGLAND.—It will be interesting to compare for the above districts the production of coal during 1864 with that of ten years before, and with the later statistics.

	PRODUCE OF COAL IN—				
	1854.	1861.	1878.	1888.	1897.
	Tons.	Tons.	Tons.	Tons.	Tons.
Yorkshire . . .	7,260,000	8,809.600	15,588,810	20,579,960	24,053,020
Derbyshire . . .	2,406,696	4,470,750	7,190,000	9,409,592	12,648,419
Nottinghamshire .	813,474	796,700	4.107,350	5,929,666	6,970.424
Lancashire . . .	9,080,500	11,530,000	18.060,025	21,176,371	22,812,422
Cheshire	786,500	822,750	616,575	637,402	738,494
Shropshire . . .	1,080,000	1,150,000	830,575	766,829	703,251
Staffordshire and Worcestershire	7,500,000	11,459,851	13,203,190	14,518,316	14,308,503
Warwickshire . .	255,000	754,000	1,025,450	1,559,031	2,552,120
Leicestershire . .	439,000	890,500	1,020.500	1,196,951	1,626,555
North Wales . .	1,143,000	1,987,060	2,222.357	2,740,753	2,924,962

The ratios of increase in ten years in the different counties are remarkably unlike; and, whilst in most cases the quantity raised has been augmented by from 20 to 60 per cent., in a few of them it has been more than doubled. The numerous canals and railways of central England greatly increase the mutual connection of these several fields, and, as time advances, new bore-holes and sinkings will ere long throw additional light on their natural relationship.

CHAPTER VI.

COALFIELDS OF THE WEST OF ENGLAND, SOUTH WALES, AND IRELAND.

BRISTOL AND BATH.—A large area shaped somewhat like a pear, of about 238 square miles, extending for some 26 miles from the Mendip Hills on the south, and closing to a point near Wickwar, consists of coal-measures exposed to the surface in large patches, but covered over much of their extent with the newer formations, red sandstones, lias, and oolite. The area so covered is approximately 190 square miles. On the southern, western, and north-eastern edges, the coal-bearing strata repose on the carboniferous limestone, whilst their eastern termination, where they pass under the Bath oolites, is still somewhat uncertain. The total thickness of the series above the millstone grit or Farewell Rock is about 8,000 feet, which is divided by Mr. James McMurtrie, in his exhaustive paper read before the South Wales Institute of Engineers (vol. XII.), as follows :—

Upper division	2,200 feet.
Pennant rock	3,000 ,,
Lower division	2,800 ,,
	8,000 ,,

In the northern portion of the coalfield, the upper division, which contains some of the best household coals, has been swept away by denudation, prior to the deposition of the red rocks, with the exception of a small area north-east of Bristol, where, in the neighbourhood of Parkfield, the lower seams of this series are found, and have been extensively worked.

In the southern portion of the coalfield, in the neighbourhood of Radstock and Midsomer Norton, the whole of the upper seams are met with, and are being explored by the Lady Waldegrave, Timsbury, and other collieries. This series of seams are already being worked at considerable depths, as, for example, 200 fathoms at Clandown (where 40 fathoms are sunk through over-laying formations).

Above 100 fathoms of barren strata—chiefly remarkable for the occurrence of 160 feet of red shales, which form a geological landmark in this coalfield—intervenes before another group of coal-seams is arrived at.

The second group occupies a much larger area than the first, and is worked at Farrington Gurney, etc. Next in order comes a great thickness of sandstones, termed the "Pennant," which occasionally present the rough structure of millstone grit. Below the Pennant we have again a deep series of shales, containing a considerable number of seams, some of which are worked at Bedminster, Stratton-on-the-Fosse, etc., whilst the lower coals, very close to the limestone base, are worked at Vobster, Ashton, and at Nailsea.

The Farrington Gurney series, although somewhat inferior to the upper series, produce good household, gas and manufacturing coals. It is generally admitted that the Parkfield seams north-east of Bristol, previously mentioned, correspond with this series. The Bedminster and Vobster, or Ashton series, have been extensively worked in the immediate vicinity of Bristol, and also in the southern portion of the coalfield, near Vobster. The Bedminster seams produce house and manufacturing coals for the most part, whilst those of the Vobster series, in the south of the field, yield good smithy and coking coals.

It is observable that the mode of working adopted in the southern part of this district, coupled with certain local advantages, has rendered it possible to work coal-seams of little more than one foot thick; nay, in one of the "little veins," I have measured the height to be only 11 inches of coal. We may, therefore, take a comparatively greater number of seams in this field to be "workable," and it would appear that they may be grouped as follows:—

Upper series, Radstock, 8 seams, with total of 11 to 13 feet of coal.
Second or Farrington series, 6 seams, with 6 to 10 feet of coal.
Pennant grit, with thin seams, 3,000 feet, maximum.
Third series, Bedminster, Stratton-on-the-Fosse } 20 to 30 seams
Lowest series, Vobster, Nailsea . . . . } (60 feet of coal).

The last two groups are not very distinctly separated, and their seams are difficult to identify, from their being variable in character, and being much disturbed where they approach the limestone. Indeed, the vertical and even overthrown condition of the strata at Vobster, on the north flank of the Mendip Hills, is our nearest approach in Great Britain to the abrupt foldings which are so remarkable in the coalfields of Belgium.

This coalfield possesses the undesirable distinction of being the most disturbed in our isles. The abrupt folding already mentioned caused by the upheaval of older rocks forming the Mendip Hills has had the effect of inverting strata for some distance along their northern flank to a sufficient extent to bring the carboniferous limestone underlying the coal-measures above them.

Another disturbance occurring in this coalfield which, owing to the immense forces which must have been at work to produce it, is of peculiar interest, is that known as the *Great Overlap Fault*, which has been traced eastward from Clandown Colliery for a distance of 1½ miles. How far further eastward it will be met with has not as yet been determined.

From a study of this fault it would appear that the upper series of seams have been thrust forward bodily until they overlap the same series of seams on the other side of the fault by distances varying from 140 yards in the upper, to 360 yards in the lowest of these seams, and thus giving for this distance a double tract of the same coals.*

When we look to the numerous and thin seams of the south portion of this field, and the violent contortions to which, along with their limestone base, the coal-strata have been subjected, we are induced to recognise the Belgian type, and to look eastwards in the direction of the axis of disturbance for a continuation of the trough of the coal-measures. Evidence, however, not altogether conclusive, has been obtained by boring, which would make it probable that the lower measures also, like the upper ones, crop up under the overlying rocks. Towards Bath, at Twiverton, seams of the lower series, much faulted and highly inclined, are worked, but it is uncertain how far they extend. We may also speculate on the coal-measures being brought in again by convolution on the south side of the Mendips, beneath the more recent formations; but on this point no trials appear to have been made.

Many years ago Mr. Godwin Austen expressed an opinion that coal-measures would probably be found in the south and south-east of England, extending in a synclinal basin from the Somersetshire coalfield to that of Calais in the

* McMurtrie's paper, S. W. Inst. Eng., vol. XII.

North of France, and this view was supported, in 1871, by Sir Joseph Prestwich, but although several borings were carried out in the south-east of England, owing to the great thickness of secondary rocks in that part of the country, it was not until 1882, when a boring was carried out at Dover, that success in proving the coal-measures was attained. This boring was carried down a total depth of 2,330 feet, and passed through a thickness of 1,173 feet of coal-measures containing 8 seams of coal above 1 foot in thickness, the thickest seam, 4 feet, being found at a depth of 2,181 feet from the surface. At the present time shafts are being sunk with a view of exploring and working these seams, and the results will be looked forward to with interest. A large number of borings are also being put down in the County of Kent with a view of proving the extension of the coalfield to the west. It is questionable whether this synclinal trough will be found to contain the coal-measures throughout the distance of 160 miles, stretching from the furthest eastward at which the coal-measures have been proved to exist in Somersetshire, to Dover, and it would appear to be more probable that the trough will be found to contain detached coalfields separated by ridges of older rocks.

The question which it is hoped the many boreholes at present being sunk will determine, is the direction which this synclinal takes westward of Dover. Coal has lately been struck in a borehole near Barham, 9 miles north-west of Dover, indicating the direction in which the extension of this coalfield may be looked for.

Forest of Dean.—This complete and picturesque little coal-basin, clothed in great part with fine oak forest, is an admirable study for the student—dipping on all sides towards the centre, and skirted by its base-rock, the carboniferous limestone. It is about 34 square miles in extent, and from its regularity is thoroughly known even where as yet unproved by pits.*

The coal-measures are about 2,300 feet thick, and comprise three series of seams.

The Woorgreen, or uppermost, which extend over a small area in the centre of the field of about 1,500 square acres, contains but a few thin seams. The middle series, extending over an area of 7,000 acres, contains 7 seams of value; whilst the lower series, with a like number of seams, is found over an area of 16,000 square acres. The total thickness of coal in this field is about 35 feet, but of this probably not more than 20 feet is contained in workable seams. Whilst enjoying certain advantages, such as freedom from firedamp and faults of magnitude, 3 only of the latter over 75 feet in throw being known, this coalfield is disadvantageously placed in respect to the thickness and varying section of many of its seams, and the quantity of water met with. In the Coleford High Delf seam—the best known seam in the coalfield—a peculiar geological disturbance is met with, locally known as "The Horse." This disturbance is thus described by Sir Henry De la Beche:—"The Horse resembles a channel cut amongst a mass of vegetable matter in a soft condition. It ranges south 31 degrees east for a length of 2 miles, and a breadth of from 170 to 340 yards, whilst a number of minor channels communicating with the main channel are called 'lows.'"

* A beautiful model, showing most instructively the position of the various seams, was constructed some years ago by Mr. T. Sopwith, F.R.S., and was deposited by H.M. Commissioners of Woods and Forests in the Museum of Practical Geology, Jermyn Street.

A probable explanation has been given that it was the channel of a river which formed the outlet of a deep lake or lagoon, where the vegetation which ultimately formed the Coleford High Delf seam of coal was deposited. "The Horse" itself is formed of sandstone.

Below the Churchway, and above the Coleford High Delf seam, there occurs a thick series of sandstones, giving rise to numerous excellent quarries, and which in some degree appears to be equivalent to the Pennant of the Bristol field.

Several of the coals about the middle of the series are remarkable for the great number and variety of fossil-plant remains found in the roofs; whilst the lowest thick coal, the Coleford High Delf, from 4 to 10 feet 6 inches, shows only sigillariæ and other large obscure trunks of trees. Ironstones are almost entirely absent, but the want of them is amply made up for by the admirable brown oxide of iron found abundantly in *churns*, or irregular deposits in the upper portion of the limestone.

The Dean Forest field produced in 1854, 420,866 tons of coal; in 1870, 907,183 tons; in 1888, 817,818 tons; and in 1898, 1,150,571 tons. From this it will be seen that the output of coal from this field is but barely maintained, owing partly to the abandonment of iron-making, which was at one time a prosperous trade in the district, and partly to the severe competition of the Midland and South Wales coalfields in the markets which were at one time largely supplied from the Forest of Dean.

DEVONSHIRE.—In the north of this county, the neighbourhood of Bideford is remarkable for the occurrence of small seams of anthracite, or culm, which have been worked to a considerable extent. They are of but small commercial importance, but are interesting as offering a parallel to the thin seams found in the large tract of carboniferous slate found in the south-west of Ireland.

South Wales.—The magnificent coalfield which extends from Pontypool on the east to St. Bride's Bay on the west, and occupies some 900 square miles, chiefly in the counties of Monmouth, Glamorgan and Carmarthen, is no less remarkable for its thickness than for the variety and excellence of its products. Based upon a foundation of bold hills of limestone, which rise on its northern, southern and eastern limits, it forms through a great part of this length an elongated basin containing a mass of picturesque hilly land, intersected by numerous valleys, which have a mainly north and south direction, and in which the greater number of the works are situated. The very numerous dislocations by which it is intersected follow a still more regular meridional course. The great breadth of the field, from 12 to 16 miles, and the rapid inclination of the strata, would soon carry them down to unattainable depths, but for their being again raised nearer to the surface by an axis of elevation, or *anticlinal* ridge, which is traceable along a considerable distance in an east and west direction.

The anticlinal ridge, which can be traced from the eastern portion of the coalfield in Monmouthshire westwards into the county of Pembroke, with the exception of that portion of the coalfield underlying Carmarthen Bay, divides the coalfield into two unequal basins, of which the northern is considerably the greater, being some 9 miles in width from north to south, as compared with a width of 5 miles attained by the southern basin.

The inclination of the strata in the former throughout that portion of the coalfield situated in Glamorganshire is moderate, not exceeding on the average 3 inches in the yard, but in the southern basin, more especially along the southern outcrop of the coalfield, the seams are found to lie at high angles, and rapidly attain a greater depth below the surface than is found in any part north of the anticlinal ridge in this part of the field. Going westward, in Carmarthenshire and Pembrokeshire, as the coalfield narrows, the strata along the northern outcrop are found to become steeper, and where the coal-measures emerge from beneath the waters of Carmarthen Bay, at Saundersfoot, the strata generally are found to become much contorted and disturbed.

In Monmouthshire the thickness of the strata is far less than in the more western portion, and the maximum depth to the lowest important seam (the black vein) may be estimated at 650 yards, whilst the lowest workable coal would be reached at 750 yards from the surface in the valleys. Here the uppermost notable seam is the well-known house coal, the Mynyddyslwyn, 5 feet 6 inches, which, occupying only the middle of the trough, has already been worked out over a great part of its area. Beneath this comes a great thickness of sandstones, the "Pennant," and below that, again, the measures including the excellent furnace coals and clay-iron ores, which have given rise to the great ironworks of Ebbw Vale, Tredegar, etc.

Farther west, the sandstones are greatly augmented in thickness, and are surmounted by a series of measures with many workable seams, which appear to be exhibited in full development to the north of Swansea. But still farther westwards, at Llanelly, an upper series of seams occupy a comparatively narrow area, coursing east and west, where the full thickness of the coal-measures is estimated to amount to no less than 10,000 feet. If, therefore, we include these where they are worked on the north-east of

Llanelly, and extending to the Llwchwr River, we have the following full section:—

Uppermost or Llanelly series, 1,000 feet, with 8 seams, and a total of 18 feet of coal.

Penllergare series, etc., 3,000 feet, with 16 seams above 18 inches, and a total of 50 feet of coal. (Down to the Hughes' seam of Swansea.)

Swansea sandstones (Pennant), 2,700 feet, with 15 seams and 28 feet of coal.

Lower series, 400 to 1,400 feet, with 18 seams and 83 feet of coal.

The local variations, and especially the thinning-out eastward of many of the beds, render a general section, such as the above, inapplicable except to a limited part of the area.

On the west of Carmarthen Bay the thickness of the measures is again greatly reduced, and their value is much deteriorated by the violent foldings and convolutions to which they have been subjected, and which may be seen at their maximum in the cliffs of St. Bride's Bay.

The north-eastern part of the field is principally remarkable for its excellent partially bituminous coals. In the neighbourhood of Aberdare the seams acquire in the highest degree those free-burning, and yet smokeless, properties, which adapt them especially to steam purposes. The run that has consequently been made upon the coals of these valleys has led to the opening of such numerous and such vigorously-worked collieries that large tracts of the best seam, the Aberdare Four-foot, have already been exhausted.

Many of the collieries established have already attained great depths, as, for example, the Deep Navigation Colliery and the Dowlais-Cardiff Collieries, the latter only lately sunk, which are each some 760 yards in depth, and from the former of which an output of over half a million tons is annually raised.

From hence westward the coals of the south outcrop remain bituminous as far as beyond the Llanelly district, whilst those along the northern side of the field change to anthracite, and this latter variety of coal alone is yielded by the seams rising northward in Carmarthenshire, and by all those of Pembrokeshire. Even within a distance of a few hundred yards, the Llanelly beds are seen to be bituminous where they rise to the south, and anthracite in the opposite side of the trough.

The approximate area of bituminous coalfields is 410 square miles, of anthracite 410 square miles, and of qualities varying between bituminous and anthracite 180 square miles.

The unworked resources of coal in this field in 1872 are given in the Report of the Royal Coal Commission as follows:—

	Tons.
Coal to be worked at a less depth than 4,000 feet . .	32,457,165,647
Coal at a greater depth than 4,000 feet	4,108,996,750
Total unworked coal in the coalfields	36,566,162,397
Since that date has been worked	644,749,785
Leaving the total unworked coal in this field at . .	35,921,412,612

Much, however, of these large resources will be won and worked only at great cost, and it is doubtful if, when these costly coals have to be worked, it will be possible for this field to compete with its foreign rivals.

The production of coal in this field for the years 1854, 1864, 1888, and 1897 has been as follows:—

	1854. Tons.	1864. Tons.	1888. Tons.	1897. Tons.
Monmouthshire	8,500,000	4,028,500	6,830,781	9,307,304
South Wales		6,948,000	20,317,528	26,499,086

Of this quantity of 35,806,390 tons in 1897, 16,418,700 tons were exported to foreign countries.

An examination of the constituent strata and of the positions of these western coalfields will lead to the induction that they have formerly been united, and that in Dean Forest we have a link between its larger neighbours, which has been preserved from denudation by its fortunately having been folded into a basin form. The 20 miles which intervene between Coleford and the Welsh hills exhibit only the Old Red sandstone, the base on which coal-measures once rested, long since swept away by the wearing action of the sea, when the land has been raised after periods of submergence.

IRELAND.—The coalfields of the sister country form a most interesting study to the geologist; but unfortunately, yielding only an average of under 140,000 tons, they present to the commercial or technical inquirer features of little present value, and of no future prospects. He who has passed long days in exploring the hilly coal country of Carlow, Kilkenny or Tipperary—now examining the fossils of the shales, which remind him of those of the lowest coal series of central England, and anon looking down upon the wide plains of carboniferous limestone, which form the great bulk of the low country—cannot but soon arrive at the conviction that Nature probably gave to Ireland with a liberal hand, but has again taken away what she had given.

The isolated little coalfields which exist at present are but the remnants of important deposits, which have been torn away by denudation; and as they are unmistakably the few lowermost beds of the formation, no discoveries are to be expected from boring. It is, nevertheless, noticeable that the lower portions of the carboniferous strata are developed in great thickness; for the limestone is succeeded by several hundred feet of black shale, as in Derbyshire, and then by some 500 to 700 feet of flagstone, which form a parallel to our millstone grit. The coal-measures, attaining sometimes a thickness of 1,800 feet, contain but a few seams, mostly very thin, of anthracite, extremely broken, compressed and uncertain in County Cork, but in the Tipperary and Castlecomer fields forming basins of considerable regularity.

In the north of Ireland, coalfields of very small extent occur in Tyrone and Antrim, which, although some of the seams are of bituminous quality, exhibit in the main characters very similar to those of the south. And thus the whole of the deposits of fossil fuel being but fragments capable of a very limited supply, it is fortunate that the town populations of Ireland can be supplied with such facility from the Clyde, Whitehaven, the Mersey, and the Dee, and that Nature has in some measure made amends for the absence of coal by the gift of peat bogs of unsurpassed extent and quality.

CHAPTER VII.

CONTINENTAL EUROPEAN COALFIELDS.

FRANCE.—Although unable fully to supply the demands of a large population and high civilisation, the French coalfields are neither few nor poor in contents. The sum-total of the coal production of France is obtained from above 50 different patches of the coal formation, only a few of which need to be cited as of permanent importance. They may be grouped as the coalfields of the north, of the centre, and of the south.

That of the north, occupying a narrow strip of land in the departments du Nord and Pas de Calais, is at the one end continuous with that of Belgium, whilst on the other it gradually diminishes in value as it is followed from Valenciennes and Bethune, towards Hardinghen and Boulogne. Considering how the coal-measures are covered by the chalk, or cretaceous strata, 80 to 150 yards thick, some of them offering very serious obstacles to the sinking of shafts, it is creditable to the sagacity and perseverance of the French engineers and coal-owners that they have so ferreted out the character and position of these concealed treasures as to have brought the production of this field already up to nearly 17 millions of tons. The seams are not actually traceable without a gap into Belgium, but are of a similar character—regular and numerous, yet thin;

thus the 12 beds of Aniche give together but 23 feet of coal; 4 beds worked at Douchy, 11 feet 6 inches; 18 at Anzin, 39 feet.

A comparison of these features with those exhibited on the flanks of our Mendip Hills, and an observation of the underground course of the sharp trough of French coal strata, deflected as it is from its Belgian direction, when it arrives at Douay, inclines us to the speculation that the paleozoic rocks may be continuous from the Severn to the Rhine. The question may possibly be of little practical importance, but is one of great interest as regards the original deposition of the carboniferous series.*

The coalfields of central France are remarkable for their irregular and small area and the fragmentary and unequal state in which most of the seams occur. They are commonly based upon some of the primary rocks, granite, gneiss, etc., and a great part of their constituent mass consists of coarse grits and towards the base of rough conglomerate. The seams attain here and there a vast thickness, even up to 40, 60, and 80 feet, but are much broken and subject to sudden changes. Some of the French geologists are inclined to consider them the result of deposition in lakes, in contradistinction to the fields of the North and of England, where they repose on the obviously marine beds of the mountain limestone.

The most important of them is the district of St. Etienne and Rive de Gier (Loire), occupying a length of about 34 miles, and in which the lower seams occupy an area of 60,000 acres. One of these varies from 30 to 70 feet in thickness. On these follow some hundreds of yards thick of barren sandstones, and then an upper series of 20 seams

* Mr. Godwin Austen long since propounded this view on purely geological grounds. "Quarterly Journal Geological Society," vol. xi.

of from 3 to 16 feet thick, which only cover a surface of about 10,000 acres, and in the midst of which the full thickness of the basin appears to be near 5,000 feet. The active manufacturing industry of this neighbourhood has raised the production to more than 3 millions of tons.

Another remarkable basin is that of the Saone et Loire, the chief working centres of which are Creusot, Blanzy, Montceau, Montchanin, and Epignac, where the measures contain only 10 beds of coal, but at Blanzy two of them run from 30 to 60 feet each; and at Montchanin, as at Creusot, one seam attains locally the extraordinary amount of from 60 to 130 feet in thickness.

Most of these central fields are unfortunately mere basins in the older rocks, so that their contents are rigidly defined; yet a few of them—as that of Creusot and Blanzy—offer some prospect of continuation, especially on the south-west beneath the covering of newer formations.

In the south, the coalfield of Alais, in the departments du Gard and Ardeche, conveniently situate for the supply of the coasts of the Mediterranean and that of the Aveyron, are both of them noticeable for a yield which has increased much within a few years past, and for having probable reserves beneath the Jurassic strata, which on certain sides bound the visible extent of the coal-measures.

In 1863, with a home production of 10½ millions of tons—increased in 1888 to 22,951,000—France consumed half as much again imported from abroad.* The production in

* The imports of coal and coke into France were:—

	Tons (1864).	Tons (1877).
From Belgium	3,500,000	3,872,051
„ Prussia	1,800,000	1,091,388
„ England	1,200,000	2,792,907
	6,500,000	7,756,346

1897 amounted to 30,797,629 tons. Since 1815 the amount raised from French pits has been multiplied *tenfold;* but it is still a problem whether the rapidly increasing demand will ever be met by the production of the country. My own visits to a few pits have impressed on me the conviction that the French coal-seams are usually much more difficult to work economically than our own; and that, the prices necessarily ruling higher than in more favoured districts, it will always be difficult for the coal-owners to compete on the large scale with those of England, Belgium, or Prussia.

BELGIUM.—The deepest pits in the world have been opened in that narrow, but actively worked, zone of coal-measures which runs from west to east by Mons, Charleroi, and Namur to Liége. Especially in its western portion, the district of Hainault, the high angle of inclination of the strata, sharply folded and even zigzagged into a narrow trough, has occasioned the shafts to attain in several cases over 750 mètres, or 2,460 feet; one shaft at the Viviers Reunis, near Gilly, even 1,040 mètres or 3,411 feet.

The Belgian coalfield consists of a narrow belt, of a maximum width of 9½ miles from north to south, stretching (excepting for an upheaval of carboniferous limestone) near Namur across the country from east to west, and is connected with the Aix la Chapelle coalfield on the east, and the Pas de Calais on the west.

Two main divisions of the coal-measures are recognised:

The upper coal-measures, comprising sandstones, shales, and various productive coal-seams.

The lower coal-measures, in which conglomerate sandstone, schist, with anthracitic slaty coal-seams, are met with.

The upper division is estimated to attain a thickness of

7,100 feet at Mons, with 125 seams of coal, whilst at Hainault, the thickness of coal is placed at 230 feet, in 125 seams, the thickest of which is 5 feet 6 inches, and the thinnest worked 10 inches to 1 foot.

Many qualities of coal are met with in this field, the upper series of 47 seams in the Mons district only yielding "flenu," or gas coals, containing 29 to 45 per cent. of volatile matter. Bituminous or cooking coals, of which 21 seams are known, with from 17 to 29 per cent. of volatile matter; semi-bituminous, or charbon de forge, in 29 seams, with from 10 to 17 per cent. of volatile matter, and 20 to 25 seams of lean, short-flaming or anthracitic coals, charbonsee or maigre, containing less than 10 per cent. of volatile matter.

The production of the different districts of this fieldwas :—

		Tons (1867).	Tons (1877).	Tons (1883).	Tons (1897).
Mons Centre Charleroi	Hainault	9,595,280	10,259,374	13,497,113	15,422,800
Namur		389,586	371,388	485,450	533,580
Liége		2,770,956	3,307,761	4,195,191	5,536,056
Total . .		12,755,822	13,938,523	18,177,754	21,492,436

The northern side of this long synclinal trough inclines much more moderately than the southern; and in the sharp-angled, zigzag contortions the same contrast between the two sides may often be seen, an arrangement recalling the phenomena of our Pembrokeshire field. M. Dormoy, a French engineer, has constructed some beautiful maps to illustrate his views, and considers that in consequence of the swerving direction of a great east and west dislocation, the southern half of the trough is wanting, except in the rich elliptical basin of the Couchant de Mons, where the total thickness of the measures is estimated at 8,000 feet.

A striking example of the zigzag structure of the coal-measures is seen in the accompanying section of the mine des Six Bonniers, near Namur.

The mode of working is generally by a modified kind of long-work, but one requiring a vast quantity of timber, much of which is lost. Within the last 30 years great strides have been made in the improvement of their machinery, and the output at the larger pits is very considerable ; whilst the expense of deep sinkings tends, as in the North of England, to increase the area worked from a

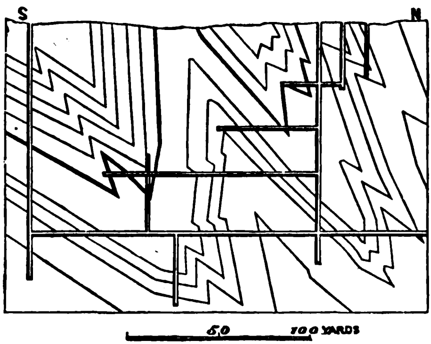


Fig. 14.

given pit. The quantity raised per man is much less than the usual English standard, partly in consequence of the thinness and difficult position of the seams. Not long ago all the workpeople were by law obliged to travel up and do wn by ladders, but at presentmay be raised by the cages ; and the fahrkunst, or as it has been termed, warocquière (from M. de Warocque, who erected an excellent one on his own works at Mariemont), has been applied with great success at several of the larger collieries.

The price of coals in Belgium is very high, 16s. to 20s. per ton being obtained for large, and 8s. to 10s. and 15s. for mixed and small.* They are divided into the following classes, according to size: *Houille*, large blocks; *gaillette*, lumps; *gailleteries*, pieces the size of a fist; *gailletins*, or *têtes de moineau*, nuts; and *menu*, smalls, or slack; whilst the name of *gilleteux* is given to mixed sorts.

PRUSSIA.—Almost continuous with the Belgian field, the two highly contorted coal-basins of the Inde, near Eschweiler, and of the Wurn, near Aix-la-Chapelle, have been worked from a very early period; and extending as they do to a very great depth, contain large reserves of coal. In the same direction, farther eastward, after crossing the valley of the Rhine, comes the large and rich coalfield of the Ruhr, or of Westphalia, which, although mined near Dortmund as early as 1302, has only within the last quarter of a century risen to a high degree of importance.

That portion of the coalfield which is visible at the surface consists, in the main, of three parallel synclinals, rich in a vast number of seams, of which the uppermost are a good bituminous coal, the middle series semi-bituminous (*Sinter* or *Ess-Kohlen*), and the lower seams non-bituminous or *Sand-coals*. There are here no less than 117 seams, in 1,203 fathoms of measures, containing an aggregate of 294 feet of coal. Nearly three-fourths of the number are of workable size, and they are now recognised and mapped over the entire district by the aid of three or four *guide-seams* of special character and persistence. Of late years numerous and systematic borings through the chalk strata which overlie the coal-measures of the north, have proved

* The prices mentioned throughout the book refer to the years 1864-6.

the existence of several additional similar folds over a still larger area, so that the prospective value of the field has been more than doubled; and it is estimated that it contains no less than 39,200 millions of tons. But perhaps the most remarkable coalfield of the Continent is that of Saarbrücken, on the south of the Hunsrück range, and on the left bank of the Rhine. In this extensive and isolated tract a greater thickness of measures and of coal exists than anywhere else in Europe. Prussia has the good fortune to possess the lion's share, whilst a small but valuable division containing the lower seams only falls within the confines

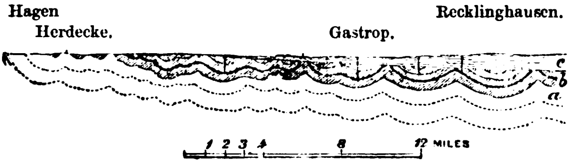


Fig. 15.

a, Lower carboniferous rocks, sterile sandstones.
b, Productive coal-measures.
c, Cretaceous strata.

of Rhenish Bavaria (Rhein-pfalz). The coal-basin, in outside measures, is about 60 miles long by 20 wide, and its lower strata attain, in a line from Bettingen to Tholei, the enormous depth of 20,000 feet, whence a great portion of the coal must ever remain practically unattainable.

The Prussian mining officers, under the lead of Noggerath and Von Dechen, have made most accurate surveys and sections of the measures, from which we find that the total number of seams above 6 inches thick is 164, containing in all 338 feet of coal; whilst the number at present deemed workable, *i.e.* above 2 feet, is 77, with 240 feet of coal, and they estimate that the quantity of workable coal down to the depth of 342 fathoms in the three Prussian circles of Saarbrücken, Saarlouis, and Ottweiler is 2,750 millions of tons, whilst the total amount in the measures for the same limited area would be above 10 times that quantity.

In the International Exhibition of 1862 perfect sections of some of these beds of coal engaged attention, and the seams called Callenberg, Schwalbach, Beust, and Blucher reared up against the walls with their full height of 10, 12, and 14 feet, afforded a fine sample of the products of collieries which now export largely into France. One notable peculiarity in the coals, and in which they differ strangely from those of Westphalia and Belgium, is that the lowest known seams are bituminous or caking coal, and that the higher they range in the series the more dry or anthracitic do they become. Of small importance, as reserves of fossil fuel compared with the two last, but yet very suggestive in a geological point of view, are the two isolated protrusions of coal of Ibbenburen and the Piesberg near Osnabruck. They consist of true coal-measures, in which from 5 to 7 seams have been proved and worked on a moderate scale. Before quitting Westphalia, it should be added that seams of exceptionally good coal, for the newer formations, occur in the Wealden strata, which traverse a part of the kingdom and extend into Hanover and Brunswick. In the districts of Tecklenburg, Minder, Osnabruck, etc., these seams, which run from 10 to 44 inches, are a good deal worked for local purposes, and yield in some places caking, in others, anthracitic coal.

Another Prussian coal region, that of Wettin and Lobejun near Halle, claims attention as forming a link between the north-western fields and those of Saxony. It has long been worked, although figuring to a very small amount in the annual returns.

On crossing the Prussian territories to their south-eastern corner, we arrive at the remote and comparatively unwrought coalfields of Silesia. That of Lower Silesia extends through the circles of Landshut, Waldenburg, and Glatz into Bohemia on the south-west. That of Upper Silesia occupies parts of the circles of Ratibor, Rybnick, Pless, etc., and passes on the one side into Moravia and Austrian Silesia, on the other by Beuthen towards Krakau. This latter field especially, which was commenced upon only in 1784, is of a value which has not been sufficiently appreciated. Measured at its full thickness from the saddle of Zabrze towards the outcrop, it is stated to contain no less than 333 feet of coal in seams, of about 2½ feet thick; whilst its extent, reaching far beyond the boundary shown in maps, is difficult of limitation, from the fact of the coal-measures passing beneath newer formations. But whilst the total mass of the strata appears to be some 10,000 feet thick, and much of the coal may therefore lie at unattainable depths, it is made out with fair probability that this repository must contain an available quantity, even within a working depth already exceeded elsewhere, of 50,000 million tons of coal.

The structure of this latter coalfield is not yet so thoroughly explored as to give certainty to calculations for the future, but the surveys of men distinguished no less as miners than as geologists, Von Oeynhausen, Von Carnall, and Krug von Nidda, leave little doubt that the district of the head-waters of the Oder may be looked to as a source of supply long after we shall have burned out our last ton of coal from most of the pits of our western countries.

With the steady advance in production of the Prussian coalfields, it may be observed that the most flourishing is that of Westphalia, where the position is eminently favourable to cheap transit, and where consumption has been fostered by the price being lowered considerably below the standard of other Continental producers.

The following table exhibits the quantities raised from the several districts of Prussia during the years 1863 and 1883, the total in 1897 being 84,253,393 tons.

Official Centre.	1863.			1883.		
	Coals.	Brown Coal.	Total.	Coals.	Brown Coal.	Total.
Breslau (Silesia) .	4,421,119	188,807	4,609,926	14,863,833	437,193	15,301,026
Halle (Pr. Saxony)	52,971	3,645,189	3,698,160	29,084	10,968,586	10,997,670
Dortmund (Westphalia)	6,875,120	1,631	6,876,751	27,863,025	—	27,863,025
Bonn (Saarbrücken)	2,955,364	190,576	3,145,940	7,440,725	254,225	7,694,950
Clausthal . . .	—	—	—	441,351	166,620	580,977
Grand Total .	14,304,574	4,026,208	18,330,777	50,611,018	11,826,630	62,437,648

The brown coal, or lignite, of Prussia, as well as of Nassau and several other North German territories, now commands a great sale as a fuel, well enough suited to many purposes. The shallow basins of tertiary rocks—generally sandstones—which yield it, are scattered in patches over a vast extent of country, but attain special importance on the Lower Rhine in the Westerwald, in the Wetterau on the River Elbe, and in the Thuringian district.

SAXONY.—These coalfields, although locally important and interesting as having been geologically well explored by Naumann, Von Cotta, Geinitz, and Von Gutbier, are not likely to exercise much influence on European production. That of Zwickau was worked at a very early date, and being found to extend beneath the New Red sandstone, offers a good magazine for future supply. Where best developed on the left bank of the Mulde, it exhibits 9 seams with 96 feet of coal.

From the careful examination of the coal plants instituted by the Saxon geologists, it is shown that, whilst the undermost seams of Silesia, the *culm* series, may be termed Lycopodiaceous or *Sagenaria* coal, the lower seams of Zwickau are chiefly of *Sigillariæ*, forming *pech-kohle*, or pitch-coal; that next above the Sigillaria zone comes the Calamite coal, principally shown in the *Russ-khole* seam, which attains locally a thickness of 22 feet 6 inches. Above this occurs the Annularia zone, and lastly, including the uppermost seams, the Fern zone.*

The coalfields of Haynichen and of Potschappel are of far smaller note, but the position of the latter near Dresden, and the silver mines of Freiberg, gives it a special value. On the whole, this little kingdom produced, in 1887, of coal and brown coal together, 5,060,149 tons; the true coal being 4,293,417 tons, raised from 74 pits by 17,974 workpeople.

The rapid increase of production in Saxony, especially since the year 1830, will be appreciated from the statement of annual raisings at intervals of 10 years:—

Year.	Saxon *scheffel*, nearly 4 cwts.
1790	30,800
1800	62,000
1820	65,000
1830	165,000
1840	780,000
1850	4,200,000
1860	7,874,000
1870	15,082,170
1880	18,000,000
1890	20,754,210
1897	22,858,425

* The flora of our coalfields of Gloucestershire and Somersetshire offers, I think, a parallel to the above, but its details need closer examination.

AUSTRIA.—The large amount of forest still existing in many parts of the Austrian monarchy has rendered coal a requirement of no serious importance until within the last few years, when the great increase of steam navigation, of railways, and manufactures has given impetus to the production of every kind of fossil fuel. The true coal formation stretches from Lower Silesia into a limited district of Bohemia, at the base of the Riesengebirge; and that of Upper Silesia forms a tract of considerable importance around Mahrisch, or Moravian Ostrau, where it is largely worked by Von Rothschild and others.

On the north-west side of Prague the coal-basins of Schlan and Rakonitz, that of Radnitz, and the western one of Pilsen, extending in the aggregate over some 600 square miles, are all being rapidly opened; but no less remarkable are the strikingly thick seams of brown coal (sometimes from 30 to 50 feet) found in the flat country of Elnbogen, Bilin, Commotau, etc., and largely shipped on the Elbe.

The Austrian States raise in the year over 36,000,000 of tons, of which above half is brown coal, but some of the varieties of the latter are so like good bituminous samples of the older coal that I have seen one of our most experienced Newcastle pitmen entirely at fault in judging of them. A very superior quality occurs at Funfkirchen, in Southern Hungary, and at Steuerdorf and some other localities in the Bannat, where it needs an examination of the fossils in the shales to convince you that they are in the lias formation. The tertiary brown coals of Hungary and in the Austrian Alps, especially in Styria and Carinthia, are not only of a very useful character, but occur in seams which in some instances attain the surprising thicknesses of 50, 70, and even 120 feet.

SPAIN.—Although the Mediterranean countries are generally devoid of true coal, exhibiting only here and there deposits of lignite of no great importance, the Spanish peninsula presents a notable exception, boasting a large coalfield of numerous seams, superposed on the carboniferous limestone of the Asturias, and two others apparently of great though unexplored value at Belmez and at Villa Nueva, near Cordova. But no great development can be expected whilst the means of communication remain so bad that the habitual transport of the produce of the collieries is effected on donkey-back. The last 30 years, however, have witnessed a change.

RUSSIA.—It is no matter of wonder if in this most extensive of European countries the abundance of forest and the scantiness of population have retarded exploration for coal. But the researches of Sir Roderick Murchison and his associates, Count Keyserling and M. de Verneuil, have proved the existence of a gigantic extension of lower carboniferous rocks, ranging along the flanks of the Ural Mountains, over a length of about 1,000 miles. It is only here and there that any coal-seams have been proved to exist; but although much interrupted, they are distinctly shown to occur on both sides of the great dividing chain.

Of the coalfields of Russia, the most important at the present day is that of the Donetz, between the Don and the Dnieper. This coalfield is stated to have a maximum length from east to west of 240 miles, and 100 miles from north to south, and to be 15,500 square miles in extent. The carboniferous strata rest upon grits, conglomerates, and quartzites of upper Devonian age, and are divided into three divisions. The lower carboniferous limestone, containing no coal. The middle carboniferous, consisting of sandstones, shales, and limestones, contain seams of from 1 to 4 feet in thickness, which are extensively worked. The upper carboniferous, stated by Messrs. Tschernyschew and L. Loutougain to be 7,000 feet thick, containing workable seams in the lower portion.

The coals of this field vary from splint to anthracite, the latter being chiefly found in the eastern portion of the coalfield.

The following table, given by Herr Michel Lentzki in the "Revue Universelle des Mines, 1896," vol. xxxiii., pages 91 to 122, shows that the coals of this field are various, and that many are of good quality.

Description of Coal.	Volatile Matter and Water.		Carbon.		Sulphur.		Ash.		Coke.	
	Min.	Max	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Splint	37·6	50·1	37·7	55·2	·6	5·15	1·28	8·1	49·1	55·1
Gas	27·8	37·4	50·5	67·4	·5	2·30	1·10	7·0	58·3	70·4
Forge	26·4	30·6	60·2	72·4	·25	1·60	1·30	4·0	69·4	72·9
Coking . . .	12·4	23·5	66·6	85·1	·4	3·10	·90	8·3	70·3	87·1
Semi-Anthracite	10·2	20·3	73·5	87·5	·2	3·00	1·50	6·2	78·4	89·6
Anthracite . .	4·2	11·4	83·4	91·0	·6	2·90	2·00	9·0	90·7	95·8

A peculiar feature of this field is the persistent character of the beds of limestone interstratified with the sandstone and shales.

The researches of Auerbach and Trautschold on the coals of Central Russia, published in 1860, describe a well-marked coalfield in the governments of Tula and Kaluga, with an area of above 13,000 square miles.

It appears doubtful whether any seams of the ordinary upper coal have yet been found, but should such be discovered to extend beneath the overlying Permian strata, it seems not improbable that Russia may one day be shown to possess stores of coal in some degree commensurate with the magnitude of her territorial proportions.

The output of coal in Russia in 1897 amounted to 9,105,942 tons, with a rapidly increasing demand.

CHAPTER VIII.

COAL OF NORTH AMERICA.

SOUTH of the St. Lawrence and the great chain of lakes an astonishing proportion of the surface of the North-American continent is occupied by the carboniferous formation; and if we merely compare the coal-areas of the New World with those of the Old, as indicated in geological maps, we should conclude that the total extent of the deposits of Europe stand as against those of America in the humble ratio of 1 to 21. But an important fallacy is involved in these comparisons, inasmuch as the position of the American coal strata, with respect to the under and overlying rocks, is such as to exhibit their entire area (in the midst of which also large tracts are barren), whilst many most valuable portions of the European coalfields are covered by newer formations; and there seems reason to doubt whether in the former there ever occur such great accumulations of coal as distinguish some of the fields of the latter.

In the British colonies, NEW BRUNSWICK and NOVA SCOTIA are especially noticeable for a great thickness of carboniferous strata which have been already explored by Sir J. Dawson and Mr. R. Brown. The number of seams is comparatively small; but it is interesting to observe that the plants found in or near them belong to the same genera, and often to the same species, as those of the coals of Europe.

The Cumberland coalfield, occupying a tract which rises towards the Cobequid hills, exhibits along the shores of the Bay of Fundy at the Joggings an unrivalled natural exposure of strata which Sir W. Logan has measured to be upwards of 14,000 feet thick. But although 70 seams of coal are included, very few of them, and those only thin, are found of workable dimensions. Near Amherst the productive division is stated by Dawson to be 2,800 feet thick, with 7 seams of from 1½ to 3 feet thick, giving a total amount of not more than 16 feet of actual coal.

A remarkable contrast to this state of things exists in a limited district at Pictou, where in a much smaller bulk of measures there occur 5 or 6 good seams, the most noticeable of which is the Pictou main coal, no less than 37½ feet in thickness, inclusive of some bands of shale and ironstone.

In the northern and central parts of Cape Breton, around the town of Sydney, another coalfield of considerable economic value forms, according to Mr. Brown, one extremity of a great coal region, the main body of which extends under the sea towards Newfoundland. The same practical author estimates the productive measures as occupying 250 square miles, and as possessing a thickness of 10,000 feet. A fine natural section on the north-west side of Sydney Harbour, shows a total of 1,860 feet of measures with 34 seams of coal, but 4 only among them are workable, each from 4 feet to 6 feet 9 inches. The excellent papers by the two above-named authors, in the "Quarterly Journal of the Geological Society of London," contain most valuable contributions to our knowledge of the plants and animals of the coal. The quantity raised amounted during the year 1884, according to Official Report, to 1,389,295 tons, and in 1897 to 3,516,433 tons.

UNITED STATES.—The extensive coalfields of the United States are evidently, from their character and positions, but the huge remnants of a vast coal area which once extended from the St. Lawrence down to the mouth of the Mississippi and from the shores of the Atlantic to Kansas and the frontiers of Mexico. Although they may be separated from one another by gaps of many miles in width, the intermediate space is occupied by the same floor of lower rock on which the coal-measures rest; and the productive portion of the strata is preserved in the several basins by occupying the depressions of the undulated flexures to which the entire mass has been subjected.

Most violent on the east, along the line of the Alleghanies, these foldings become more and more gentle westward, so that in the great regions of the Ohio and the Missouri the inclination of the beds is very small, and their unbroken extent proportionally great. Coupled with this fact, moreover, it is found that the character of the coal changes: bituminous and caking in the broad flat areas, it becomes more and more dense when affected by the contortions of the Appalachian chain, until in the parallel synclinal deposits of Pennsylvania it becomes a pure anthracite.

Professor Rogers, in his elaborate "Geology of Pennsylvania," dwells upon another broad feature of general interest. The beds of conglomerate (millstone-grit) and sandstone, which occur in great thickness, and of coarse grain, on the east, gradually thin away and become finer as they approach the west; whilst the slight traces of limestone, associated with the coal-measures of Pennsylvania, become more and more important as they reach the successive western districts, until beds, that in the Potomac basin are only 10 feet, become expanded at Wheeling to 200 feet in thickness. And as the coarseness of grits and conglomerates points to the proximity of the land whence they were derived, whilst the limestones abound in marine organisms, it results that in the coal period deep-sea conditions prevailed in the west; and that the mass of land, from which the sandy constituents of the coal-measures were derived, must have existed where the Atlantic now rolls its billows.

The coalfields of the United States, estimated by Rogers to occupy an area of 196,850 square miles, are 5 in number :—

1. *The Appalachian Coalfield.*—The field stretches for a length of 875 miles north-east and south-west on the west slope of the Alleghany and Cumberland mountains, and its area has been estimated at 56,000 square miles, or four times greater than the area of the British coalfields. To the south-west the coalfield tapers away in the States of Alabama and Georgia, and divides into narrow tracts, whilst to the north it is divided into six detached basins, where the lower coal measures only are worked, by name, the Potomac, Sullivan County, Towanda, Blossberg, St. Mary's Clarion, and Western Pennsylvania. In the 2 former of these, 2 or 3 seams, of thicknesses varying from 3 to 6 feet, are met with in the lowest coal-measures; in the southern part of the Sullivan County basin, the well-known Pittsburg seam of coal, to which I refer later, here 8 or 9 feet in thickness, is met with.

The western boundary of this great field is formed by an anticlinal ridge, stretching from the western end of Lake Erie, through Kentucky and Tennessee. In the southernmost basin, and deepest, of the Pottsville trough of anthracite, it appears that about 25 workable seams have been proved, in other parts only 10 or 12; so that although a maximum thickness of 207 feet of coal has been ascertained, the average would not exceed 70 feet.

Some of the lower seams of the anthracite attain exceptionally the thickness of from 10 to 40 feet, probably in consequence of the local disappearance or attenuation of the shales and grits which elsewhere divide from each other 6 or 7 different seams. At Lehigh Summit mine, the great coal-bed is a magnificent seam of 50 feet, containing 30 feet of good coal. To guard against misapprehension, it is well to remember that it appears to be the local practice to name a seam by the thickness of the coal, as roughly measured in the driving of a crosscut; and as the beds rise at various angles, the amount thus taken is generally much in excess of the true thickness. Thus Mr. Rogers states that the so-called "39-feet vein" is really 26 feet horizontally measured, and 15 feet measured in an European way fairly across the seam; and after all 8 feet only are of saleable coal.

In the bituminous field of Western Pennsylvania, 7 to 10 workable seams (near Pittsburg, above the P. seam of 10 feet, is the Waynesbury coal, 6 feet, and below it, 5 seams with about 22 feet coal) are found in a thickness of about 2,100 feet of strata, and the same number may be identified in North-west Virginia; whilst as a proof of gradual attenuation westward, it seems that in the western coalfield of Missouri and Iowa 7 or 8 workable seams at the utmost are included in about 700 feet of strata.

The upper series, cropping out a little to the north and north-west of Pittsburg, is based upon a remarkable seam of coal, named after that town. Professor Rogers has traced out, *con amore*, the prodigious extent of "this superb bed," and shows how incompatible with any *drift* theory are its persistency and regularity. With a thickness of 8 feet at Pittsburg, rising to 12 or 14 feet in the south-eastern basins, and dwindling on the Great Kenawha to 5 feet, and at Guyandotte to 3 feet, its superficial measurement amounts to about 14,000 square miles; and, if we include some detached basins, which indicate its former extent on the east, it would appear that the Pittsburg seam formerly (before denudation) occupied a surface of no less than 34,000 square miles.

Another observable feature of the upper series consists in the intercalation of bands of limestone charged with marine fossils, and amounting sometimes in the aggregate to 150 feet thick. One bed especially, which overlies the Pittsburg coal, has been remarked to increase from 2 feet in the Cumberland basin to 41 feet at Brownsville, and 54 feet at Wheeling.

The aggregate thickness of coal contained in the measures generally of the Appalachian coalfield is far less than that above given for the anthracite region. Even where the basin is deepest, and the seams are 15 or 16 in number, it scarcely amounts to 40 feet; whence it is inferred by Rogers that, considering the great amount of denudation, we are hardly entitled to assume a higher general average for the whole field than 25 feet.

The quality of the lower coals in these several basins varies from stony anthracite in Massachusetts to the well-known anthracite of the Lehigh Valley, becoming semi-anthracite further south-west in Sullivan County; whilst in the basins such as Blossberg, Broadtop, further west, the seams are semi-bituminous. The well-known Pochahontas coal is obtained from the southern portion of this coalfield in West Virginia.

The coal trade of Pennsylvania may be said practically to have commenced with the first shipment in 1820, and the following numbers show the increase in quantity sent to market at intervals of several years :—

Year.	Tons.
1820	365
1830	174,384
1840	841,584
1850	3,177,537
1860	8,151,569
1875	20,973,805
1882	51,120,096
1897	97,300,445

2. *Illinois and Indiana Coalfield.*—This is a somewhat oval tract lying between a wide anticlinal exposure of Devonian and Silurian rocks on the east, and the saddle of carboniferous limestone of the Upper Mississippi on the west, having a total area of some 51,000 square miles, occupying two-thirds of the state of Illinois, the western part of Indiana, and Kentucky. The coalfield is divided into two zones by an anticlinal. The eastern zone, estimated to be 450 square miles in extent, contains a free-burning bituminous coal known as Block-coal, which possesses the peculiarity of being the only bituminous coal that has as yet been used in smelting furnaces without first being coked.

The thickness of coal in this zone has been estimated at 28 feet, of which, however, only a small portion is worked.

The western zone, estimated to be 6,000 square miles in extent, is stated to contain at least 10 feet of coal in three seams. The lower coal-measures are only met with in the central and southern parts of the zone; the upper measures cover the northern portion and rest direct on older rocks beneath.

The coals in this zone appear to contain a large percentage of moisture.

Within this vast district, nearly as extensive as the Appalachian, many local disturbances and undulations affect the strata, and confine the available basins within limits which are not yet thoroughly explored. In Western Kentucky, the productive coal-measures are estimated at 3,429 feet thick; the lower series—including a hard sandstone, called the Anvil Rock, at the top—being 1,029 feet with 9 workable seams, and the upper group being 2,400 feet with 8 workable seams and numerous bands of limestone. An aggregate amount of 40 to 50 feet of coal has here been proved, but since all explorers agree that there is a great amount of undulation bringing the older strata to the surface—the flexures running north-west and south-east, or oppositely to those of the Appalachian range—no satisfactory estimate of the average quantity of coal can yet be obtained. The production of this field in 1897 was 18,209,712 tons.

3. *Iowa, Missouri, and Arkansas.*—In this enormous area, where upwards of 73,000 square miles are stated * to be occupied by coal-measures, we cannot but look upon the latter as being of a degraded type; not only the stony strata, but the beds of coal also having greatly dwindled, both in number and thickness. Prof. Swallow, reporting on the geology of Missouri, estimates the total sections of the coal-measures on that river at 650 feet; the upper portion containing thin beds of buff limestone and no workable coal; whilst the lower group, between Booneville and the mouth of the La Mine, includes 6 coal seams, 2 only of which, of 3 feet and 6 feet respectively, are workable. Dr. Dale Owen, in reporting on Arkansas, mentions the occurrence of several seams of coal opened upon in different counties for smiths' use; but most of them are only a few inches

* Rogers, "Geology of Pennsylvania," vol. II.

thick, one alone, the Spadra seam, being 3 feet. They appear to be semi-anthracitic, and to be intercalated among the lower members of the formation: viz., with the millstone grit, and close down on the "Archimedes" limestone. Sundry outlying deposits of coal and cannel promise to be of local value; but the contents of the field, as hitherto described, are so utterly disproportionate to the magnificent show which it makes in a geological map, that in a comparison of the coal-measures of different countries, the mere statement of its area is of no value.

4. *Coalfield of Texas.*—This extreme south-western district, estimated at 3,000 square miles in extent, has, through the researches of Mr. Hiram Haines, been referred to the lias period.

5. *Michigan Coalfield.*—A very considerable extent of land between Lakes Huron and Michigan, and estimated at 12,000 to 15,000 square miles, is occupied by a shallow basin of gently-inclined or horizontal coal-measures. The foundation on which they rest appears to be carboniferous limestone; frequently containing, as it does also in British North America, deposits of gypsum. It appears singular that the interior of this coal-district is imperfectly known, and that as yet only a few points have been noticed where coal crops out. From these appearances it has been conjectured that but very few beds of workable coal—probably the very bottom of the series—exist here; and a parallel is offered to the bad plight of the Irish coalfields—robbed of their chief contents by Nature's great planing-tool of denudation.

It will excite no surprise that, in a country of which the interior is so scantily peopled, and the timber-land still so abundant, the coal-trade should be but of recent origin, and the quantity of fossil-fuel brought into the market from native mines very inferior to the yield of European countries in proportion to the extent of the coal-rocks. It was only in 1820 that the first modest instalment of 365 tons of coal was sent from the mines of Pennsylvania; and we have seen that, doubling itself, sometimes in five, sometimes in ten years, the amount had increased to above 10 millions of tons in 1864.

In 1875, the total quantity of anthracite appears to have been close on 21,000,000 tons. The other coal-producing States are now, in numerous instances, giving a very large output. The following table brings home to us the vast production of the United States for 1883 and 1897 :—

	1883 (Tons)	1897 (Tons).
Alabama	1,400,000	5,748,414
Arkansas	75,000	675,136
California	200,000	93,810
Colorado	1,000,000	429,056
Dakota	50,000	78,114
Georgia	200,000	246,347
Idaho	10,000	—
Illinois	10,508,791	19,780,000
Indiana	2,400,000	3,909,864
Indian Territory	175,000	1,366,365
Iowa	3,881,300	3,955,848
Kansas	850,000	2,886,435
Kentucky	1,650,000	3,329,109
Maryland	2,306,172	4,144,014
Michigan	135,000	92,800
Missouri	2,250,000	2,332,980
Montana	50,000	1,543,485
New Mexico	250,000	622,893
Ohio	8,229,429	12,877,500
Oregon	60,000	101,600
Pennsylvania, anthra.	31,793,627	54,381,715
,, bitum.	24,000,000	49,530,250
Tennessee	1,000,000	2,664,648
Texas	100,000	544,887
Utah	250,000	419,843
Virginia	225,000	1,255,000
Washington Territory	260,000	1,195,632
W. Virginia	2,250,000	12,877,650
Wyoming Territory	700,000	2,232,120
Total	96,259,719	189,315,515

It used to be reported* that "great looseness seems to exist in the compilation of figures involving large sums, as well as in the returns required to be made by the companies," whence it is probable that, allowing for local consumption, etc., the amount raised in the States was, in 1875, not less than 50,000,000 of tons.

Years ago, the progress of the Pennsylvanian mines would have been much checked but for the duty placed upon the importation of foreign coals, which has been varied from time to time, and reached 1 dollar 25 cents per ton, reduced since. The distance from the mines to the chief centres of population along the seaboard is from 80 to 120 miles, and the carriage appears to cost nearly as much as the value of the coal at the pit's mouth.

The great wealth in fossil-fuel of North America does not end with the true coalfields above described.

In Eastern Virginia, a tract some 26 miles long by 4 to 12 miles wide contains coal in the lower part of the Jurassic group (with fossils very similar to those of our Whitby beds in Yorkshire), and the main seam is stated to attain the thickness of 30 and even 40 feet of good bituminous coal. The measures form an irregular basin resting upon granitic rock, and the seams are much disturbed, and subjected to thinning where they are closely superimposed upon their primary bed.†

On the Pacific side of the continent, lignites of good quality, and often in seams of from 3 to 10 feet thick, make their appearance at divers localities. They appear to belong to the cretaceous series; to which age Dr. Hector has

* Reports from Her Majesty's Secretaries of Embassy and Legation, 1866.

† This formation is now referred to the Trias; *vide* also Texas, page 110.

satisfactorily referred the lignites of the Saskatchewan River and of Vancouver's Island.

The geologists and statistical writers of the United States have constructed diagrams and numerical tables, which get handed about from one book to another, and give, as I think, very erroneous ideas of the overwhelming importance of the American coalfields as compared with those of Europe. It may be true enough that a vast area of country is occupied by rocks of the carboniferous period, and a proclivity to big figures may be gratified by calculating the tens of thousands of square miles of extent; but it should be recollected that among the European coalfields are several in which, as in Westphalia and Silesia, the greater part of the productive ground lies covered by a cloak of newer formations. The total area of coal-measures in the United States is given as 200,000 square miles, whilst that of Russia is set down as 100 square miles; and this simple "unit of measure" is then applied as a standard showing the littleness of all the European fields. But if the same method of calculation were applied to Russia that has been acted on in Iowa and Missouri, and we were to take the length and breadth of the tract over which coal-bearing rocks have been found to exist, and may be deemed continuous, that Empire, instead of figuring as a petty unit, would run the States a hard race for mere extent of carboniferous formation.

On passing, then, to what is of more weight—the thickness of workable coal—we are constrained to believe, whilst fully recognising the colossal value of the Appalachian and of the Illinois and Indiana deposits, that the data for the estimation of the contents of the others are not yet satisfactory, and that the progress of such exploration in such vast tracts will show many an element for subtraction.

CHAPTER IX.

COALFIELDS OF ASIA AND THE SOUTHERN HEMISPHERE.

On turning our gaze eastward from Mediterranean Europe to the Levant, we may observe the continuation of similar characters in the rare occurrence of true carboniferous strata, and in the frequent exhibitions of lignites of cretaceous or tertiary age. The only remarkable instance of the former which we know in Western Asia is the coalfield of Eregli, on the south shore of the Black Sea, a district which was urged into some little activity during the Crimean War, but which appears to have so far sunk back again into the old sleepy state of ill-management, as not even to supply the limited requirements of Constantinople, and the other towns bordering on the Euxine. Every now and then the disclosure of something black cropping out on hill or riverside, leads to the publication of a paragraph which makes the round of the European newspapers, and tells of the discovery of a new "coal-mine," generally of "inexhaustible extent," and "quality equal to the best Newcastle coal." It turns out to be an instance of the patchy distribution of the lignites, which have seldom been good enough to command serious attention; although in one case, in the Lebanon, considerable workings were carried on for this article, during the occupation of Syria by Ibrahim Pasha.

In India large tracts of land, in the upper Damoodah, in Burdwan, and again in the river basin of Godavery in the Central Provinces, are occupied by coal-formation, which, besides its extent, is notable for very peculiar geological features.

The active missionaries, Messrs. Hislop and Hunter, in 1855 described to the Geological Society of London the occurrence of plants in the coal-bearing sandstones, some of them of genera which might be taken as common to the coal-measures of Europe, but others, such as *Zamites*, *Tæniopteris*, *Glossopteris*, *Vertebraria*, and *Trizygia*, which indicate a Jurassic age. Some of these bear a close resemblance to the contents of our oolitic coal-beds of north Yorkshire, and to those of Virginia, and the parallel is rendered stronger by the presence of remains of *Lepidotus* and *Æchmodus*, Jurassic fish in the Kotá shales, which appear to belong to the same series as the Nagpur plant-bearing beds.

Messrs. Blandford, and others of the geological staff under Professor Oldham, have been working out the relations of these eastern coalfields. They divide the coal-bearing strata of Bengal into the Barakar, or Lower Damoodah, the ironstone shales, and the Raniganj beds, ascribing them to the upper palæozoic period, and the overlying panchet group to the Trias.*

In the Damoodah Valley the coalfields are divided by Professor Hull into the following, with their approximate extent:—

* The output of coal in all India, for 1868, was 547,971 tons, and this quantity appears now (1897) to be 4,128,330 tons.

Raniganj	1,000	square miles.
Karaupura.	472	"
Bokaro	220	"
Jherria	200	"
South Karaupura . . .	72	"
Ramgush	40	"
	2,004	

In the first-named coalfield the coal-measures are stated to attain a vertical thickness of 12,000 feet, with 354 feet of coal in numerous seams. The thickness of coal contained in the remaining coalfields would appear to vary up to 100 feet, divided into numerous seams.

The Godavery coal-basin is also found divided into several detached basins, stretching over 11,000 square miles of country. In the Wardha coal-basin, forming the northernmost of these detached fields, three seams of coal are met with in the Barakar division, giving a varying thickness of from 35 to 90 feet of coal inclusive of dirt-bands. Two of these seams are being worked by the Central Province Government at their Wardha Colliery.

The output of coal is given by Mr. C. Z. Bunning * in 1888 as 134,236 tons. The coals contain a high percentage of volatile matter with a correspondingly low percentage of fixed carbon; the quantity of ash also varies from 10 per cent. upwards. The coal is chiefly consumed by the Great Indian Peninsula and Bengal Nagpur Railways, and neighbouring cotton-mills.

Farther to the north-east, the ingenious and closely-packed natives of China and Japan discovered at a very early period the value of the fossil-fuel which in both countries exists in large quantities. Writing of the northern part of China, Marco Polo stated, in describing his travels between

* North of England Institute, vol. XXVIII.

1270 and 1290, "through the whole province of Cathay, certain black stones are dug out of the mountains, which, put into the fire, burn like wood, and being kindled preserve fire a long time; and if they be kindled in the evening they keep fire all the night; and many use these stones because that, though they have plenty of wood, yet there is such frequent use of stoves and baths, that the wood could not serve."

There appears to be no doubt that several large and rich fields, producing coals of good quality, exist in China; but we have obtained hitherto only meagre and fragmentary accounts of some of them from travellers unprepared with technical knowledge. On the upper waters of the Yang-tse-Kiang coal-seams crop out to the surface over a very large area, and are worked on a small scale by levels driven into the hills.

In the prefecture of King-hua, W.S.W. of Ningpo and near the town of E-u, coal-pits are described by the Rev. R. Cobbold which have been opened upon seams of a bright non-bituminous coal. The mines are from 300 to 500 feet deep, sunk in lifts of 40 to 50 feet at a time, and having the mineral raised by successive windlasses at the intermediate stages.*

Notwithstanding the facilities of water-carriage existing throughout a great part of China, it is manifest that great improvements must take place in the mining operations before these stores of mineral fuel can be made fully available for manufacturing, and for the requirements of the steam-navigation of the eastern seas.

* Part of the produce of Schansi, over an area of 1,500 square German miles, is described by Von Richthoven as an anthracite field with seams 12 to 30 feet, mostly horizontal. *Vide* also Pumpelly's Travels.

If we turn further north into the vast territory of Siberia now being opened up by the Trans-Siberian Railway, we are again met with the difficulty of lack of accurate information, but that considerable development of coal-bearing strata, probably of Jurassic age, exists in this country is known. The chief district where coal has been found is the Konznetsk, lying between the Alatan and Salairsk Mountains, estimated to be 18,000 square miles in extent, and which contains several seams of good thickness and quality. Coal is also known to exist on the Kirghiz Steppes, where seams suitable for steam-raising are being worked. On Saghalien Island, again, good coal is being worked and consumed by coasting-vessels. At several other points in eastern Siberia, coal outcrops have been met with. The output of coal from Siberia in 1895 was 42,872 tons.

A certain amount of prejudice, derived no doubt from negative evidence, disinclines us to believe in the existence of carboniferous formations within the tropics, and the discoveries of coaly substances hitherto made in the warmer regions of the earth have generally tended only to show that beds of lignitic matter were formed even in these latitudes amid some of the later formations, whilst the true carboniferous rocks have not yet been traced within many degrees of the Equator. A great local value may attach to these coaly lignites of superior quality when workable in certain situations accessible to steam-vessels, as at Labuan and elsewhere in Borneo.*

On arriving at the southern latitude of Sydney, in Australia, we meet again a great development of the carboniferous system, exercising already a considerable influence on the fortunes of our rapidly-growing colonies.

* See Quar. Jour. Geo. Soc., vol. IV., p. 96; and vol. IX., p. 54.

Since the systematic description of the coal-bearing beds of this region by Count de Strzelecki, in 1845, numerous observations upon them have been contributed by Mr. Beete Jukes, the Rev. W. B. Clarke, Mr. Selwyn, and Mr. W. Keene, which leave no doubt as to the palæozoic character of the lower part of the great conformable series of strata, although the upper portion presents anomalies reminding us much more of the Indian coalfields than of anything which we possess in Europe.

Mr. Clarke proposes the following divisions :—

1. Wianamatta shales, 700 to 800 feet thick, 2. Hawkesbury Rocks, or Sydney Sandstone, 800 to 1,000 feet thick, 3. Upper coal measures, with the coal-seams of Newcastle, etc., 5,000 feet thick,	Upper carboniferous, or Permian (Dana), Jurassic (McCoy).
4. Lower carboniferous rocks, 8,000 feet thick.	

The presence, along with the coal-seams, of such plants as two species of *Glossopteris*, *Cyclopteris*, *Angusti-folia*, and certain species of *Sphenopteris* and *Phyllotheca*, gives a parallel to the fossils of strata more recent than the European carboniferous, but there is at present a difficulty in drawing a line of demarcation between the groups No. 3 and No. 4, whilst in the latter both plants and shells of the carboniferous and Devonian series are abundant.

The carboniferous formation is found to extend from Port Macquarie, a coast-town 200 miles north of Sydney, southwards to a point 55 miles north of that town, where it becomes overlain by the Hawkesbury sandstones, appearing again some 25 miles south of Sydney, and can be traced southwards from this point in a narrowing belt for 125 miles. The width from east to west occupied by this great coalfield is very various, 200 miles has been stated as the maximum. Detached portions of the carboniferous formation are also met with on the coast immediately south of the Queensland border, again near the sources of the Darling River, further inland.

Three districts or centres of coal production may be said to exist in the New South Wales coalfield proper, the most important of which is that in the neighbourhood of the town of Newcastle, 75 miles north of Sydney, followed by that of Illawarra, or southern field, commencing 25 miles south of Sydney, whilst the third district, or western, lies 60 miles due west of Sydney, and has for its centre the town of Lithgow.

In the first mentioned of these districts the carboniferous strata have been divided into four series, the lowest, known as the Stroud series, in which no workable coal has yet been found, above which comes the Greta series, containing a valuable and thick gas coal, varying from 12 to 30 feet in thickness, about 1,000 feet above which comes the Rathluba series, containing several coals of inferior quality, of which probably the Tomago seam, 3 feet to 9 feet thick, is the best.

Ascending still further through a considerable thickness of barren ground, the Newcastle series is reached, containing several seams of value, stated by Mr. Keene, the Government Examiner of Coalfields, to be 11, the lowest and chief of which is the Borehole Seam, found at its best in the proximity of Newcastle, and deteriorating both in thickness and quality 10 miles south of that town. This fine seam of coal varies from 4 to 20 feet in thickness, and produces excellent house and gas coal, and is also largely used for steam purposes. By far the greater portion of the output of this district is obtained from this seam.

That the coal-measures of this northern district are directly connected underneath the overlying Hawkesbury sandstones with those of the southern district has not been definitely proved, although the borehole put down on the shore of Sydney Harbour, which, starting in the Hawkesbury sandstones, reached the coal-measures, and proved a seam of coal at a depth of about 3,000 feet, is strong evidence in favour of this being so.

One seam only of value has as yet been proved in the southern district, varying from 4 to 12 feet in thickness, producing coal suitable for steam-raising purposes.

In the western district several coals of bituminous quality are being worked, but the coal production of this part of the field is comparatively small. The occurrence in this district of kerosene shales producing at their best 130 gallons of crude oil per ton, and 18,000 cubic feet of 40 candle-power gas, should be noted.

It will thus be seen that the products of the Australian collieries are various in character, smith's, household, and gas coal being obtained from different pits, and a large amount of steam coal of very serviceable quality being regularly supplied to sea-going vessels. Imitating the mother country not only in the names of its seams and mining localities, New South Wales has opened out a considerable foreign trade, and shipments of coal have long been made to China, India, and even to the ports of California. The coal raised in New South Wales in 1876 was 1,319,918 tons, of which more than half was exported; increased to 4,736,000 tons in 1898.

It is not our object in this chapter to do more than invite attention to a few among the coal-bearing formations of parts of the world distant from Europe, which appear to promise future importance. We need not refer except in passing to those minor deposits of lignite or of true coal, which, undoubtedly, may be developed and acquire a local value, although unable to weigh much in the coal trade of the world.

Tasmania and New Zealand come under this category; in the latter country, however, valuable deposits of true coal have been met with in the neighbourhood of Westport and Greymouth, on the west coast of the South Island, occurring in scattered and detached basins flanking and capping the several mountain spurs of this district.

The coal seams, of which two are known in the northern part of the field, attain thicknesses of 5 feet, and 30 to 40 feet in the case of the lower seam, and occur in strata of tertiary age in miocene cretaceous formation, which rest unconformably upon the edges of metamorphosed slates of paleozoic age, resting in their turn upon granite.

In the southern part of the field, in the neighbourhood of Greymouth, only one seam 16 feet in thickness—a good gas coal—is known, and is being worked to a considerable extent.

The coals of this field are pure and suitable for steam and gas making, but are handicapped by the lack of good harbours, the present ones of Westport and Greymouth being dependent on the river bars, and are necessarily somewhat unreliable. A production of 854,204 tons was obtained in the year 1897 from this colony, including the output of the several fields of lignite met with in different parts of both the North and South Islands, some of which stand high for quality.

The opening up of the southern portion of the African continent, which has progressed so rapidly of late years, has resulted in the discovery of a very large development of coal-bearing strata, occurring at a considerable elevation (3,000 to 4,000 feet) above sea-level, overlying portions of the northern part of Cape Colony, and stretching northwards through the Orange Free State into Transvaal territory, and eastwards into Zululand and Natal. The approximate area covered by this formation so far as its outline has, as yet, been determined, is 56,000 square miles.

The coal seams occur in what is known as the Karoo formation, which has been correllated by Professor Green and others with the lower Mezooic age, and to rest unconformably upon the denuded surfaces of the old crystalline and metamorphic beds which form the base of the South African strata.

The exact horizon in which the several coal seams are met with over this large area has not as yet been very clearly defined. Mr. Draper proposes the following general divisions of strata, and places them at the base of the Molteno beds:—

Upper Karoo	Volcanic rocks	Probably Jurassic.
	Cave sandstone	
	Red beds	
	Molteno beds	Probably Triassic.
Lower Karoo	Beaufort beds	
	Ecca beds	
	Dwyka conglomerate : probably Permian.	
Primary rocks	Quartzite of Gats Band.	
	Malmain limestone.	
	Bokkeveld beds.	
	Table Mountain sandstone.	
	Malmesbury schists.	
Basement beds—Gneiss and granite.		

There, however, appears to be considerable doubt as to whether the coal seams met with in the Transvaal in the northern portion of the field should not be placed in a lower horizon, *i.e.*, in the Beaufort Beds, variously correlated with the Upper Permian or Lower Trias of this country.

The chief centres of activity in this large coalfield, of which only the fringe has, as yet, been opened upon, are Molteno, in the Stormberg Mountains, Cape Colony in the southern extremity of the field; at Vereeinugen, on the Vaal river, on the borders of the Transvaal, and again near Boksburg, a township some 30 miles east of the town of Johannesburg in the Transvaal, and at Dundee in Natal.

It is from the neighbourhood of Boksburg that the chief supply of fuel for the great and growing gold-mining industry of the Witwatersrand is drawn; the consumption of coal by this industry during the year 1898 amounted to 1,535,000 tons, and the quantity is steadily increasing.

The coals as a general rule contain considerable quantities of ash, but a few seams of good quality have already been discovered. A feature of interest in the Boksburg portion of the coalfield is the occurrence of the Mammoth coal seam, which attains a thickness of 78 feet at the Great Eastern Colliery in that locality.

The carboniferous strata is met with again in Zululand and Swaziland, thrown down to a level of not more than 400 feet above sea-level. Again in Rhodesia, in the valley of the Zambesi, a large development of coal-bearing strata is known, and will doubtless be rapidly developed to supply the needs of the gold-mining industry of that country.

Turning farther westward, we find that coal-beds exist in the Falkland Islands, and that South America promises great results—of but little value at present, whilst her population is sparse and her forest lands of enormous extent. Very interesting, however, is the coalfield of Santa

Fé de Bogota, in New Granada, the fossils of which prove it to be of cretaceous age. Mr. David Forbes has pointed out the existence of true carboniferous rocks near the mountain lake of Titicaca, situated no less than 12,600 feet above the sea; and within the last few years successive notifications have been made of important areas of true coal in various parts of the flourishing Empire of Brazil.

CHAPTER X.

SEARCH FOR COAL—BORING—AND SINKING OF SHAFTS.

A VALUABLE amount of light may be thrown upon the character of a coal district by surface researches, unaccompanied by the breaking of the ground. Quarries, roads, protruding rocks, sea-cliffs, ploughed fields and water-courses will all yield to an experienced eye their quantum of information. Even when, as in parts of Lancashire, the general surface is occupied by a thick cover of clay, gravel, etc. (*the drift*), good facts may be gleaned in the channels and banks of the brooks which have cut their way down to the harder rock. Now and then a very complete view of the raised edges of a whole series of strata may be seen : as in the cliffy shores of the Bay of Fundy, Nova Scotia, and of Cape Breton, whence we have sections, measured by Sir William Logan and Mr. R. Brown, embracing thousands of feet of strata. In the county of Carlow, Ireland, in South Wales, and in the north of England there are frequent opportunities of thus obtaining a measurable profile of some of the lower coal-measures.

In this kind of search we must learn to avoid being deceived by vain resemblances. Especially dangerous is it to trust to mere outward likeness in the shales or "metals" to those of the coal series: such may belong to the Silurian, to the Lias, or to other formations.

If true carboniferous shales, we ought to be able to find in them some of the fossils proper to the period before pronouncing on them. Still more irrelevant is it to form conclusions on the presence of coal-measures because the surface is covered with a cold clay, or because you have limestone on one side of your field of action, or because ironstones have been found about the place. Each of these circumstances *may be* true of a coalfield, but is not necessarily so; each may also be true of many other formations, and would require corroboration by other characters. The presence of a spring of water depositing ochreous oxide of iron is often noticeable near the outcrop of a coal-seam, but the mineralogist will recollect that since this appearance is derived simply from the decomposition of iron pyrites, it may occur in many other classes of rock in which that common mineral has been accumulated. Not even the underclay, with its matted carbonised roots, is sufficient evidence of the nearness of a bed of coal, for such a material has sometimes been deposited, and either the conditions for the abundant growth of the coal-plants have not supervened, or the coal may have been formed, and subsequently been removed by natural denudatory action.

In these cases, a pick and shovel may sometimes lend useful aid; but more commonly it becomes advisable to resort to "boring," either for the actual testing of a particular spot or for filling up the gaps between portions which may be tolerably well determined at the surface.

The ordinary mode of boring through the alternating rocks overlying or forming a coalfield is by means of a steel chisel or bit (Fig. 16B), screwed to hollow rods of best bar-iron, about an inch in diameter, screw-jointed at intervals of from 6 to 18 feet. At the spot selected for the borehole it is usual either to erect a wooden staging or to sink a preliminary pit to a few feet or yards in depth, so that a greater length of rods may be drawn at once, and part of the tedious delay of screwing and unscrewing may be avoided. To aid in this object, too, a tall triangle, derrick, or shear-legs, with sheave, will be erected, within which the rods may be drawn and lowered by the agency of a windlass. The height of this derrick should be determined in relation to the length of a single bore-rod used, and will be a multiple of its length. In order to lift the rod and cutter a few inches for each stroke or blow, either a spring-pole (Fig. 16K) may be used fastened down at the butt-end, and with the rods suspended at the thin extremity, or over a windlass, around which a rope coming from the rods is passed with two or three turns, whilst a man holds the "slack," and when the cutter is raised to a sufficient height by the men at the windlass, slips the rope to allow the rod to fall. Meanwhile a rotary motion is given to the rods at each turn by the master borer and his assistant, holding a cross-bar, termed the bracehead, which passes through the iron loop (Fig. 16I), and clutches the upper rods a little above the surface.

The chisel thus at each blow cuts the ground in a fresh position, and when this action has been continued long enough, the rods are withdrawn, by unscrewing length after length, and the "sludger," an iron tube of 6 feet long (Fig. 16A), with a valve in the bottom, is lowered by a rope, and being dropped heavily several times to the bottom of the hole, soon gets filled with *débris*, which, when brought to the surface, is carefully examined, whilst the rods are again lowered to go on with the pounding action.

In order to reduce the time and expense of this mode of boring, the Chinese system of boring by a rope instead of

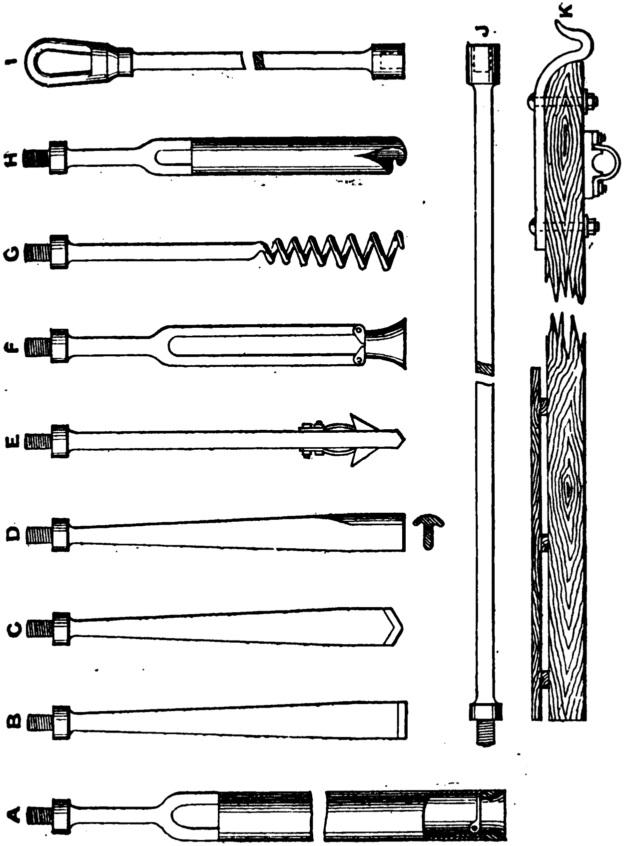


Fig. 16.—Boring Tools.

rigid rods has been a good deal employed of late years; but it is open to the objection of sometimes making the hole untrue, and more often of ending in the catastrophe of a broken rope, and of the heavy iron cylindrical cutting-tool remaining at the bottom of the borehole.

The number of tools necessary to carry out a boring is considerable. In addition to the bore-rods, flat-chisel and sludger already described, provision has to be made for boring through different kinds of strata, when the form of chisel is often varied. In hard rocks, for instance, a diamond-pointed or V chisel is used (Fig. 16C). This class of chisel has the disadvantage of being difficult to sharpen. Is it gravel that has to be bored through, a T chisel, with two cutting edges at right angles, is used (Fig. 16D); whilst in soft clay an auger, or wimble (Fig. 16H), the lower portion of which is hollow, and the bottom partially covered over to retain the core which is forced up into it, is brought into use.

A breakage of either rods or tools in the borehole is, unfortunately, by no means a rare occurrence, and special tools are required to extract the broken parts often with the best appliances, a matter of great difficulty.

Fig. 16 shows some of these necessary tools, G being a spiral worm, used to extract broken rods, whilst E is a spring dart, useful in extracting tubes with which the boreholes are sometimes lined; F is termed a "bell," and is another tool used to extract broken rods when the fracture has taken place a few feet above a joint.

In boring through soft strata, such as sand and clay, it is usually necessary to line the borehole by forcing down tubes of sufficient diameter to allow of the bore-rods passing through them. It will be therefore evident that where a considerable thickness of such strata is likely to be met with, it is advisable to make sufficient provision in the size of the borehole at the commencement, as each successive lining will reduce the diameter of the hole.

In a boring for coal, when carefully carried out, and a minute record of the strata passed through kept, a considerable amount of knowledge can be gleaned from a single borehole, as for instance, the approximate thickness of the seams of coal, the nature of the strata to be sunk through, whether much water is likely to be met with; but in an undeveloped coalfield more than one borehole will be necessary to arrive at the direction and amount of dip of the strata, and the continuity of the seam or seams of coal over a certain area. If three boreholes be put down on a property assuming no faults to intervene, those conversant with trigonometry can, by the employment of certain formulæ, calculate both the direction and the amount of the full dip of the strata.

Exploring boreholes are generally from 3 to 5 inches diameter. When larger diameters are to be employed, and greater depths than 300 or 400 feet attained, the serious difficulties which supervene are met by various contrivances, such as the hollow rods, first successfully used by Œynhausen; wooden rods with iron connections, the free-falling cutter, first devised by Kind, etc.; but as these relate chiefly to the boring of artesian wells, for water or for brine, we need but mention them here. We may, however, cite as among the most remarkable boreholes yet accomplished, that at Sperenberg, near Berlin, which was carried to a depth of over 4,000 feet.

Steam power has for these purposes been largely employed of late years. Messrs. Mather & Platt have made remarkable borings by their ingenious cutter, worked with a flat wire rope, and several patents have been taken out in England and Scotland for different means of applying this more economical power, while Messrs. Kind, Dégousée and Mulot have severally availed themselves of it in their great works in Germany, France, and Belgium.

At some mines a set of boring-rods is specially kept for exploratory work, and for occasional operations to assist the working of the mines, whilst in many of our districts the work is performed under contract by borers who devote themselves to this particular task.

The tariff for boring at Newcastle was, in 1854:

For the first 5	fathoms	7s. 6d.	per fathom.
„ second	„	15s. 0d.	„
„ third	„	£1 2s. 6d.	„

and so on, irrespective of charges for carriage, fixing apparatus, and boring through rocks of unusual hardness, as *whin*, etc. For deeper boreholes, *i.e.*, from 1,000 to 2,000 feet, it is difficult to give an approximate idea of the expense; but thousands of pounds are soon involved, and cases might be quoted of such operations in this country where the cost has been at the end no less than £9 and even £12 per foot.

A patent was taken out in 1844 by Beart, and a similar plan practised by Fauvelle in France, for hastening the work by employing a tube as the boring-rod. Down this tube a stream of water was made to flow in sufficient volume to carry off and bring up round the circumference of the borehole the *débris* made by the cutting tool.

At the present day, where a boring of any magnitude is to be undertaken, the method of boring by diamond drill is usually adopted. This method depends for its action upon the abrading power of diamonds set in a steel ring, and at the end of a tube rapidly rotated. The ordinary black diamond is used, and in favourable strata very rapid progress is made. This system of boring is not so successful in soft strata as the older method already described.

The cost of boring by diamond drill in this country, to moderate depths, is usually 8s. per foot for the first 100 feet; 16s. for the next 100 feet, and so on, increasing by 8s. per foot per 100 feet. In deep boreholes, and under unfavourable circumstances, special prices are arranged.

A great advantage which boring possesses over the ordinary sinking of a shaft is that the operation can be carried on without the necessity of pumping out the water. In order to combine this source of economy with the mode of gaining personal access to the coal, shafts from 3 to 15 feet diameter have, in Westphalia, been sunk by gigantic boring apparatus; successfully so far as related to the total cost, and forming a process applicable with great advantage if only a suitable lining or tubbing can be inserted, and a water-tight junction effected below the points of influx of water. (See p. 146.)

The shafts by which all collieries are opened, and worked, except the few which in hilly districts have the advantage of free drainage, are generally circular in England, though many elliptical and a few rectangular ones may be seen in South Wales, and the latter form is common on the Continent. In Belgium a polygon of 10, 12, or even 16 sides is a frequent form, and is adopted, like our circular ones, for the better resistance, by aid of the special kind of lining employed, to the pressure exerted upon it from the rock around.

A very few only can now be seen of the little old pits, like draw-wells, of 4½ feet in diameter; and whilst for ordinary purposes they are now commonly 8 or 10 feet diameter in the clear, they attain, when intended for an important upcast, or for a large get of coal, to as much as 16 or even 20 feet diameter

The site upon which the shafts should be sunk to work a coalfield to the best advantage will be a matter of grave consideration. Many circumstances will have to be taken into account in deciding this question, as, for instance, the most advantageous position for the erection of the necessary machinery on the surface; the best position for connecting with the railway; whether it will be advisable to sink the shaft at the deepest point of the property and work the coal to the rise, or should they be sunk at a shallower point and the coal seam followed to the dip. These, and many other points, will have to be considered and balanced before the best site for the shafts will be decided.

The actual sinking, when in ordinary coal-measures, is effected by the heavy pick, called a *hack*, by hammers and wedges, and by blasting with powder; whilst the broken ground is raised to the surface at first by a common windlass or jack-roll; then, as the work gets deeper, by a gin or horse-whim, and afterwards by a steam-engine, often a temporary one only, to be replaced, when the pit is down, by the regular winding engine.

But when the measures are covered by other and more absorbing strata, saturated with water, the *winning* of a colliery becomes a most serious undertaking, tasking the energies of the best men, and sometimes collapsing after a ruinous outlay.

Examples of these difficulties are afforded by surface beds of sand and gravel, by the well-known red sand under the magnesian limestone, through which so many of the North-country pits have been sunk, and by the *terrains morts* encountered by the colliers of Mons and Valenciennes.

As long as the coal-seams are accessible at small depths, managers are liberal in the use of shafts, indeed, there are districts where the great number of old shallow pits are a positive nuisance to the modern workers. But as expenses increase with depth, it becomes an object to work a larger area from one establishment of pits, and for this purpose it is worth while to improve ventilation and the underground carriage, so that shafts at frequent intervals shall not be needed. Even when flying along in a railway train you may remark the difference how in parts of Staffordshire you will see the ground riddled with crowds of pits, whilst in Durham and Northumberland a single "plant" of pits and engines will work the ground for a mile or two on each side.

The cost in extreme cases being some £60,000 for a pit of near upon 300 fathoms in depth, and being stated once or twice to have amounted to near £100,000, there is great temptation to make *one* suffice; and by means of *brattices* or divisions (of wood or brick or stone), wonderfully good mining has been done in the Northern coalfield with a single shaft. But since the sad catastrophe at Hartley, which resulted from a concatenation of omissions and misfortunes, an Act of Parliament requires that where there is no second outlet another shaft shall within a limited period be sunk. Many of the larger works, however, are able to apply a special shaft to the ventilation as an upcast, whilst at others coal will be drawn, and at one of them the pumps worked.

When the measures through which the pit is sunk consist of stony rock they are sometimes allowed to stand open, but when shales preponderate, and in all cases where much traffic is carried on, the pit would become a dangerous thoroughfare, and have to be walled with brick or stone, to which, in some cases, as against the influx of water, wood or cast-iron may be preferred.

In fragile ground the commencement is to secure the shaft by temporary timber. Curbs, or *cribs*—rings formed of segments of wood—are prepared to fit the dimensions of the shaft, and having their joints in the direction of the radii of the circle will, when 4, 5, or 6 inches square, resist a heavy pressure from the sides. They are supported at intervals generally of about 3 feet by a few upright props, and are, as it were, hung together by thin planks, termed *stringing deals*, which are nailed against them; whilst the whole structure may be temporarily suspended, if need be, by attaching it to a couple of stout balks laid across the top of the shaft. Behind the cribs a *backing* is formed by driving down planks some 6 feet long, close together in bad ground, or at small intervals in favourable rock. When a firm foundation of stone or bind has been reached, a bed is prepared with hacks or chisels to receive a broader curb of either wood or cast iron, and on this a wall of brickwork is built up to the surface, or above it when tip-room is required. The pit is then recommenced, of a smaller diameter at first, afterwards opened to its former dimensions, and at a suitable place a fresh length of walling is begun, and carried upwards, till, by careful adjustment, it is made to coincide with the upper length and to join up to its curb. In some

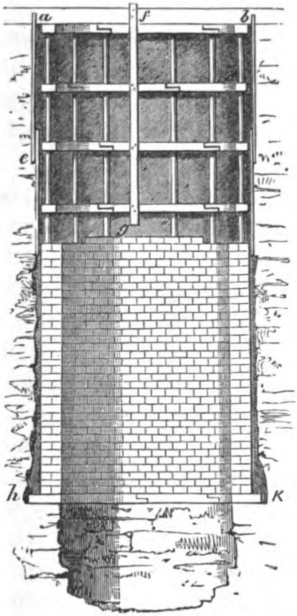


Fig. 17.—Lining of Shafts.
Scale—1 inch to 10 feet.

a b, *c d*, Curbs of the timbering.
a c, *b d*, Punch props.
a e, Backing planks, shown in section, but otherwise omitted for clearness.
f g, Stringing deal.
h k, Curb for the walling.

few cases, where soft material has to be passed through, the walling has been built at the surface, held together with tie-rods, or clamping-bars, and gradually sunk downwards by cautiously removing the ground from beneath the curbs upon which it is constructed. But where actual quicksand occupies the surface, various other contrivances have to be employed. The method of *piling* is to drive down iron-shod 3-inch battens of 12 or 14 feet in length, supported by curbs, and forming a circle as much larger than the ultimate size of the shaft as to leave room for successive inner circles of piles down to the depth at which solid ground is expected to be found. The sand is, of course, excavated in proportion as it is practicable to drive down the piles; and at length, when a firm foundation is reached, a broad curb is laid and the walling built up in the midst, while the space around it is carefully filled up and packed closely.

To obviate the expense and delays of this system, iron cylinders have been in some cases sunk by pressure; but this again—from the difficulty of keeping them vertical, and (if they be intended as the permanent lining of the shaft) from the obstacles to making a water-tight joint with the solid ground at the bottom—is a very troublesome process. In order to accomplish the latter object, M. Triger, in the year 1845, introduced in France the ingenious idea of keeping out the water by forcing down compressed air. He formed, by means of a flooring in the tube, a lower air-tight compartment, in which he found it feasible to work under a pressure of as much as 3½ atmospheres obtained by air pumps driven by a steam-engine, and by this means succeeded in establishing his water-tight joints at depths of 60 and even 82 feet. For the more convenient working of this method a second chamber was formed above this lower working one, which had a trap-door communicating with the shaft above, and another opening into the chamber below; and one of these doors being always closed whilst the other was opened, the excavated material could be drawn up without any serious loss of the compressed air. A stand-pipe, passing from the surface down into the bottom of the working, afforded a ready means for the water to rise in a constant stream. Triger's method has been applied with success in several shafts in the valley of the Loire, and more recently at some difficult sinkings in Belgium and Westphalia.

Another ingenious process of sinking through running sand, which has been carried out with marked success in the north of France, is that of M. Poetsch, which consists of freezing the soft ground sufficiently hard to allow of its being sunk through as though it were ordinary strata. A refrigerating mixture, consisting of a solution of chloride of calcium, is produced on the surface and is circulated through wrought-iron tubes forced down through the quicksand.

Figs. 18 and 18A will illustrate the process: A A are wrought-iron tubes, to the lower end of which are attached circular cutters, which are forced down through the quicksand at varying distances apart, but usually not exceeding 4 feet. The lower end of these tubes, when sunk low enough, are closed by lead plugs, covered in turn with cement and pitch, to render the joint water-tight. *Inside* the tubes A A inner tubes of a less diameter are inserted, which have an opening near their base; these latter tubes are connected by branch pipes to one another, and each one of them is fitted with a valve, B B, by which the circulation of the freezing liquid is regulated. The tubes A A are also connected to one another with branch pipes. The liquid

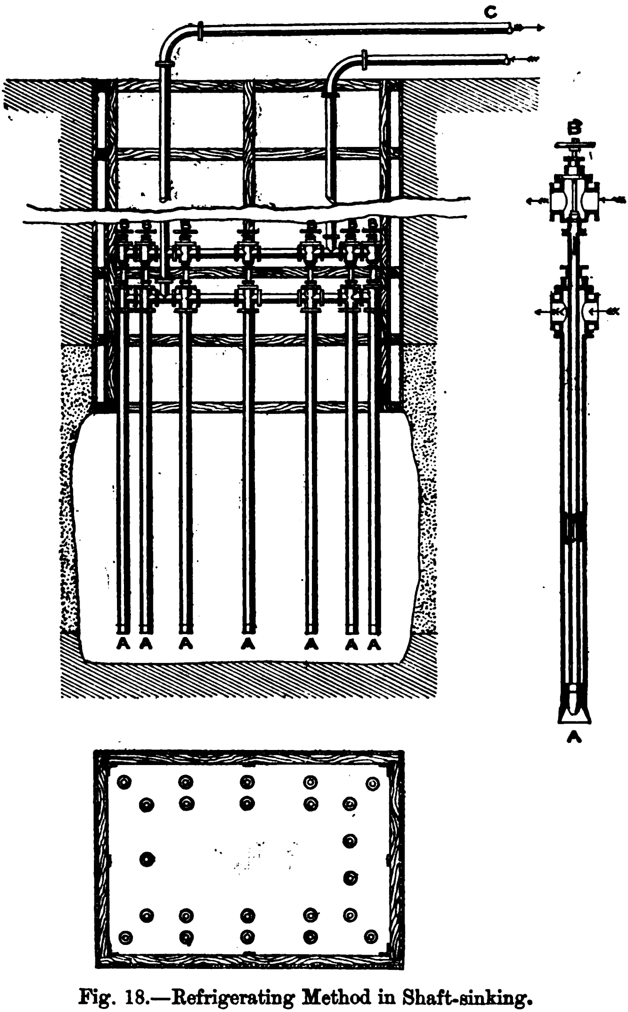


Fig. 18.—Refrigerating Method in Shaft-sinking.

passes from the refrigerator through the valve B B down to the base of the inner tubes, passing out through the openings at their base into the tubes A A, thence ascends

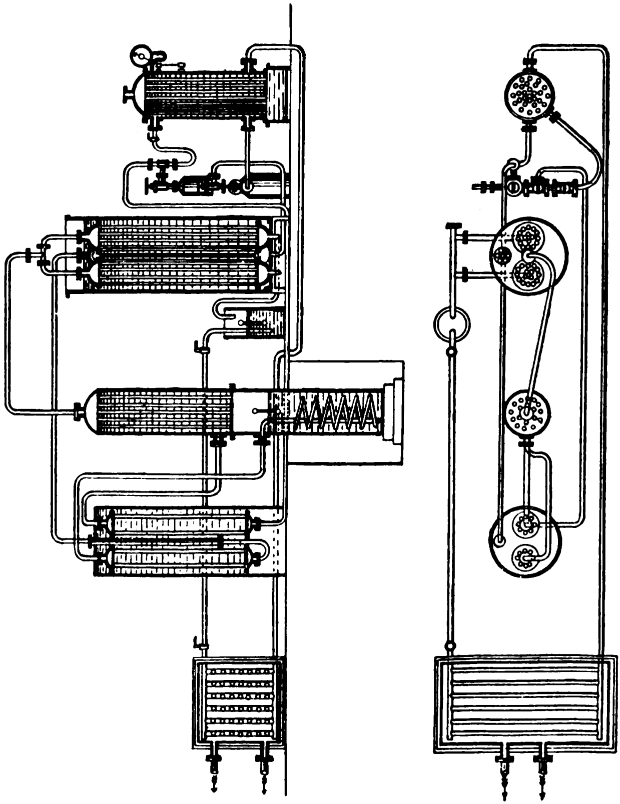


Fig. 18A.—Refrigerating Appliance used in Shaft-sinking.

these latter tubes and regains the refrigerating machine by the pipe C. The soft watery strata in contact with the tubes A A thus becomes frozen.

It is necessary in employing this method to keep a sufficient barrier frozen outside the area requiring to be excavated.

One of the most important benefits conferred on coal-mining has been the introduction of *tubbing* of shafts (*curvelage*, Fr.), largely practised in the north of England, and on a somewhat different method in Belgium, northern France, and Westphalia. Whenever large springs or feeders of water occur in the sinking of the pit, and a series of water-tight measures intervene between the watery beds above and the seam of coal beneath, it is possible by this means to keep out the whole or nearly all of the water, and thus to relieve the mine of a constant and sometimes ruinous water-charge.

Towards the close of the last century several of the shafts near Newcastle were thus fitted with *plank-tubbing*. At a small distance below the watery strata a bed was carefully cut and dressed to receive a wedging-curb of oak, between the segments of which thin deals were placed edgeways; the joints were then wedged with wedges of seasoned fir, introduced by means of a flat chisel, and the space between the curb and the stone at the back was similarly driven full of wedges. Lighter rings of wood, the *spiking curbs*, were then placed at intervals of 18 inches to 3 feet, according to the pressure, and to these were fixed by iron spikes planks of 2½ or 3 inches thick, bevelled to suit the sweep of the shaft, and the whole structure was thus carried up to a point above the watery strata, and there capped by another well-wedged curb. Thus the water was prevented from entering the pit, and a pressure of as much as 100 lbs. to the square inch could be resisted.

The corrosion of the spikes and the consequent serious leakages have caused the abandonment of this first method.

Soon afterwards the solid *wood-tubbing* was tried, which is now largely practised in the polygonal pits of the Belgian and French collieries. A wedging curb, *trousse picotée*, is, as before, placed on a carefully smoothed bed, and sometimes superposed on a narrower one called the *trousse colletée*; thin slit deals are placed between all the joints, moss or oakum is packed in at the back, and by wedging as long as a chisel can be made to enter, all the joints are made tight, and the space at the back crammed full with thousands of wedges—at first of a broad, flat shape and afterwards narrow pointed ones. The tubbing itself consists of blocks of good oak or elm, with the joints well planed to fit, and lined with sheeting deal for further wedging. In the polygonal pits the vertical joints are made to coincide, the horizontal ones are irregular. As before described, the length of tubbing is carried up past the watery ground, and capped by another wedging curb, or jointed to an upper length of similar work. A tubbing of this kind has the advantage of resisting the action of corrosive water, and when well executed withstands a pressure of 200 or 300 lbs. to the inch. At Carling, in the Department of the Moselle, a pit was sunk by M. Pougnet, some years ago, to work seams at 230 and 280 metres depth, and it has been tubbed in the manner above described, for a length of no less than 160 metres, or 524 English feet.

The forcing down of cast-iron cylinders has in many cases been successful; but when the diameter is large, and the tubbing needed at some depth in the shaft, they have been cast in segments, having flanges towards the inside of the pit by which they were bolted together. This variety has now become almost obsolete, since the introduction of the modern method, but is nevertheless capable of doing good service, especially in going down through alluvial matter at the surface. My friend the late Mr. Fletcher, M.P., F.R.S., by this means carried a shaft successfully through 60 feet of coarse gravel and boulders, full of water, in the valley of the Derwent, between Workington and Cockermouth. This shaft is 12 feet diameter in the clear; the lower ring of 18 inches high was sharp-edged below, and above this only the vertical joints were bolted, the horizontal ones left free to a little play. The exterior of this tubbing is, of course, flush, to facilitate its passage downwards, and the joints lined with sheeting deal to make them tight.

The great facility of dealing with cast iron, or *metal* in any desired pattern, has led to the special advancement of this variety of tubbing in England. The commencement is very similar to what has already been described. One, two, or three wedging curbs, according to the pressure expected, in segments of cast iron, are laid and wedged with the greatest care, since perfect tightness here is of the utmost importance. Upon the upper one the plates or segments of tubbing are built up, sheathing of pitch-pine, $\frac{3}{8}$ths or $\frac{1}{2}$-inch thick, being inserted between *all* the contact surfaces, and the vertical joints broken, as in stonework. The plates are from $\frac{3}{4}$ to $1\frac{1}{4}$ inches thick, and between 3 feet and 12 inches in height, according to the amount of pressure to which they will be exposed. They are smooth towards the inside of the shaft, but strengthened on the outside by flanges and cross-ribs, supported by brackets. Before being placed, they should be tested for soundness by being smartly struck all over with a moderately heavy hammer. Every segment has a hole in the middle, through which the water may escape, until the whole structure is prepared. The vertical joints are meantime wedged, but the horizontal ones, for fear of lifting the plates, wait until a sufficient height of segments has been built up, and is surmounted by another wedging curb. Then, beginning at the bottom, open plugs are driven into the centre holes as

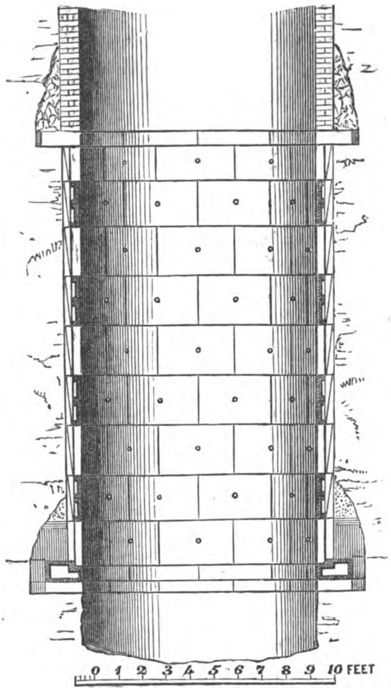


Fig. 19.—Cast-iron Tubbing, resting on two wedging curbs, the upper one hollow cast-iron, the lower one of wood.

the water rises behind the plates, and the wedging of the joints is completed. The air or gas must be allowed to escape freely above the water, and caution, therefore, is exercised in not plugging too rapidly. Should any aeriform fluid thus be imprisoned it will be apt to burst a plate or blow out the sheathing; and in order to relieve the pressure a pipe is sometimes fixed from the upper ring of plates to the next length of tubbing above, and again from that to a higher part of the pit.

One of the most remarkable instances of tubbing is that of the Shireoaks Colliery, sunk some years ago by the Duke of Newcastle. The pits are 515 yards deep to the "Top-hard Seam," 12 feet diameter, and the tubbing in 11 lengths

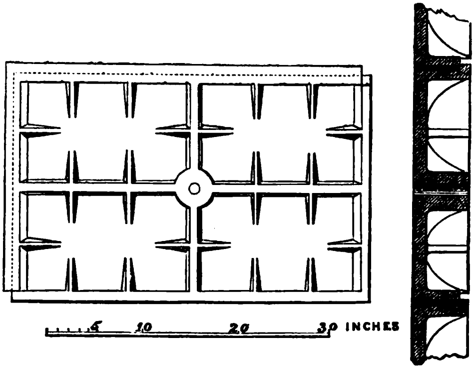


Fig. 20.—Cast-iron Tubbing Plate, in elevation and cross-section.

extends for a total depth of 170 yards, and weighs about 600 tons in each pit. My friend Mr. Tylden Wright, under whose supervision it was completed, informs me that the pressure at the bottom was about 196 lbs. per square inch, and that the cost of the lower and stronger parts was as follows, per yard:—

	£	s.	d.
126 cwts. of cast iron at 7s.	44	2	0
Fixing ditto	3	0	0
Wedging above	3	0	0
Laying rings (about 10 yards apart) .	10	0	0
	£60	2	0

In order to give a vent to air and gas, taps and pipes are applied, communicating from behind the tubbing to the surface, through which a large volume of water is now discharged; and by the final completion of the work in 1858 heavy feeders of water, which during the sinking yielded as much as 500 gallons, or 2¼ tons of water per minute in the two pits, were thoroughly excluded.

Cast iron is so subject to destruction by the corroding action of the water, and of the smoke and gases from the ventilating furnaces, that many schemes have been tried for its preservation; a close lining of brick answers well, but makes it difficult to get at and wedge up a leak or replace a faulty plate; a coating of paint or tar and a lining with wood (3-inch brickwork at Shireoaks) are more or less efficacious.

M. Chaudron, a Belgian, has succeeded in tubbing pits by a method which is proved in watery ground to offer great economy. The shaft is *bored* by Kind's apparatus, and the cast-iron tubbing lowered when the boring is done. The bottom ring of the tubbing has a sliding case, in which is placed a quantity of moss or oakum, which, when the whole length of the tubbing comes to rest on the water-tight bed, cut for it by the borer (under water), gets so packed as to form a tight joint. The water is then pumped out, and the pit is ready for working and completion. At the colliery of Pérrones, where the watery strata extended from 141 to 344 feet deep, the pit was tubbed at one-fourth the usual cost.*

In Westphalia much attention has been given to tubbing with stone set in hydraulic cement, but although appli-

* A full account of new examples of the successful application of this method was given by the Author in the Trans. North. Inst., 1871.

cable in some cases, this method is comparatively clumsy when a heavy pressure has to be met, and the cement is liable to destruction in a furnaced shaft. The first outlay for a substantial tubbing, whatever be the material, is, no doubt, very serious, but the great advantages to be gained when it can be suitably applied are such as to make it desirable to extend the practice more generally. It is not only a benefit to the mine in relieving it of a heavy and constant charge, and of the interruption and accidents inseparable from the use of large pumping apparatus, but it is an advantage to all the dwellers around and may thus interest the general public, as retaining the waters in their natural channels and thus obviating that destruction of springs which is often charged upon the miner as a heinous offence by other members of the community.

CHAPTER XI.

DRIVING OF LEVELS AND CUTTING THE COAL.

THE preparatory work of a colliery is far from being completed when the shaft has reached the bottom of the seam. It would be ruin, especially in deep workings, to attempt at once to extract coal in any quantity, for the weakening of the ground by its removal would not only tend to bring in or destroy the pit, but would crush the roads which should remain open as thoroughfares for the working of the distant parts of the "royalty" or field of operations.

In the first place, then, a large mass of coal should be left unwrought around the pit as a *shaft-pillar*, having only the narrow drifts cut through it, which are to be employed as roads and as channels for air and water. One of the first things the coal-viewer will have to decide will be the size of such pillar of coal to be left around the shafts, and for this purpose the following formula, according to Professor Merivale,* will approximately give the necessary size:—

X = size of shaft pillar in square yards.
D = depth of shaft, in fathoms.

$$X = \sqrt{\frac{D}{50}} \times 22.$$

Having determined this point, the two shafts which

* "Notes for Mining Students."

every colliery must possess, as regulated by the Coal Mines Regulation Act, will be connected by drivages in the seam to provide for ventilation. Next, the levels or drifts, for these purposes, are to be driven out in the directions required by the lie or position of the strata. Where the beds have a definite dip in one direction, the working pits are usually placed as far towards the deep as it is convenient to go, so that underground the coal may be brought down-

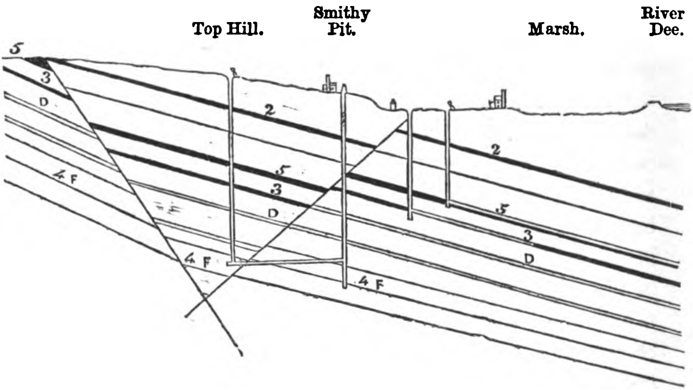


Fig. 21.—Section of Coal seams at Bagillt—160 yards to the inch.

2, 5, and 3 are the two, five, and three-yard coals respectively.
D and 4 F are the Durbog and four-foot seams.

hill to the pit bottom. But as the workings advance, it may, after a time, be convenient, instead of sinking fresh pits farther to the deep, to sink the existing pits deeper, and drive out crosscuts, or to work downhill and bring the coal upwards by engine-power.

The annexed figure represents in section the valuable upper seams of the Flintshire coalfield, where they dip beneath the estuary of the Dee.

The pits at Top Hill have crosscuts driven through the measures; the pits nearer to the marshes have downhill drifts carried in the inclination of the seams.

Should the strata lie in a *trough*, the pits may advantageously be placed in its middle line, so as to command the coal on both sides.

In those few districts where coal still remains to be got by "free drainage" the workings will be started much the same as from the pit bottom, the levels being driven at once into the hillside; but the arrangement is usually a defective one for quantity, as not allowing so readily of extension in each direction.

One of the most serious questions to be solved by the coal-viewer in the very outset is the system by which he means to work his mineral; and in order to form a judgment upon this head it is important that he should not only be acquainted with the various modes in use elsewhere, but should have acquired a knowledge of the peculiarities of the seams in his own district. The first step must be nearly the same in all cases, although it may be so much the simpler, as the colliery is shallower, smaller, and not required to stand open for so many years. This step is the opening forward of the levels, drifts, or way-gates, which are the pioneers of the excavations, and must precede, at least to some extent, the removal of coal on any large scale. They are, in fact, generally characterised as narrow, or *dead*, work in contradistinction to the wider working places which follow, and which alone are expected to be remunerative.

Is the proprietary well provided with capital, the extent of the area not very great, and the ground firm, the levels may be driven to the boundary of the royalty, and the coal worked back towards the shaft, leaving the dangerous spaces from which the coal is extracted (the *waste* or *goaf*) behind, entirely done with. But if the opposite conditions hold good, coal must be got as soon as the levels have advanced sufficiently far beyond the shaft-pillar.

If the water is to be mechanically raised from the workings, the pit will have to be sunk to some little depth beneath the seam, for a *sump* in which the drainage may collect; and it is well, in addition, to open out on the deep of the intended roads sufficient excavation to serve as a pound or *standage*, for water, where it may accumulate for a few days in case of breakage of machinery.

A level cannot be driven singly, unless divided into two parts for the in-going and out-coming currents of air, and hence it is usual to prefer to drive two parallel ways with a rib of from 6 to 10 yards thickness between them, cut through at intervals as required for the ventilation. The lower of these is the drain, or water, gate; the upper, the main road, rolley-way, or way-gate; whilst in extensive collieries a third is usually added, for more efficient ventilating arrangements.

In coal-seams of moderate thickness, these leading drifts will be carried between the floor and roof of the seam, and of such a width as is most consistent with their security, commonly from 5 to 10 feet. If the seam be thicker than 6 or 8 feet it is usual to leave a part of it overhead as roof; if, on the other hand, it be too low for convenience as a horse-road, either some of the roof must be ripped down or a sufficient depth dug up from the thill or floor. Few of the roads, however, comparatively speaking, will stand long exposed to the pressure from all sides, and to the oxidising action of the air, without being artificially secured. The most usual method of effecting this important end is with timber placed in sets of three, at intervals of 3 or 4 feet. Two of them, commonly larch poles, or sometimes oak, 4 to 8 or 10 inches thick, are placed as uprights, legs, or stanchions against the sides, and the third laid crosswise upon the heads of the others, as a cap or head-piece. When the roof is apt to crack off it is additionally protected by planks laid upon the cap-pieces from one set to the other. Many modifications of this method of timbering exist, dependent upon the nature of the strata to be secured. Are the sides sufficiently strong to stand unsecured, the cap or collar only is needed, fixed into recesses cut in the sides of the roadway; where the floor is soft and has a tendency to rise, whilst the roof and sides also require support, timbering, such as shown in Fig. 23, may be adopted.

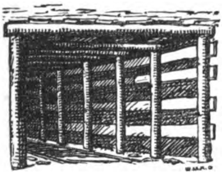


Fig. 22.

Better still, and in some cases absolutely necessary, is the arching of the main roads with brick or stone, now and then—when the floor is very soft—resting on an invert flat arch below. Especially near the pit bottom, where more room than usual is wanted for two trains of waggons, and wherever a pass-by is required, it is needful either to construct a good, wide arching, or to have the wooden caps so long that they should receive the support of an additional prop in the middle. In this case, however, side walls of masonry are often built, on which iron girders or heavy rails are placed. This method, although expensive, forms a strong and reliable roadway; it has been found advantageous in this method, where heavy side pressure is met with, to build the side wall 2 feet away from the side of the roadway, and to keep the space at the back of these walls free from *débris*.

It is obvious, although sometimes neglected, that in order

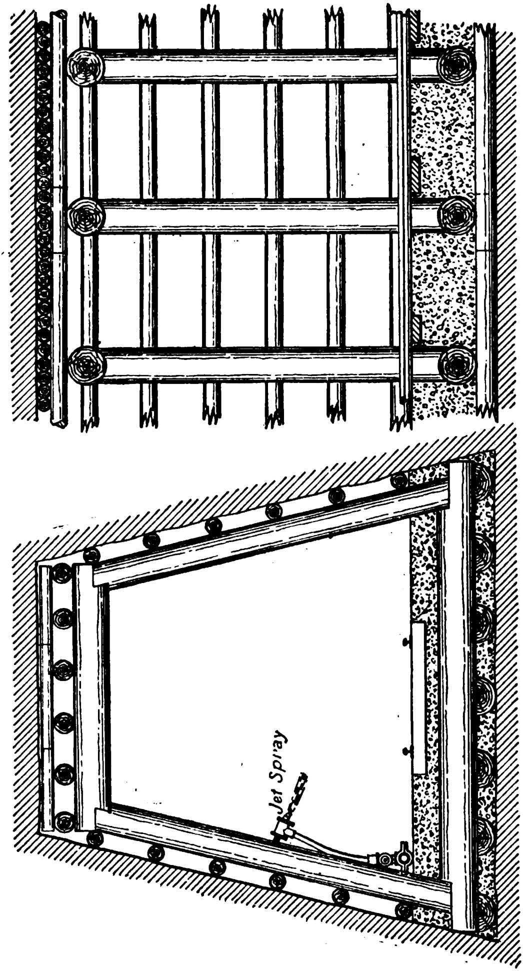


Fig. 23.—Timbering.

to obtain the full advantage from the timber, the direction of the main pressure should be duly considered, and that no unnecessary cuts should be made in the pieces, which may weaken their full resistance; also that the caps should be so fitted as not to act like wedges in splitting the uprights as soon as the weight presses; and again, that in inclined seams the props should be placed at right angles to the floor and roof, so as to prevent their being forced out of position by the weight from above.

Instances might be cited where, as soon as the main roads have to be maintained near extensive workings, it is found to be the better course to remove all the coal, and to trust to pack-walls, built up of *débris* to sustain the roof rather than to leave a rib of coal.

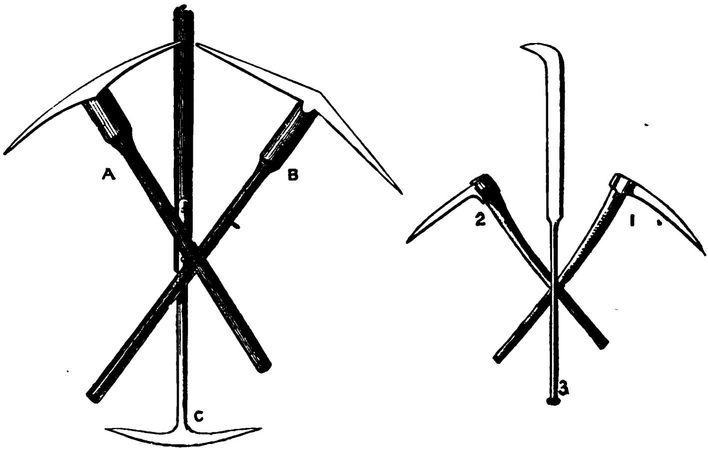
Although commonly called *levels*, and carried theoretically in a horizontal line at right angles to the main dip of the bed, these drifts cannot be carried perfectly level, or the water would not flow back towards the mouth or the pit bottom. Add to which a certain moderate amount of inclination is needed in order to facilitate the bringing out of the loaded trains or waggons. A rise of 1 in 130 appears to give the *maximum* of effect to horse-power in drawing the full waggons down, and the empty ones back, but 1 in 200 is often adopted, especially where it is an object to gain the greatest possible area of coal from a given winning. In certain districts, as in Dean Forest, a colliery may be limited on the deep side by a level to be driven from a certain point, in which case the utmost endeavour will be applied to drive it as nearly horizontal as practicable. The men occupied in driving will often be found to swerve upwards with the floor of their drift, and constant attention is therefore needed to keep it in its true direction; and when intended for a traffic road, to make it as straight and regular as possible. In former days all the little rolls and inequalities of the beds were closely followed; but at present, when the cheap conveyance of large quantities is a more prominent object, they are, when it is feasible, neglected, and the levels cut boldly through coal or stone, as the case may be. When *troubles* or dislocations occur, their magnitude must determine how far this regularity may be carried out, or whether the level will have to be swerved from its direction in order to catch at the nearest distance the coal on the farther side of the line of fault.

In certain modes of working the removal of the coal will begin at once from the rise side of these main levels, but in others upper pairs of levels will be driven parallel to the first and connected with them by rise drifts or cross-headings at certain intervals. In other modes, again, the chief working places will be started from pairs of uphill drifts (*bord-gates*) carried up the rise of seam.

The expense of this narrow work is, to a great extent, got rid of, when, as in certain varieties of *long-work*, to be presently described, the levels themselves can be included in a broad face of excavation, which is simply pushed forward in advance of the remainder of the colliery.

We may here glance at the cutting or hewing of the coal, which in the levels has to be effected by much the same means as in the larger workings, although the greater amount of labour which in the former must be expended on a given quantity of coal, and the smaller size into which it is cut and broken, renders it necessary in general to pay the men by so much per yard on their progress instead of by the ton or tram.

The *pick* (pike, slitter, or mandril) is the special tool of the collier, much varied in different districts, even for cutting coal; and of different weight and strength in the same pit, according as it is intended for under-cutting (horizonally), for shearing, or cutting vertically, or for working in shale or stone. The handle (shaft or hilt) is from 27 to 33 inches long, and the double-pointed head from 18 to 20 inches; sometimes straight or nearly so, as in central England, and in some varieties of the Belgian *rivelaine*, frequently a little curved, and sometimes in the



Coal-miner's Picks.

Fig. 24.—Scale, $\frac{3}{4}$-inch to 1 foot.

A, North Staffordshire holing pick.
B, Anchored pick, Durham.
C, Rivelaine, Belgium.

Fig. 24A.—Scale, $\frac{1}{2}$-inch to 1 foot.

1, Coal-pick, Landshipping, Pembroke.
2, Do. Westphalia.
3, Do. (*Haveresse*) Liége.

North much "anchored." The points are steeled and sharpened four-square, with a very narrow cutting edge.*

In breaking down or getting the coal, the first operation

* Coal-picks with single points are rarely to be seen in these islands; in Pembrokeshire they have been used for the anthracite; but on the Continent they are common.

is to *bench, kirve,* or *hole* it along the bottom of the seam, or in other words, to cut a groove to the depth of 2 or 3 feet either in the lowest part of the coal, or in the clay that underlies it. If the clay be tough and hard, it often follows that great waste is caused by holing in the coal, for as the groove advances in depth it must also be cut higher at its commencement, and the whole of the material is chipped so small as to be useless. Some coals are so strong as to

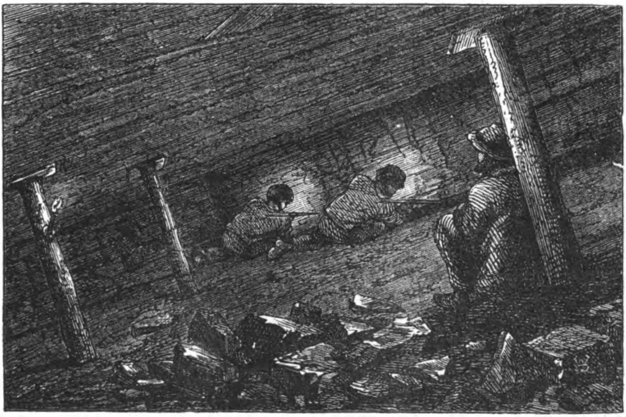


Fig. 25.—Colliers holing Coleford High-delf Seam, Forest of Dean.

require no support during this operation; others, which are tender, or divided by frequent planes of cleat, backs, etc., require to be propped or spragged, especially when, in very deep holing, the hewer has to place himself almost beneath the seam which he is detaching. For thus holing at the bottom of the seam, the collier lies on his side, and in this apparently constrained attitude swings the pick almost horizontally, and delivers a number of smart and well-pointed blows before he proceeds to remove the *débris.* In certain seams there may be an advantage in holing in the middle or even at the top, according as partings of soft shale or friable coal may occur; and in one and the same colliery you may sometimes see two or three methods of holing in practice.

When the coal to be cut away is a short block, as in the driving of levels, it will generally need shearing or vertical cutting to free it at the sides, and even in wider workings this operation is sometimes required; then at length the final breaking down or "falling" of the seam, thus partially freed, is completed by applying taper wedges at some few feet apart, and driving them with heavy hammers; or in the case of a more resisting material, by blasting with gunpowder. The operation of boring a hole and firing the shot for this latter purpose is very rapid and easy compared with the blasting in hard ground. A *drill*, with broad and sharp bit, is quickly driven forward by hand in the soft and brittle coal; the hole is usually dry; plenty of safe tamping is at hand; risk there is none in using an iron needle (except of course in stone); and danger is only to be apprehended where fire-damp is apt to be present, and where the anomaly exists of using safety lamps, and yet firing charges of powder.

This state of things has in fact caused frequent accidents, which can only be guarded against either by allowing the practice under the careful supervision of officers, or by forbidding it and giving the men a so much better price for their work as will be needed to make up for the smaller amount they can get by wedging, as compared with blasting.

The cutting of coal by means of machinery, and thus doing away with the heavy manual labour incurred in some coalfields in hewing, has made rapid progress in America, and to a limited extent in this country.

Whether the application of machinery to the hewing of a certain seam will be advisable, will be determined by a number of circumstances; as also the type of machine to be adopted in the event of circumstances being favourable to its adoption.

Several types of machines, variously driven by compressed air or electricity, are known, but they may be divided into two main divisions, viz., machines adopted for use both in comparatively narrow roadways and longwall faces, consisting usually of sliding frames, carrying a cutter-bar or chain with cutter attached, and those only applicable to longwall faces, and consisting of a disc chain or bar-cutters. The former type of machines are usually heavy and require a considerable space, from 7 to 9 feet, from the coal in which to work. The conditions satisfactory to their use are thick seams, possessing good roofs. They can be worked in headings or "bords," 20 to 40 yards in width. In the latter type of machine, a long length of face is desirable, if not essential, and the coal should be sufficiently strong to hold together when undercut by the machine; these machines are usually lighter than the former, and do not require more than 4 feet in which to work; they travel the length of the working face, undercutting either in the coal or underlying "thill," if the latter be sufficiently soft, and automatically moving forward by the gradual coiling of a rope anchored to some point ahead of the machine on a small drum attached to it.

Present knowledge of cutting coal by this means points to the following conclusions:—

That where circumstances are favourable to its adoption, such as thick seams free from "slips" or "backs," with good roofs, lengths of from 100 to 200 feet can be undercut in a longwall face, for depths varying from 3 feet to 4 feet 6 inches, in 8 hours, and that considerable saving in cost per ton of coal cut may be obtained when the work is well organised; whilst in thin seams, again, where roofs are good, the saving over hand labour is often greater than in thick seams, and the production of "large" or "round" coal, which is the most valuable part of the production, is increased.

In America a very large quantity of coal is annually cut by machinery, whilst in this country, at the Wharncliffe Silkstone Collieries, under the able management of Mr. George Blake Walker, a large daily output is thus obtained. The Lidgett Colliery, in the same district, offers an example of a colliery working a thin seam of coal, about 2 feet 8 inches in thickness, at one time unprofitably, but which, by adoption of coal-cutting machinery, has been converted into a profitable undertaking.

We may, therefore, look for a more extensive use of coal-cutting machinery in the future.

Some seams there are which will not bear this systematic mode of work, where the coal will not stand to be holed, and must be picked down in irregular pieces. In collieries in the South of France I have seen this operate as a draw-back to cheap "getting," and to obtaining a due proportion of large coal. But a magnificent example to the contrary is the pure "spiry" 4-feet seam of Aberdare, where, at Nixon's Navigation Pit, a pick seems to be hardly needed, one smith suffices to sharpen for 300 men, and the coal in the face comes down so readily that a man has only to show it the point of a bar and in a few minutes has spread before him masses enough to fill a tram.

CHAPTER XII.

POST-AND-STALL AND LONG WORK

Is the general form in which the colliery is to be laid out determined on, the position of the shafts, main levels, and direction of the working faces settled by local conditions; we have next to solve the question of the best mode of the working away (*exploitation*) of the coal.

The most simple and natural method would appear to be to open ranges of working places, each as wide as the nature of the floor and roof will admit of with safety, and each divided from its neighbour by masses of coal broad enough to sustain the pressure from above. This is, in fact, the rudimentary idea of the system of *post-and-stall* or *bord-and-pillar* (*stoop-and-room* of Scotland). In fullest opposition to this method is that of removing the whole breadth of coal over a long continuous face, supporting the roof at the immediate "face" by temporary props, and allowing the superincumbent strata to break down bodily at a few feet distance behind the workmen—known as *long-wall* or *long-work*. Other modifications there are, which partake, more or less, of the character of one or other of the above two systems, and which are in vogue in special districts.

The post-and-stall work is most largely practised in the northern collieries, but in one form or another is met with in most coal districts, and is sometimes called for by particular conditions, such as thickness of seam, tenderness of coal, or position of workings beneath sea, rivers, or other surface which must not be disturbed.

In the earlier stages of coal-mining it is apt to be the case that the working-spaces (*stalls* or *bords*), driven across the grain, or *cleat*, of the coal, are made as wide as possible, and that the pillars between them are left as thin as is required for immediate security. Thus, towards the outcrop of the Durham coalfields extensive areas have in former days been worked where the bords were from 3 to 5 yards in width, and the pillars between them 1 to 3 or 4 yards. As the bords advanced it was necessary to communicate between them for ventilation, and cross-drifts, called *headways*, were carried, about 2 yards wide, *in the direction* of the cleat, *or on the ends*, and at 28 or 30 yards apart. Where the pillars were only 3 or 4 feet thick it is obvious that they would soon be so crushed as to be utterly useless, and thus a third or fourth part of the coal would at once be wasted by this means alone. When the pillars came to be laid out of 4, 8, or 12 yards *to the wall*, or in breadth—and it was found towards the end of last century that they might be *robbed*, or have a great deal of coal taken from them after the first opening of the bords—it became a matter of moment to adopt the proportions which would be most favourable to the full utilisation of the seam. Two great evils have to be avoided, evils on so large a scale that perhaps thousands of acres have been rendered useless to the community by the neglect of proper dimensions. One of these is the *thrust*, which, when pillars are too slight, and when the floor is hard, cracks the pillars, forces off large slabs of coal, and at last crushes the whole into slack. The second is the *creep*, a disorder more uncertain and insidious in its approach, and which, in spite of all attempted remedies, will sometimes destroy a valuable colliery. It arises when the thill or underclay is soft, and the proportion of pillars to bords such that after a time a downward movement takes place; the pillars then force the clay to rise upward in the bords, the roadways are injured and have to be constantly repaired, the air-ways are partially choked, and the pillars crack. The mischief has perhaps taken its rise only at some unusually weak place, against a *trouble;* but as it spreads from bord to bord, and infects an entire district, the floor bursts asunder, the roof, unequally supported, breaks down, the workings are closely filled with rubbish, and there remain the isolated *crept pillars,* only accessible by fresh and dangerous workings, and generally so crushed as to be nearly worthless.

The experience of the Newcastle miners has led them—especially in their deeper pits—to increase more and more the dimensions of their pillars, employing them no longer as mere supports, but taking out, in the preliminary stage of working in the *whole coal,* only from one-fourth to one-fifth of the coal, and leaving the pillars for subsequent entire removal, when operations are commenced *in the broken.* Hence, in the deep collieries the pillars are left of 24 or 30 yards long, by 16, 18, or 24 yards wide, and even 40 yards by 40.

In the earlier days of pillar-working it was usual to open out in bords and headways-drifts extensive areas, amounting often to many hundreds of acres, and to begin the thinning or removal of the pillars only after they had stood for a long time. Sundry disadvantages arise from this course—the deterioration of the exposed surfaces, the difficulty of ventilation, and the tendency of creep, or of the results of explosion, to spread through the entire colliery. Mr. Buddle introduced a great improvement when he laid out the workings in *panels* or compartments of moderate acreage, divided from one another by ribs of coal 40, 50, or 60 yards wide; and when he followed up this division of the colliery

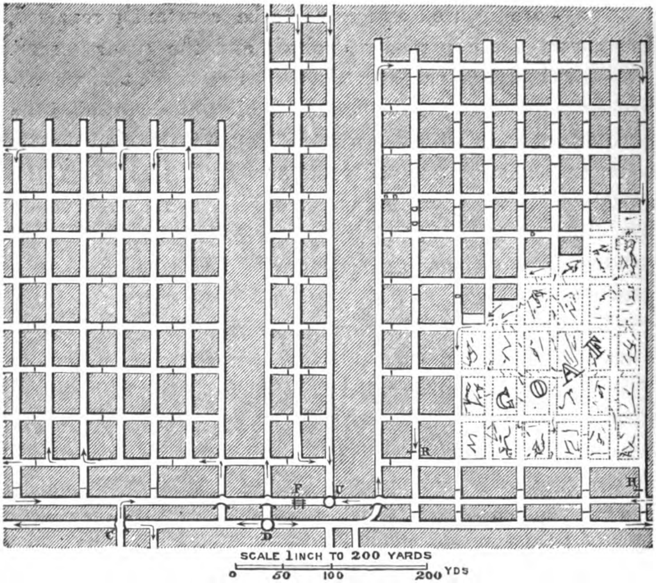


Fig. 26.—Post-and-stall Work.

D, Downcast shaft.
U, Upcast shaft.
F, Furnace for ventilation.
R, Regulator for ventilation.
C, Crossings for ditto.
D D, Doors for ditto.

The arrows indicate the direction of the air currents.

by making pillar-working follow very closely after the opening of the bords in the whole coal.

This arrangement is shown in the plan, Fig. 26, where the unwrought coal is left black, and the *goaf*, or portion from which the pillars have been removed, and into which the roof has fallen, is lightly shaded.

The actual getting of the pillars is managed in various forms: by driving a bord through its midst, by taking oft slices parallel to its longer face, or by paring it off in a succession of steps, each farther pillar being a grade more reduced in bulk. Some of these operations may thus be assimilated a good deal to the *long-wall* method, and need, for the due protection of the men, that faces of work be protected by rows of props, or by pack-walls so placed as to regulate the fall of the roof.

The Lancashire post-and-stall system is somewhat different, partly in consequence of a generally steep inclination, and partly from the softness of the floor. The seams, like those of the Tyne and Wear, are generally between 3 and 6 feet in thickness; but the working-places cannot be carried so wide as in the former district. The working drifts, or *bays*, like the above-mentioned bords, having to be directed at right angles to the cleat or divisional planes, it happens that with the varying undulations of the coal-measures, the direction of cleat remaining constant, they may have to be arranged very differently in starting from the main roads or water-level drifts. Thus, if the level course happen to be parallel with the cleat, the bays will be opened up the rise and again joined with one another by drifts carried on the end, generally 10 yards apart. If the direction of the level course be at right angles to the cleat, it will be thus also that the bays must be opened, and they will be connected with the main roads by pairs of drifts (up-brows) carried up the rise of the seam; or sometimes, if working to the dip of the main road, by down-brows, whence the coal has to be pulled up by engine-power.

The pillars are thus left 10 yards on the rise, by 20, 30, or 40 yards the other way, and are intended to be *robbed* as soon as a sufficient tract has been opened. This last operation, as in the Northern fields, in contact with the *goaf*, and exposed not only to the successive falls of the roof but to the invasion of fire-damp, loosed from the disturbed measures, needs every caution in its practice, and makes it often necessary to admit safety-lamps alone, whilst the other parts of the same colliery may be securely worked with candles.

There are still many coal-mines in which the stalls or *wickets*, and the cross-headings or *thirls* are driven as wide as they will stand, say 5 yards, and pillars of only 2, 3, or 4 yards square are left; or where, again, the stalls are driven of this full width, and long pillars of a few feet thick are left standing between them. In either case a considerable waste of coal must occur, and the irregular openings left as goaf are fraught with danger when fire-damp is present. The method most usual in South Wales is of this latter kind: cross-headings are driven out from the main level at such an angle of obliquity as to be convenient for horse-roads, whilst from the latter the working stalls are opened, narrow at the entrance (to protect the roads) and wider inside.

A last variety remains to be mentioned, viz., the "square work," employed for the getting of the magnificent seam, varying from 25 to 36 feet thick, called the Dudley Thick or 10 yard coal. The shafts are sunk to the bottom of the seam, and a mainway, the *gate-road*, is carried forward in its lower coals, ventilated by means of a separate *air-head*, or drift, of very small dimensions, opened in the coal also, at a few feet on one side of or above the gate-road.

From this latter the main workings, called *sides of work*, are opened in the form of a square or parallelogram, 50 yards in the side, or more, and shut off by a rib of coal 7 or 8 yards thick, at the least, from all other workings, except at the entrance, a narrow *bolt-hole*. Driving out in the lower coals, and gradually rising to the higher ones, the colliers open stalls of 5 to 8 or 10 yards wide, forward and across, so as to leave square pillars, generally 9 or 10 yards in the side, and whenever the unsoundness of coal or roofs appear to require it, sparing additional supports of coal in *men-of-war* 3 or 4 yards square.

The men get at the upper divisions of the seam by standing on the slack and coal already cut, or on light scaffolding. No ordinary timbering can be used to support so high a roof, nor can the eye in these vast and murky chambers

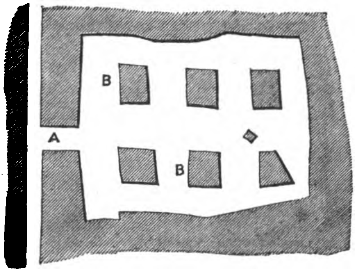


Fig. 27.—Square Work, South Staffordshire. Scale—2 chains to the inch.

A, bolt-hole; B B, pillars.

easily detect where special danger threatens overhead; but the sense of hearing comes valuably into play, and a sharp ear often catches the preliminary cracking which indicates the approach of a fall. Nevertheless, the work is the most dangerous in which the collier can be engaged; and no mode of getting this coal with a less serious destruction of life by "falls" has been devised, except that of working, in two lifts, by the long-wall method, which, in despite of much opposition, appears at a few works to have stood successfully the result of many years' practice.

The pillars in the "square work" are often in conclusion thinned to a smaller size, and when at length the roof begins to break in, the side of work is abandoned, a dam put into the bolt-hole, and thus the air is excluded from the heaps of waste small coal, and the crush prevented by the ribs from extending to other parts of the pit.

It scarcely needs to be added that, although after this first working, operations may be set on foot for getting *ribs* and *pillars*, much of the coal is so crushed, or "frenzied," as to be of little use. The waste of some thousands of tons of coal per acre, and the great sacrifice of human life in the process, lead one to contemplate with no pride or satisfaction our mid-English working of the finest seam of coal in Europe. The risk to which the men are subject in this district from falls of roof and coal may be inferred from the inspector's figures. Deaths from "falls" in South Staffordshire and East Worcestershire:—1856, 88; 1857, 81; 1858, 97; 1859, 92; 1860, 75; 1861, 78; 1862, 79; 1863, 55. Later years have shown a marked improvement, viz., in 1897, the deaths from this cause numbered 15.

Some of the coal-seams of central France, although more broken up than the last, are much thicker, and have led to many varieties of working, in order to find out the safest and best. In the department of the Saone et Loire, I learnt, on a recent visit, that every other mode has given place to the working by *remblais*—that is, taking a horizontal slice of 2 metres in height across the seam, and filling up the space with stone and earth brought down from the surface. At Montceau, near Blanzy, I found the seam to be no less than 78 feet thick, inclined at about 20 degrees. The works are carried forward horizontally from floor to roof, 6 feet 6 inches high, alternating with "middlings" of coal of the same height; and within a few months of the working and stowage of one horizon fresh openings are made in the range below, and the remblais or stowage is found to be so closely packed as to form a very good roof for driving under—assuming the use of plenty of timber. The *plan* of the working is in pillars of 10 metres wide, which are sliced off as in long-wall working.

The long-wall method may be applied either by driving out roads in the solid coal to the extremities, and then working back, leaving nothing but *goaf* or *gob* behind, or by commencing at once, near the shaft, to work away the mineral, maintaining means of access to its fresh face by roads, artificially supported, through the waste. Beyond this, great differences occur, according as to whether the faces of work need to be straight, following the lines of cleat, or are divided into "stalls," or may be set off in several directions at once. The working faces are for the most part so arranged as to advance *against* the planes of cleat; but there are certain tender coals in which it will be found that, *when the pit is deep*, they are upon this system much broken up by the pressure, and that a far better proportion of round coal will be obtained by working *on the end*, *i.e.*, in the direction of such cleat. The most regularly laid-out varieties of long-wall are those of Shropshire, Leicestershire, and Derbyshire; but others, more or less modified to suit local requirements, may be seen in Lancashire, Somersetshire, Dean Forest, South Wales, Scotland, Belgium, and Saxony.

Without exceeding the limits of a book like the present, it would be impossible to dwell upon the details of the various kinds of long-work, but the diagram Fig. 28 may show some of the chief features of several plans of arrangement diverging from one pair of pits.

In some instances it will be seen that a great length of face may be opened in a single line, as much indeed as 100 to 400 yards; in others 30, 40, or 50 yards of straight face form a stall, and one such is followed up closely by another. In many instances, again, the face forms on the large scale

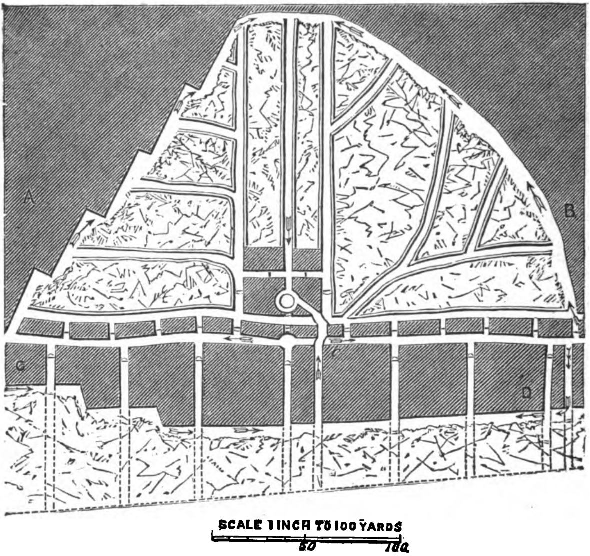


Fig. 28.—Long-wall Workings.

The portion A represents advancing *stalls*, or *tooth-work*, taking the *face* of the coal; the side B works in the *end* of the coal, whilst the part C D is carried in a straight line irrespective of the cleat. The double edge of the gob-roads represents the pack-walls.

a curvilinear working, which may be adopted when the coal is not so divided by *cleat* or *backs* as to cut more freely one way than another.

Let us now turn our attention to the "face," or the front of the workings, which, as it is but a few feet or yards away from the waste, where the roof has "come down," requires to be carefully protected. The usual way is to plant a double row of props (sometimes three rows are needed), arranged alternately, and at right angles to the roof and floor. Each prop takes a good bearing on the roof by carrying a piece of wood, the *lid* or *tymp*, 12 or 15 inches long, which first receives the pressure, and is soon squeezed or broken. Cast iron has been occasionally employed for the purpose, but the props are usually of larch, or, in low

Fig. 29.—Cross-section of Long-wall Face.

seams, of oak, and whilst with unsound roofs they have to be set thickly, in the common way they may be many feet apart. Where the heaviest roof-pressure is expected, nogs or chocks are employed instead of single props; these are pieces of timber 2½ to 3 feet long, built up, two and two, crosswise, thus giving a broad base and summit, and the advantage of being easily knocked asunder for removal. Suppose the coal now holed to a sufficient depth all along the face, the pressure of the overlying mass will tend to force it down, and in some cases actually saves the collier the labour of falling the coal, by itself performing that office in the course of a few hours. Otherwise, by wedging or blasting, the coal is brought down, then broken up and removed. And now, all slack, unsaleable coal, and rubbish being thrown behind the men into the gob or waste, the back row of props is pulled out, and they are set up again in front of the fresh face of coal, when the whole operation starts for the succeeding day *de novo.* Meanwhile, the removal of the coal from the face towards the shaft is a care of the first magnitude.

If the roof be excellent, the coal strong, and the output important, iron rails (to be moved from day to day) may be laid along the face, on which the trams or tubs will be cheaply conveyed. But when, as most frequently happens, this advantage cannot be had, the coal has to be dragged or *putted* in sledges along the uneven floor in front of the face to the nearest outlet, and it hence becomes necessary to have roads opening on the face at frequent intervals. If we are working back from the extremities, no more need be said than that the roads as the work advances are constantly being shortened, and that the expense of their maintenance is thus diminishing; but if we follow the usual method, the *gob-roads,* as they are called, are daily increased in length, and the charges of keeping them in order become a very heavy item. There is then one evil to be balanced against another: on the one hand the expense of numerous gob-roads, on the other the cost of *putting* the coal a great distance to get to the roads. A working stall is for this reason commonly from 24 to 50 yards in breath, so that the broken mineral need not be conveyed more than 12 to 25 yards to be placed on a good road. If the coal be a thin seam (and as little as 11 inches of coal is thus worked in the Radstock district), the roads must, for efficient conveyance, be cut higher, for which purpose either the floor or roof must have a foot or two taken off, whilst the material or *débris* so broken will help, like "partings," "dirt-bands," and other rubbish from the seam, to fill up the waste or gob, and assist in letting the roof down gently. Such stone, and what breaks from the roof, is often built up in *packs*, or masses of dry rubble walling; and the roads which pass through the gob have thus to be protected by a pack wall of some feet thick on either side. Management will do a great deal in regulating this apparently dangerous work, for each kind of roof needs to be studied, that it may be brought down in the safest manner. Some kinds will break short, so that you are insecure a single foot behind the back props—nay, in bad cases, will smash props and everything up to the face of the coal; others will bend gently down to the refuse or gobbing, and press the whole firmly together; whilst certain rock roofs will hold up for a long distance unpropped, but are apt to break suddenly with a crash, which will blow out all the lights far and near, and if there be fire-damp about may force it dangerously into the roadways.

The gob-roads, meanwhile, stand the pressure variously; in some the floor rises, and has to be frequently repaired; to this end men are occupied in *roading* work during the night, whilst the pit is otherwise clear. Or the pack-walls gradually squeeze down, and the roof requires to be hacked or shot away to give height, and, after a time, the road will be found to be almost entirely to be cut in the roof-stone. In certain districts it is attempted to protect the roads by leaving a thin rib of unworked coal on each side; but an unequal resistance is in this way offered, which generally entails a greater expense in the long run.

In some of the Welsh and Forest of Dean collieries an economical method is adopted for working by the long-wall, and forming their main-level roads by the same process. Instead of driving a pair of narrow levels as usual, a bold face of work, 20 to 50 yards in breadth, is pushed bodily forward, the requisite roads are *packed* on both sides and additionally fortified, when needed, by timber, whilst the space behind them, partly filled with refuse, forms a portion of the general waste or gob.

The great advantages of the "long-work" method are simplicity of plan (and consequently of ventilation) and the entire removal of all the coal; added to which, under most circumstances, are greater safety to the men and a larger proportion of *round* coal in comparison to *small* or *slack*—a matter which, considering the prices, is of vital importance in the selection of the mode of working. It has been mostly practised where the seams are thin, or where they contain a band of refuse; but neither condition is indispensable: for, on the one hand, coals of 6, 8, or 9 feet thick are at the present moment worked advantageously in this manner; and on the other, we have seen bind, or stone debris, carried from one seam to another, or even taken down from the surface to assist in the packing where it was needful. Nor is it necessary that the roof be good, although the expense will be very different according to its fragility; but if the operations be carried on with sufficient smartness to push the working-place daily under a fresh or "green" roof, it may be managed upon this system, even when composed of mere fireclay with slippery joints.

Some years ago the long-wall system was much decried, except in a few localities; but its manifest economy is gradually introducing it elsewhere; and even in some of the deepest Durham collieries it is successfully applied to the working off of their gigantic pillars; whilst in a few of the pits near Dudley it has been employed for removing bodily first the upper and afterwards the lower half of the 10-yard coal, with greatly increased yield of coal and security to life.

In Yorkshire and in some of the North-Welsh collieries, methods have for a long time been practised which unite some of the characters of the pillar system with a certain amount of long-wall.

From the main levels, which are protected by sufficiently massive ribs of coal, bord-gates (generally in pairs) are driven up the rise of the seam in advance of the main workings, and between them *banks* are opened in the form of bords of 20, 30, or 40 yards wide, and, like the bord-gates, worked across the grain of the coal. The roof, of course, falls behind the men, so that the face has to be protected by a double row of props, and sometimes by leaving small pillars, which are mostly lost. If the ground is bad, pack-walls are also built here and there, to prevent the falls being too sudden; and by similar walls an air-way is carried along part of the side of the bank, so that the ventilating current shall pass along its upper end. But the roof here does not settle in the same uninterrupted manner as in the regular long-wall work; and the establishment of a number of separate goafs in proximity to, and generally below, the places where the colliers are working, renders outbursts of gas extremely dangerous and has led to the fearful explosions of the Ardsley Oaks, Darley Main, Warren Vale, and Lundhill Collieries.

Indeed, so fraught with danger has been this plan of working, even where other requirements had been duly attended to, that some of the collieries of the Yorkshire district have been changed into long-wall workings, and apparently with very advantageous results. And under this head we must remember that, since the distribution and quantity of the ventilating air will depend upon the arrangement of the workings, a very serious responsibility attaches to the selection of the method most suitable to the character of the strata and to the expected magnitude of a nascent colliery.

CHAPTER XIII.

CONVEYANCE UNDERGROUND.

WHEN, in the early periods of coal-mining, the works extended but a short distance from the shafts, and only a small quantity of minerals was extracted, it used—as in many small works at the present day—to be conveyed by dragging in *sleds* or sledges, along the somewhat slippery floor of the seam.

In some districts the ruder method of carrying in baskets was practised, as even now in Spain and South America, and this toilsome work ceased to be performed by women "bearers" in Scotland only in 1843. In other pits barrows were employed, the wheel running upon a plank called the barrow-way. The sledges have to be still commonly used in *putting* the coal along the face of the workings to the better roads; but in all large pits the conveyance along the main ways has for a century past been conducted on constantly improving methods.

The Germans were ahead of us in the introduction of wooden rails underground; for in 1550—as described and figured by George Agricola, in his folio "De Re Metallicâ"—we find a rectangular iron-bound waggon, with four small wheels beneath it, and a projecting pin to run between the rails and thus guide the movement. It is still called the *hund*, or dog, and is in common use in parts of Prussia, Saxony, and Austria.

About 1630, "one Master Beaumont," a gentleman of great ingenuity and rare parts," went to the Newcastle district for the purpose of introducing various mechanical improvements, among which were wooden rails for the running of wheeled waggons; and although he failed as a speculator, these rails appear to have been a good deal applied, within the following century, both in these collieries, those of Whitehaven, and the lead mines of Alston Moor. They are described by M. Jars, in 1765, as in use with flanged wheels, both in the pits and for conveyance to the shipping places.

Mr. John Curr, of Sheffield, in his "Coal Viewer and Engine Builders' Practical Companion," 1797, states that 21 years before that time he had introduced at the Sheffield colliery the use of railroads and corves. At that period, "till of late," the prevailing practice in the Newcastle collieries was to draw a single corf on a sled from the workings to the shaft; but lately the viewers have "introduced wooden rails, or waggon-ways, underground (Newcastle roads), and fixed a frame upon wheels, capable of receiving two or three of their basket-corves, then drawn by one horse." But Curr laid cast-iron tram-plates, ½ inch thick, and employed waggons, or tubs, with 10-inch wheels, and carrying 5½ cwts. of coal. A horse, generally, he states, takes 12 of these "corves" at a draught, and for a moderate day's work conveys the quantity of 150 tons a distance of 220 yards.

The wooden rails and Curr's tram-plates, besides performing useful service underground, were largely employed for the transit of coal at the surface, and it was thus that the miners of the North laid the foundation of the modern railway system, which in the last half-century has been brought to its present perfection and world-wide usefulness, chiefly by the agency of the same class of men. A railway was constructed in 1789, at Loughborough, by Mr. William Jessop, of Derbyshire, with cast-iron edge rails, intended for a flange on the waggon-wheel; and rails of wrought iron were at length invented in 1820, by Mr. Birkenshaw, and were rolled at Bedlington, near Newcastle.

My esteemed friend, the late Mr. Nicholas Wood, after a long series of experiments, made in conjunction with his associate, Mr. George Stephenson, published in 1825 a practical work on "The Establishment and Economy of Railways"; and more recently, in 1855, prepared a most valuable treatise on the conveyance of coal underground in coal mines. To this excellent paper (published in the "Transactions of the Northern Institute of Mining Engineers"), which will be found based on a vast number of examples and experiments, I must refer the reader for further details on this important subject.

The conditions under which the roadways of a mine are placed, their frequent sinuosity and unevenness, the confined space, and tendency to disturbance, both in the roof and floor, render it impossible to compete in economy with railways laid upon the surface. Moreover, certain requirements in connection with the raising of the mineral in the shafts have to be kept in view, and necessitate the use of particular kinds of waggon.

Until within a few years past the Northern method was to fill the coals, at or near the face, into a large basket (*corve*) of wicker, having an iron bow, and to drag it on a small carriage or *tram*, generally by a pony, to the crane-place on the main road, where it was lifted, and placed with several others on a *rolley*, or larger waggon, on which they were then drawn by a horse to the pit bottom, whence they were raised to the surface, whilst the rolley returned with a load of empty corves.

In the central districts the principle remains even now; instead of the corve a *skip*, having a strong bow of wrought-iron for raising it, is placed on a *trolley*, and loaded with coal, by having several broad iron rings placed loosely over it, within which the lumps are stacked up. It is then wheeled away to the shaft, where it is hooked on to the rope or chain by the bow.

In Somersetshire and in Belgium the method generally in use until very lately was to convey the coal in waggons to the shaft, where it was capsized into a great iron bucket, holding about a ton, called the *hudge* (*cuffat*, Belg.), which was then drawn up the shaft, and had to be again unloaded at the bank.

It is unnecessary to follow up the variations in these modes, which are applied to the conveyance of the mineral in different coalfields, but we may usefully glance at the steps which within the last quarter of a century have totally revolutionised the methods of all our larger British collieries. When the cast-metal tram-plates came into vogue, the old broad wheels of the waggons, or rolleys, were superseded by cast wheels, fined off very sharply at the periphery, in order to diminish the friction; and these are still retained at some works, partly from want of appreciation of the newer methods, partly from the desire to fully utilise the materials of an old-established plant.

As the scale of operations increased, the expenses attaching to the use of corves were found to be so serious as to lead to the resumption of small wooden waggons or *tubs*, with wheels of 8 to 15 inches diameter, which are run from the face of the coal to the pit bottom, without the delay and cost of lifting a smaller on to a larger carriage, and without involving the other great objection of unloading and loading, to which some of the methods are open.

It appears, at first sight, undesirable to have to raise in the shaft the weight of the rolling apparatus, the wheels, axles, coupling chains, etc.; but the preponderating advantage of running the same waggons throughout, and the facility of raising them at high velocity through the pit by the application of cages and guides, have been universally established as a successful innovation in the Northern and many of the larger works of other coal districts.

When the seam is thick, and roof good, the tubs may, as above stated, be taken close up to the face of work; but the more the actual present workings are hampered by lowness and want of room the higher will be the expenses of *putting*, etc., in addition to carriage along the main ways. This work used to be carried on almost exclusively by boys, but in the Northern collieries great numbers of Shetland and other ponies, of 3½ to 4 hands high, driven by younger boys, are employed for bringing the coal from the face to the horse-roads or the engine-planes. Where very thin seams are worked, as in the Somerset coalfield, the cost of "carting," as it is called, becomes very onerous. The height of the coals, averaging between 13 and 28 inches, scarcely leaves room in the lower places to go on all fours, and renders the work so laborious that, although the distances are not very great, it costs from 8d. to 1s. 9d. on the ton to cart the coal from the face through the twin-ways and branch roads to the main level.

The movement of the carriages on the roads is retarded by three kinds of resistance: first, the friction of the periphery of the wheels on the plates or rails; second, the attrition on the axles; and third, the rubbing, by oscillation of the waggon, of the face of the wheels against the flange of the tram-plate, or the flange of the wheel against the upright rail. The first is diminished either by narrowing the edge of the wheels, or by running broad wheels on edge-rails, and by increasing the diameter of the wheels; the second, by careful make, using steel axles and efficient lubrication; the third, by making the wheels fast to the axle, instead of having them loose upon it, by straightening the road, and by adopting a suitable form either of bridge or T-headed rail.

At the present day, where the quantities of coal to be conveyed over the main roadways of a mine at a large colliery are very considerable, and the speeds at which the sets have to travel are often high, the description of the permanent way and rolling stock to be used (from an economical point of view) is a matter of importance. More especially is this so when, as in the case of coal, the mineral is not of great value, except in considerable bulk, and it is essential to convey the material as cheaply and with as little breakage as possible.

The tendency during the past few years has been to increase the weight of the rail used on the main haulage roads, and to more nearly approximate the condition of these underground roadways to the conditions prevailing on surface railways. It is not uncommon to find a main haulage way laid with flat-bottom rails, weighing 40 lbs. per yard, secured with steel sleepers in place of wood. In branch roadways, the rails will probably not exceed 18 to 25 lbs. per yard, and where horses are employed in hauling coal the wood sleeper will be more advantageously employed than steel. In small collieries there is often a great waste of the oil or grease used to lubricate the tubs, but in those better appointed a self-lubricating tub-wheel, in which the lubricant is contained in a box on the tub-axle, is used, and it has been found that, by the use of this, in the place of a tub requiring to be oiled every journey, once a week will be sufficient to keep it running satisfactorily. In some cases an automatic greaser, usually consisting of two toothed wheels fixed to a shaft, revolving their lower halves in a well of grease, is employed, and is fixed in some portion of the main roadway where all the tubs will require to pass over it, and thus become automatically greased.

The old system of signalling from the pass-byes to the fixed hauling engines by means of a single wire attached to a *rapper*, and worked by a lever, has to a great extent given way to electric signalling, consisting either of a single or double wire attached to electric bells. In the former, it is only possible to signal from fixed stations; but in the latter, the rider in charge of the set is enabled to signal to the engine-man from any point of the engine-plane.

The electric current for these bells is supplied from batteries of La Clanche cells.

In thin seams, the *tubs* or waggons must necessarily be low, and the wheels small; but even in seams of ordinary height the convenience of keeping the total weight so moderate that the *putter* can readily place his tub on the rails when it gets displaced, and that the on-setter and banksmen can easily handle and run the tubs on the iron plates at the bottom and top of the shaft, give the preference in Northern practice to tubs weighing not more than 3 or 4 cwts., and carrying from 6 to 9 cwts. of coal. At Seaton Delaval, Northumberland, and neighbouring pits, the tubs weigh 3½ cwts. each, and hold 11 to 12 cwts., but these require exceptionally strong men to handle them with requisite rapidity. In the South, carts or trams of much greater weight, sometimes of iron, are often employed, carrying a weight of a ton ; but in such cases the number is smaller, and long delays are caused by getting off the rails.

The tub most generally used has an oak framing below, on which the bottom and sides, of ¾ inch or inch oak or

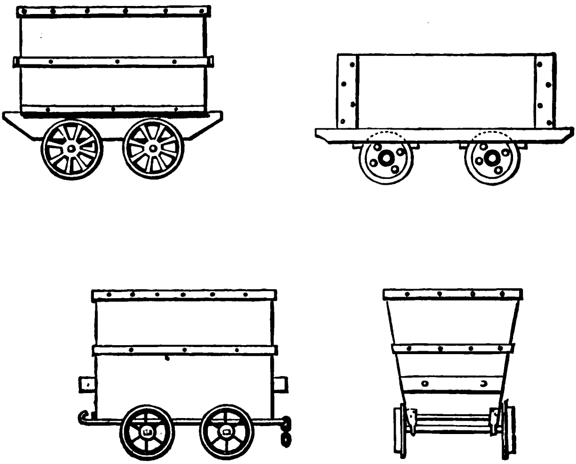


Fig. 30.—Colliery tubs. 1 inch to 4 feet.

other strong wood, are attached, with corner pieces of iron to strengthen them, and a light bar of iron passing from end to end upon the framing, with a hook at one extremity, and coupling chain at the other. When the box part has vertical sides, the wheels are placed below, and are only 8 to 12 inches in diameter ; but when it is narrowed below, the wheels may be set outside, and are 15 to 18 inches diameter. They are generally fixed to the axle, but sometimes are, as well as the axle, made to turn. The form, in fact, must depend partly on the roads and partly on the varieties of coal to be conveyed; but it would be manifestly inconvenient in a colliery where a large traffic exists to have carriages of different sizes and shapes.

For the purpose of bringing the weight low, and at the

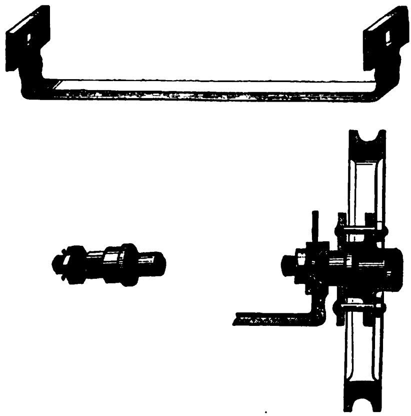


Fig. 31.—Cabany's Elbow-axle for Coal Tubs.

same time employing large wheels, M. Cabany, the ingenious director of the great collieries at Anzin, has constructed the modification of elbow-axle shown in Fig. 31, which he states can be repaired at half the cost of the common elbow-axles. The mode of attachment of the wheel is shown in the figure, and the waggon is made to belly out above it, to increase the capacity on a narrow gauge.

The large blocks in which the coals of the South Wales coalfield are worked, and the system there employed of throwing back the small coal made into goaves, has led to the adoption in that district of a larger tub or tram, more suited to their requirements. The tram is made either of steel or iron, of a length of 5 feet 6 inches, with two iron bars at each end in place of iron plates. The tram has a gauge which varies from 2 feet 6 inches to 3 feet 2 inches. The weight when empty will be not less than 8 to 10 cwts., and its carrying capacity varies from 1 up to 2 tons.

Certain disadvantages are inherent to its use, such as the greater difficulty met with, should it leave the rails, in replacing it, and greater trouble in keeping the roadways clean; but corresponding advantages are found in the larger percentage of round coal filled out by the collier. An even larger tram than the above described, carrying 2½ tons of coal, has been introduced, but the conditions generally prevailing in collieries would appear to be unfavourable to the adoption of so large a tram.

The main levels of a mine are generally carried too horizontally to allow the loaded waggons in one direction and the empties in the other to be drawn by a perfectly equal force. In order to have the resistance equal in both directions, the empty tub being 3 cwts. and the loaded one 12 cwts., and the friction $\frac{1}{80}$th of the weight, the inclination would have to be 1 in 133, and if the friction be $\frac{1}{60}$th it would be 1 in 100.

Mr. Wood found in his experiments that a horse dragging a carriage on a level railroad at surface will give a useful performance of 6⅔ tons for 20 miles, or 133 tons for 1 mile per day, which forms a convenient maximum standard for judging of this—the most general means of conveyance, as carried out in various mines. Actual practical trials in several pits gave the following results :—

Locality.	Diameter of wheel. Inches.	Inclination of road.	Weight of tram. Loaded Cwt.	Empty. Cwt.	Number of trams at once.	Tons per mile per horse.
1. Elemore Colliery	12	1 in 130	12·5	4	14	29·75
Ditto . . .	12	1 in 202	12·5	4	14	51·23
2. Hetton . . .	8	1 in 130	12·5	4	9	30·6
3. Andrew's House	10·25	1 in 222	13	5·3	11	54·15
4. Marley Hill . .	10	1 in 144	13	5	—	31·6
5. Springwell . .	10	Level	11·5	3·5	6	15·26

Similar trials made in South Wales, where the work was done by drawing 3 to 7 larger trams, weighing, when loaded, 25 to 32 cwts. each, with wheels from 17 to 21 inches diameter, principally along water-levels, but in part along inclined headings, gave results of from 10 to 17·8 tons per mile as the day's work of a horse.

These surprisingly different amounts of useful effect depend in great part on the arrangements as well as the condition of the roads. If only a single line of rails with passing places be employed, much delay ensues; and if the distances travelled are short, and the stoppages at the termini more frequent, there must be a similar disadvantage.

In the second and fourth examples above cited, the horses were particularly strong and in good condition, and yet the result falls so strangely short of what can be accomplished at the surface as to give great weight to Mr. Wood's corollary, that it becomes daily more important to substitute, as at the surface so also underground, engine-power for the costly stable of 60 or 80 horses, which otherwise has to be maintained in the larger collieries.

The substitution of mechanical in lieu of horse power to convey the mineral to the shaft bottom becomes of increasing importance as the working face becomes more distant. At certain fixed points distant from the working face the main roadways will be widened if necessary, sufficiently to allow of at least two lines of permanent way being laid, termed "pass-byes" or "partings," which are moved forward when convenient as the working face progresses. These pass-byes are kept within a moderate distance of the working face, usually not exceeding 300 yards. The coal is conveyed from them to the shaft bottom by mechanical power, and this portion of the underground haulage is often termed primary in contradistinction to the haulage from the working face to the pass-bye, which is worked either by men known as *putters*, or by horse power. In large collieries a further subdivision may be said to be made when subsidiary engine-power is introduced to convey the coal from the face pass-bye already mentioned to the primary hauling power; in this case the haulage in the working face would be termed "face" or "individual haulage."

The system of primary haulage which the coal-viewer will adopt will depend on the circumstances of the mine and the gradients of the roadways over which it is proposed to convey the coal. Does the roadway incline downwards from the shaft bottom to the pass-bye or "in-bye" at a steeper gradient than 1 in 28, the main rope system, consisting of a single rope attached at one end to the drum of the stationary engine, and at the other to the end of the set of empty tubs, may be adopted; the "journey" or "set" will in this case have sufficient momentum to carry the weight of the rope trailing behind with it, whilst the drum of the fixed engine is allowed to revolve freely as the rope uncoils; on reaching the "pass-bye" the rope will be attached to the front end of the loaded set, which will then be hauled out by the fixed engine driven by steam or compressed air. If, on the other hand, the haulage road inclines upwards from the shaft at more than 1 in 28, the momentum of the full set of tubs running down the incline may be utilised to draw the empty set up over a parallel set of rails, the rope connecting the two sets being passed over a pulley at the top of the incline. The speed will be regulated by a brake affixed to the pulley. This system is variously termed "Incline plane," "Jinny roads," "Jig brows." So long as a sufficiently long pass-bye is allowed for in the centre, it will not be necessary to lay a double set of rails throughout the incline; above the pass-bye three lines of rails will be required, whilst below two lines or a single road will suffice as the empty and full set can travel over the same metals. The sheave fixed at the top of the incline may, according to the nature of the work, be so fixed by the aid of wooden props as to be easily moved forward as the workings advance. This is, of course, a very inexpensive mode of conveying the coals, and is sometimes applicable for very long distances; although, for the avoidance of accidents, it is needful then to establish a very strict discipline as to signalling when the train of tubs is to be set running, and also to have side stalls cut out here and there for the safety of those men who may happen to be travelling the plane at the time. In the rudest of such inclines, a boy goes down with the sled, digging his heels into the floor by way of a drag; whilst in large and well-laid-out collieries a regular series of such inclines, fitted with substantial brake-drums, wire ropes, and friction-rollers for them to run upon, vie with the best of inclined planes to be seen at the surface.

A contrivance of great ingenuity, Fowler's clip-pulley, has been most successfully used by the Messrs. Pease, at the Upleatham mines, for some years past, and is now very generally applied in the working of inclines and engine planes in collieries also. Its advantages are that the rope need only be passed simply over the periphery of the wheel, instead of being coiled or lapped round it as on a drum; that it then holds the rope more equably and advantageously without flattening the wires or grinding them against one another, and that it prevents a surging movement. The movable clips on the circumference, which embrace the rope, clutch it so tightly that on a double incline one set of tubs may be thrown off—as by the breakage of the rope—and yet it is capable of sustaining the other.

It sometimes happens that the pitch or inclination of the seam approaches so near the vertical that it is not possible to convey the mineral in tubs running on their own wheels; a special form of platform (shaped as shown in Fig. 32), upon which the tubs are placed, is in this case used.

It will often be found, however, that the roadways of a mine are comparatively level or undulating, and in this case the hauling engine provided with two drums, set loose on a second motion shaft, and having each its clutch gear, the second motion being connected by spur gearing to the engine shaft. The rope from one of these drums will be connected to the front end of the set, and the other passing round a sheave on the pass-bye to the back end; the former known as the main rope and the latter the tail rope, the system being termed the "main and tail rope," and the sets are travelled at speeds up to 12 miles an hour. By this means the set can be hauled either in or out, and the drum upon which is the uncoiling rope (dependent upon the direction the set is travelling) will be disconnected or ungeared from the engine and revolve freely.

Partially applicable to the same conditions of gradient is the "endless rope or chain" system, consisting of one rope

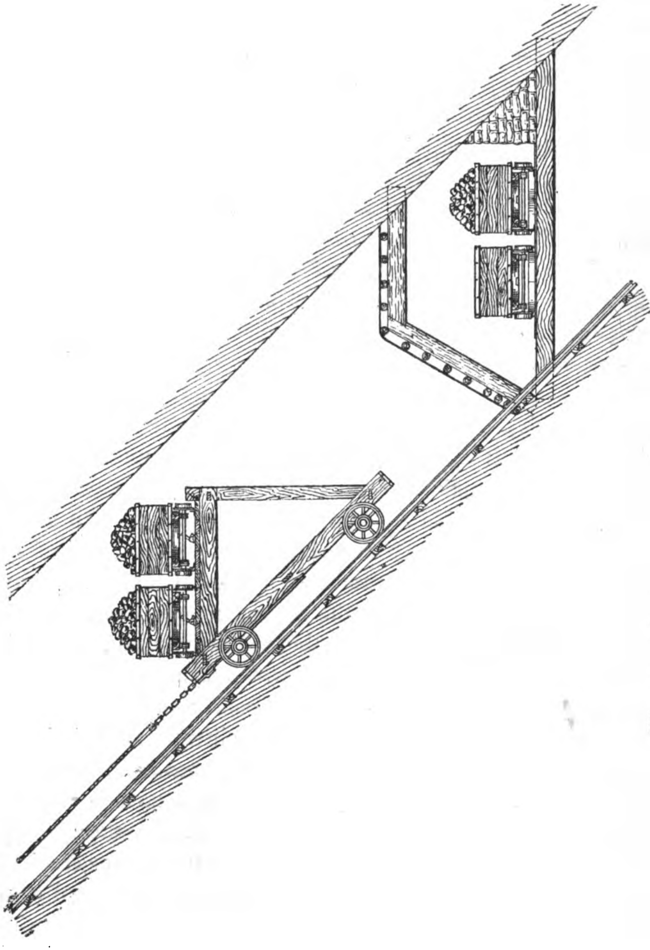


Fig. 32.—Platform for Colliery Tubs in inclined seams.

or chain passing two or three times round a pulley driven by the hauling engine, thence along one set of rails round a pulley at the far end of the engine plane, returning along a parallel set of rails to the engine. If a rope be used, it may travel under, over, or at the side of the tubs, which are attached in the former case (singly or in sets) by some form of clip, or the rope may, if the gradient be flat, rest in an iron V attached to the tubs. If a chain be used it must travel either over the top or along the side of the tubs, which are attached at sufficiently frequent intervals to prevent the chain dragging on the ground. In this system a double roadway is required and the rope is travelled at a slow rate, usually not exceeding 4 miles an hour.

Generally, in comparing these two latter systems of haulage, which are more or less applicable under similar conditions, the main and tail rope system may be said to be especially applicable to crooked engine planes, with many branches, where, on account of the badness of the roof or floor, it is inadvisable to make a sufficiently wide roadway for two sets of rails, whilst the endless rope or chain system lends itself to straight undulating roadways with good roofs and floors, with branch roads which can be worked by branch endless ropes driven by the main rope.

In one of the New Vancouver colliery companies' pits small electric locomotives, travelling by means of an overhead electric cable, similar to the electric cars to be seen in the streets of many of our large towns, are successfully employed to haul sets of tubs long distances over crooked engine planes, but this system could only be employed with safety in a non-fiery mine.

Secondary or face-haulage may, as previously pointed out, be done by horses, men, or mechanical means, the two latter only under favourable conditions. In some districts, as in the north of England, ponies are employed in preference to horses, and when this is so the distance from the working face to the pass-bye is often divided, and a smaller pass-bye made to which the ponies draw one or more tubs, as the case may be, whence they are conveyed in sets by horses to the engine parting; the men in charge of these horses being termed "drivers," whilst the lads in charge of the ponies are known as "putters."

In South Wales, amongst other districts, horses are employed in lieu of ponies to draw single trams, or if the gradients be favourable, as many as 3 trams or 4 tons of coal direct from the collier to the main pass-bye.

Men or hand-putters are employed in thin seams with favourable gradients, where the cost of cutting each roadway to a height sufficient to allow a pony or horse to enter would be excessive.

Where the working faces are carried to the dip, hauling ropes from small stationary engines fixed in the workings may be led to the face, but conditions favourable to this system being carried out in its entirety are rare.

As the distance of the working face from the shaft becomes great, or it may be in order to bring coal from some district inaccessible to the main hauling engine, to the main pass-bye, it is often necessary to employ mechanical power; and in order to save the long length and weight of ropes that would be required if the engine be fixed at the surface or the shaft bottom, the hauling engine is situated in the workings, and the necessary power for driving it conveyed to it either in pipes or by cable. The practice of erecting steam boilers underground, by which the risk of fire and explosion is increased, is not to be recommended. The conveyance of steam for long distances, owing to the great loss of power due to condensation, and the detrimental effect on the roadways of a mine, which the moist heat engendered results in, renders the driving of machinery situated remote from the shaft by this means undesirable. It therefore becomes necessary to utilise another source of power to obviate these drawbacks.

If atmospheric air be compressed and thus reduced in volume, and the temperature were constant, the pressure of the resulting air will increase inversely as the volume.

Air so compressed is capable of being transmitted long distances, and some portion of the work done in compressing it utilised in driving machinery at distant points. The usual method of compressing air is by the employment of horizontal or vertical steam engines, the pistons in the steam cylinders of which are directly connected with similar pistons working in cylinders provided with valves at each end through which the atmospheric air is drawn. As the piston travels in the direction of the arrows in Fig. 33, the air which has been drawn through the valves at A becomes reduced in volume and its pressure increased; eventually, when the required pressure has been attained, it forces its way through valves into "receivers" or cylindrical boilers, whence it is conveyed in pipes to any part of the mine required.

In the act of compressing air its temperature is raised, and it consequently tends to expand, resulting in a loss of pressure; it is therefore evident that it is desirable to keep the temperature of the air as cool as possible. For this purpose the air cylinders are usually surrounded with a water-jacket, or in some forms of compression an internal spray of water is introduced.

The air pressure most commonly adopted at collieries is 50 lbs. per square inch, but the tendency at the present day

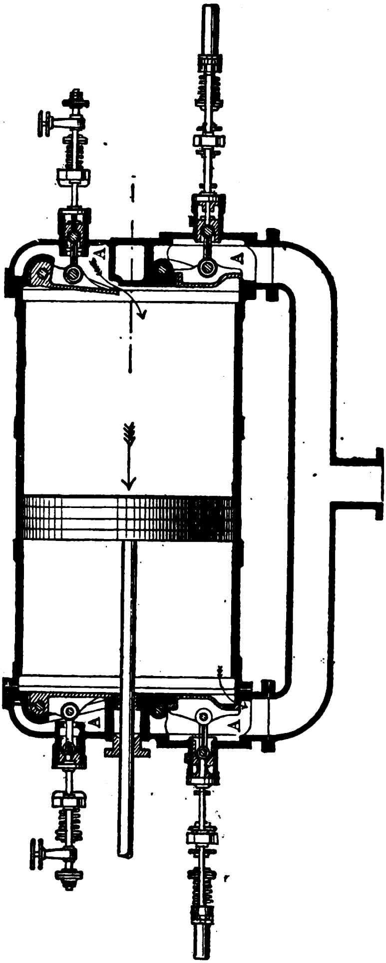


Fig. 33.—Air Compressor.

is to increase this pressure, and when this is the case the air will be compressed in two stages in separate cylinders, and passed through a cooler to reduce its temperature before entering the second cylinder.

The process of compressing air is far from economical, probably not more than 35 per cent. of the power developed on the surface being utilised in the machinery driven by its means underground; but its convenience, absolute safety, and its beneficial effect on the ventilation of a mine by its cooling action, renders it a method of transmitting power in coal mines which will hold its own against rivals for some time to come.

In non-fiery mines more especially, electricity has made rapid progress during the last few years as an economical method of transmission of power. The power will be generated in a dynamo placed on the surface, and driven by belting from a small steam-engine. The electric current is conveyed from the dynamo to a motor (which is very similar to a dynamo in construction) by copper cables well insulated. The motor is revolved by the electric current, and has attached to it either a pulley or spur wheel from which the hauling engine or pump is driven.

Up to the present this system of transmitting power has been more successful when applied to continuous running machines, as for example, pumps, than to intermittent running engines such as those often used for haulage purposes.

CHAPTER XIV.

RAISING THE MINERAL IN THE SHAFTS.

A FEW steps only, and of a simple kind, appear to intervene between the modes of slowly winding up small quantities of coal in the pits three centuries ago and the vehement, yet well-disciplined extraction of the present day. But although the improvements have not been marked by any startling inventions, they have only been rendered possible by the simultaneous advancement of the other mechanical arts. And even now it is solely under favourable conditions that the greatest eminence is attained, and we need but to travel a few miles into the hills from some of the noble collieries of Durham or of Lancashire to see, near the outcrops of the seams, little works carried on for local or *land* sale, where the apparatus, if not the ways and language of the people, will recall the days of a pristine simplicity.

As long as manual labour is employed for the raising, it may be of a few tons of coal per diem, the windlass and a round hempen rope are the means commonly used. In the hills of the West Riding of Yorkshire a pinion on the crank-axle works a toothed wheel on the barrel-axle; and thus, by giving a slower motion, enables a man or two at the surface to raise a greater weight at once, and thus to keep even with several who are working below. With a depth of 30 or 40 yards, a more economical power has to be brought into play.

For horse work the invariable arrangement is to erect the "wheel-and-axle" kind of machine called a horse-*gin*, or *whim*, and consisting of a rope-drum built round a vertical axis, the foot of which turns on a stone or iron casting, and the head pivot of which is supported by a long "span-beam," resting at the extremities upon inclined legs. The horses are attached to one or both ends (according as power may be needed) of a strong horizontal beam, generally 30 to 36 feet long, which embraces the vertical axis close beneath the drum, which is 12 to 16 feet diameter. The ropes passing off from opposite sides of the drum are conducted over little guide-pulleys — jackanapes — to the sheaves set in the shaft-frame overhanging the pit.

Although very largely employed in metalliferous mines, the horse-gin is now seen in colliery districts only during the sinking of pits, or permanently employed at shallow works doing a very small trade. In the last century, before the introduction of the Boulton-and-Watt engine, it was in very abundant use in the English and Scotch coalfields, and we have in the travels of M. Jars an account of a powerful horse machine newly completed in 1765 for raising the coal at Walker Colliery, 100 fathoms deep. It was put in motion by 8 horses kept at a sharp trot, and by means of a large horizontal toothed wheel, giving a greater velocity to the rope-drum, lifted a corve of coals in two minutes; but, unfortunately for the result, the corve held only 6 cwts. The simple gin, therefore, worked by 2 or 4 horses, remained the common machine for small depths.

It is only in districts more hilly than most of our coalfields that the streams flow with a sufficient fall to give a useful amount of water-power; but the convenient way in which the drum could be built upon the prolonged axis of a water-wheel led to that arrangement being commonly adopted by the middle of the eighteenth century, even where the supply of water had to be raised by a special Newcomen or atmospheric steam engine. Many attempts were made to convert the alternating jerky action of this engine into the rotatory motion needed for winding, but to very little purpose. Smeaton meanwhile lessened the consumption of water, and thus reduced the expense. The wheels had been made with a double row of buckets, each row opening oppositely to the other, so that when motion had to be reversed, the supply of water was cut off by a valve and laid on the other way, and thus the wheel turned in the opposite direction. Smeaton applied reversing gear of strong toothed wheels to the drum, so that the wheel could always revolve in the same direction, and the turning of the drum only be reversed.

In Wales another mode of employing water-power came into use, which is still to be seen at a few of the collieries, as well as some of the slate quarries, where this cheap power is abundant. A large sheave fitted with a powerful brake is fixed above the pit top, and has a rope or chain passing round it, to one end of which is attached an empty cistern, carrying over it a waggon of coal, to the other a cistern which, when filled with water, is heavier than the loaded waggon and empty cistern together. Suppose, now, the former is at bank, the latter at the pit bottom: the cistern is filled from a tank placed close by, and is regulated in its descent by the brake; when it reaches the bottom a self-acting valve is opened, which lets the water flow out, either to escape by the adit, or to be raised by the pumping engine; meanwhile, the loaded waggon is taken off the empty cistern, and by the time the latter is filled with water from the same tank the cistern at the bottom has been emptied and a waggon of coal placed upon it, and thus the action is reversed, and a cheap, although slowly-working, machine kept in reciprocating movement.

The chief forward step was made when Watt's double-acting engine, having the steam applied alternately on both sides of the piston, rendered it feasible to apply a rapid rotatory motion. In the smaller engines, and such, in fact, as are in work at the great majority of the collieries of our central and western districts, the motion is communicated from the main crank-shaft, through the intervention of toothed wheels, to a drum-shaft placed also horizontally, and to which a lower velocity is given. The ropes, or chains, wound in opposite directions on the drum, are carried over pulleys either down a single pit, or to two different pits, and thus, with their respective cages or skips, exercise a counterbalancing effect upon one another.

But in the larger collieries, where rapidity is essential, two different forms of engine have for some years been in use. First, a large vertical cylinder, from which the piston-rod acts *direct* upon the drum-shaft, and the drum being often 16, 18, or even 20 feet in diameter at the first lap of the rope, communicates to the load a velocity of from 10 to 30 feet in a second. The second is the engine of two cylinders placed horizontally, acting also—it may be, *directly*—on the drum, and from their reciprocating action on the crank introducing great regularity of motion.

The winding engine of the present day forms a most important feature of a colliery, as upon it will depend to a large extent the output or "get." At no time, owing to its necessarily intermittent action, an economical engine, yet its design and workmanship has been much improved in late years. Usually consisting of the latter type of engine, with two horizontal cylinders, connected direct by means of connecting rod and crank to the shaft of the drum upon which the winding rope coils, the cylinders have been constructed of sizes up to 48 inches in diameter; whilst in the case of vertical engines, a single cylinder is employed of 60 inches in diameter, and, as in the case of the Harris's Deep Navigation, in South Wales, engines of two vertical cylinders 54 inches in diameter.

In order to reduce the consumption of steam, compound winding engines have been erected, in which steam of high pressure is introduced into a comparatively small cylinder and expanded in a second and larger cylinder, thus enabling more work to be done from the same quantity of steam. The largest example of this class of winding engine at present erected in Great Britain is probably that at the Llanbradach Colliery, in South Wales, which has two high-pressure cylinders 24 inches, and low-pressure 44 inches, winding from a depth of 500 yards. Another example is to be seen at the neighbouring Great Western Collieries.

The first cost of this class of engine is greater than that of the ordinary high-pressure, but where the winding shafts are of considerable depth there is, without doubt, considerable economy to be obtained by their adoption.

As examples of some of the more powerful engines employed for these purposes at British works may be mentioned :—

Monkwearmouth : Vertical cylinder, 65¼ inches diameter; 7 feet stroke; depth, 286 fathoms, or 1,716 feet; wire flat rope; useful load 4 tubs, with 9 cwt. of coal each; time of raising, 1¼ minutes.

Dukinfield, Cheshire: No. 1 pit: Vertical cylinder, 60 inches diameter; stroke, 7 feet; low pressure; flat wire rope; load 4 tubs, with 8 cwt. of coal each. No. 2: Cylinder, 48 inches diameter; stroke, 6 feet; high pressure; drawing depth, 678 yards, or 2,034 feet; time, 70 to 90 seconds.

North Seaton: Vertical cylinder, 60 inches diameter; stroke, 7 feet; depth, 124 fathoms; flat wire rope; load, 4 tubs, with 50 cwt.; weight of steel cage, 25 cwt.; time, 35 seconds.

Rose-bridge, Wigan: Two coupled horizontal cylinders, 36 inches diameter; 6 feet stroke; depth, 806 yards (2,418 feet); flat steel rope; load, 4 tubs, or 28 cwt. of coal; wire rope guides; time, 50 seconds.

Boldon Colliery, South Shields: Two coupled cylinders, 48 inches diameter; 6 feet stroke; depth, 466 yards; round steel rope; load, 8 tubs, or 5 tons 7 cwt. of coal; wire rope guides; time 55 seconds; total weight of lift, 16 tons 4 cwt.

Harris's Navigation Colliery, South Wales: Two coupled vertical cylinders, 54 inches diameter; 7 feet stroke; depth, 760 yards; round steel rope; load, 4 trams, or 6 tons of coal; steel rail guides; time, 60 seconds; drum, conical, varying from 19 to 32 feet; weighing, inclusive of shaft, 90 tons.

Whitburn Colliery, South Shields: Two coupled high-pressure horizontal cylinders, 48 inches diameter; 6 feet stroke; depth, 360 yards; load, 8 tubs, or 4 tons of coal; oak guides; time, 46·45 seconds.

Seaton Delaval: Two horizontal cylinders of 36 inches diameter; 6 feet stroke; high pressure; depth, 112 fathoms, or 672 feet; flat 5-inch wire rope; load, 4 tubs, with 11 to 12 cwt. each; weight of iron cage, with its chains, 3 tons; time, 30 seconds.

Navigation Pit, Aberdare: Two oscillating cylinders, 43 inches diameter; 6 feet 2 inches stroke; depth, 365 yards, or 1,095 feet; round wire rope, 2 inches diameter on conical drum; load, 2 large tubs, 17 cwt., with 47 cwt. of coal; cage and bridle chains, 2 tons, 3 cwt.; total weight, with rope, at bottom of pit, 9 tons; time in shaft, 46 seconds.

It may be well to here glance at a very important part of a colliery fitting, viz., the boilers, from which the steam power necessary to drive the elaborate machinery of a modern colliery emanates.

The efficiency of a boiler will depend upon the amount of water converted into steam from a given quantity of fuel burnt on the fire-grate.

Various forms and shapes characterised the early stages of boiler construction, but the types now to be met with at colliery works will be found to consist of some of the following:—

Plain cylindrical, with hemispherical ends. The "Cornish," cylindrical, with two flat ends, and with one inner tube running through the centre of it, in the front end of which is placed the fire-grate. The "Lancashire," similar in shape, but containing two such inner tubes. The "multitubular," comprising a large number of small inner tubes, through which the gases from the fire-grate passes; and the water-tube boiler, of which the Babcock and Wilcox is probably the best known.

In the cylindrical boiler the fire is placed outside the boiler, under the front end, but owing to the small heating surface thus obtained the evaporative power of this class of boiler, of about 3 to 4 lbs. of water per 1 lb. of coal, will not compete with the more modern types, which will evaporate from 10 to 12 lbs.

In the Cornish and Lancashire boilers the heated gases pass from the fire-grates, placed in the front end of the inner tubes, to the back, returning to the front through a firebrick-lined flue underneath the boiler, and gaining the chimney-stack through similar flues on each side. These boilers are usually constructed of mild steel plates, varying up to $\frac{7}{8}$th of an inch thick, according to the pressure at which it is intended to work the boiler, which may vary from 40 to 200 lbs. per square inch. The usual size is 30 feet in length by 6 to 7 feet in diameter in the case of a Cornish; and 7 to 8 feet in a Lancashire. The inner tubes in the latter case will each be from 2 feet 9 inches to 3 feet 2 inches in diameter, and may contain cross-tubes, known as Galloway tubes, named after the patentee, to ensure the better distribution of heat. The fire-grates are usually from 6 to 7 feet in length, placed in the upper portion of the inner tube, and in the case of the Lancashire, two such fire-grates will pertain to one boiler.

The front ends of the boiler tubes are closed by doors. Apertures are left in these for the better regulating of the air to the furnace, which can be opened or closed at will.

In the multitubular type of boiler the heated gases pass direct through the numerous small inner tubes, and eventually are led to the chimney; the advantage of this class of boiler is its rapid steaming power, and it is very much for this reason that locomotive boilers are constructed of this type. The repairs, owing to the necessity of renewing these inner tubes, are, however, heavy.

The water-tube boiler, of which Fig. 34, illustrating a Babcock and Wilcox, will serve as an example, consists of a series of tubes, M M, 4 inches in diameter, and about 18 feet in length, lying at an angle with the horizontal, connected at each end with a series of vertical pipes to a steam and water cylindrical receiver, N, constructed of steel, placed

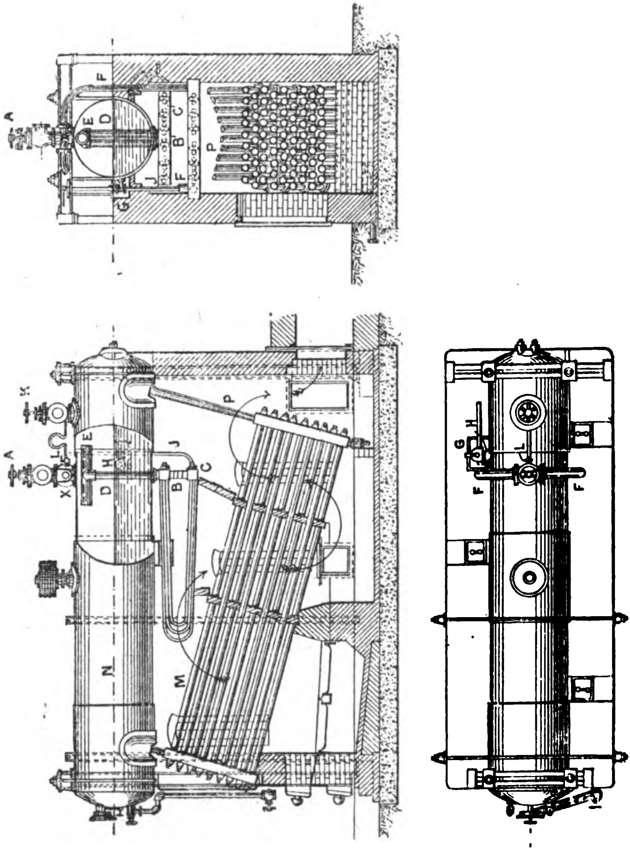


Fig. 34.—Babcock and Wilcox Water-tube Boiler.

horizontally above. The fire-grate is placed under the front and higher end of the tubes M M. The water-level is placed halfway up the receiver. The water in the tubes, when heated, rises rapidly into the front end of the receiver, passing down through the vertical tubes, P, at the back end of the boiler, thus securing a rapid circulation of the water. The steam occupies the upper portion of the cylindrical receiver N. This type of boiler occupies little space, possesses large heating surface, and is, therefore, a rapid steam raiser.

To ensure the safe working of a boiler, safety valves

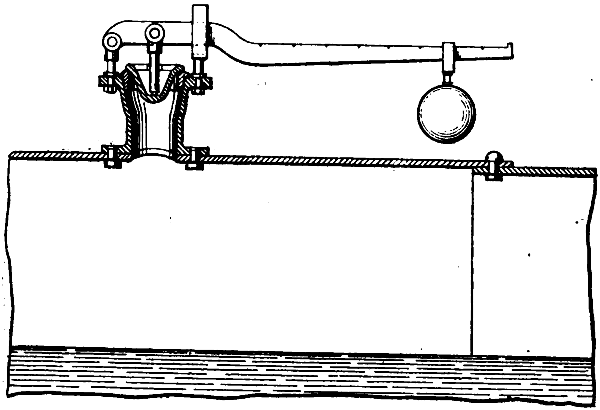


Fig. 35.—Lever Safety-valve.

must be provided, consisting of different forms of weighted valves, which will allow of the steam escaping after a certain fixed pressure has been attained. It is usual to have two such valves, a lever safety valve, as shown in Fig. 35, and a dead-weight safety valve, either Hopkinson or Cowburn, on Fig. 36.

In addition to safety valves, the boiler will be fitted with a steam gauge to indicate the pressure of steam;

a blow-off cock, consisting of a short pipe, in which a valve capable of withstanding the steam pressure is fixed at the bottom of the boiler; by the release of the valve the water can be run out; a feed-water valve, by which the boiler will be filled; water-gauges, placed in the front in good view of the stoker, to indicate the level of the water.

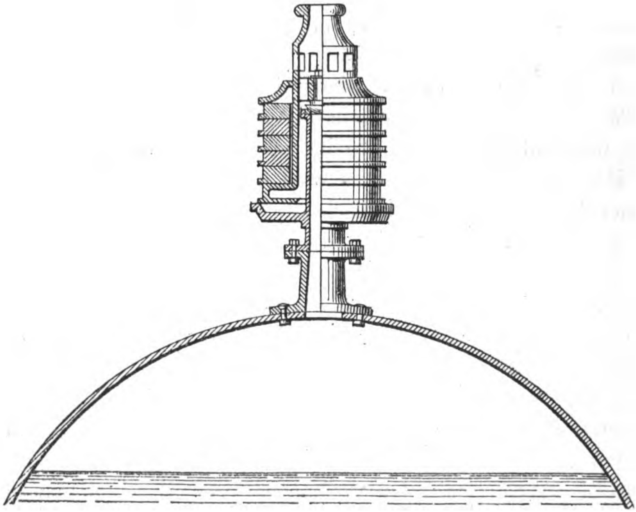


Fig. 36.—Dead-weight Safety-valve.

An ingenious arrangement to guard against explosion from lack of water is generally employed, consisting of a fusible plug made of an alloy with a melting point a little above boiling point, fixed in the crown of the furnace tubes at a point just below the lowest safe level at which the water can stand; so long as the water covers it the plug holds good, but should the water fall below, it immediately melts, and allows the water to flow into the flues and furnace, and thus damp out the fire. Its action, however, is not implicitly to be relied upon, and it is advisable to trust to the level of the water being maintained by a continual inspection of the gauge glasses by the attendant in charge.

An opening in the shell of the boiler, termed a manhole, secured by a special form of door when the boiler is under steam, will be required to allow of its inside condition being periodically examined.

To enable the best efficiency to be obtained from the working of a boiler, care must be exercised in the manner in which it is built on to its seating, and the top of the boiler will require to be covered with some non-heat-conducting substance, or by bricking.

In order to further increase the efficiency of colliery boilers it is now usual to heat the water which is to be fed into them by the waste gases escaping from the fuel used to fire them on their way to the chimney-stack, or by the exhaust steam from the colliery engines.

A well-known arrangement for carrying this out is that known as Green's Economiser, consisting of a series of vertical tubes 4 inches in diameter and 9 feet in length, placed in the main boiler flue between the boilers and chimney; the feed water is pumped into the lower part of the economiser, eventually passing out at the top-end, whilst the waste gases pass through the vertical tubes, and by this means the temperature of the water can be raised from 250 to 300 degrees Fahr.

A series of scrapers are kept slowly moving up and down the inside of the vertical tubes, to keep their sides free from soot, which, being a non-conductor of heat, would soon, if allowed to remain, depreciate the efficiency of the apparatus.

The amount of labour required to stoke a number of boilers is considerable, and several arrangements have been devised for lessening this labour by an arrangement of mechanical stokers; they generally take the form of some type of spring shovel, fixed on the fire-grate doors, worked by means of shafting and a small engine, and on to which the small coal is automatically fed from small "hoppers" above. Coupled with this arrangement, in some cases, moving fire-bars are employed, which gradually work the fire towards the back-end of the fire-grate, thus making room for the fresh fuel continually being fed on to the grate, and at the same time helping to keep the fire free from "clinker."

The fearful effects caused by boiler explosions, which were common occurrences in the early days of coal-mining, and even now occasionally arrest our attention, are now happily more rarely heard of.

The improvement which has taken place in the loss of life from this cause latterly is well seen from the following figures:—*

	Average number of explosions per annum.	Average number of persons killed per annum.
Ten years—1866 to 1875 . .	56·1	63·6
,, ,, 1886 to 1895 . .	31·7	18·5

This improvement is due in part to the better construction of boilers and the more rigid system of inspection now adopted at collieries.

Boiler explosions may arise from several causes: (*a*) defective or the sticking of a safety valve allowing of an excess of steam pressure being attained (as a precaution, it is, therefore, advisable to have two safety valves, and to have them regularly inspected and tested); (*b*) defective water supply,

* E. G. Hiller, "Trans. Inst. Min. Engineers," vol. XIII.

when the cause of an explosion is usually due to the carelessness of the attendant in charge, and should be prevented with ordinary caution; (*c*) incrustation, produced by salts contained in the water, as, for example, carbonate of lime, which, when heated, becomes deposited on the boiler-plates, will cause an explosion if allowed to accumulate by severing the plates from contact with the water, thus allowing them to become over-heated and weakened; (*d*) acid in the water, again, will cause corrosion of the plates, and cause an explosion by weakening of them. The addition of lime to the water will neutralise acid.

The high velocities which are now attained in shaft work, by means of which from 500 to 1,500 tons of coal are drawn from a single pit in a day of 10 hours, have been rendered possible only by the use of guides or conductors, which ensure smoothness of movement and prevent collisions. Mr. Curr, of Sheffield—already mentioned for his valuable innovations—introduced, at the end of the last century, wood conductors for guiding the corves, by aid of which he asserted that he could draw from 140 yards depth in half a minute. Yet for years he found but little response; they were applied at a few of the Midland pits, and about 1827, by the late Mr. Holwey, at Welton Hill, near Midsomer Norton. In the North, they began to make their way between 1835 and 1840, and are now universally employed as essential to economy, and to the safety of the men.

The conductors now in use are in some cases of wood (Memel pine), about 4 inches by 3, attached to *buntons* or cross pieces, fixed across the pit at intervals, and are commonly only two in number, one on each side of the cage, and costing, with labour, 10s. to 14s. per fathom. In others a pair of vertical iron rails; in some instances, lengths of angle-iron similarly attached to buntons are employed. In

Lancashire many pits have been fitted with a continuous round bar of iron, fixed at the pit bottom, and screwed up to the head-frame, the cross-bar of the cage having a ring at each end which runs upon the rods. The suspension of strong wire ropes, kept in place by heavy weights at the pit bottom, and giving a clearance of 20 to 24 inches between the cages, are now very usual.

Where this latter system is in operation, and the winding velocity great, it is necessary to suspend two extra guide ropes in the centre of the shaft in addition to those upon which the cage will run. These extra guides are termed rubbing-guides, and form an extra safeguard against the cages coming in contact with one another when passing in the shaft.

One of the important shaft-fittings, upon this method, is the cage, or chair, for the reception of the tubs or trams, which simply traverses up and down the pit. It is almost invariably constructed of malleable iron, and, since lightness is highly desirable, as small as possible for the weight it is destined to carry. For a single tub, a cage of 5 or 6 cwts. will suffice; for two, whether to be placed side by side, or one over the other (a two-decker), 9 to 10 cwts.

At Monkwearmouth, the 4-tub cages weigh as much as 24 cwts.; others no less than 3 tons, including their tackling-chains. Cages of combined strength and lightness have of late been advantageously made of steel.

The slide parts of the cage of thin wrought iron, which loosely fit to three sides of the wooden conductor, are applied both at the upper and lower bar of the framing, and are a little bell-mouthed upward and downward to allow them to slip more freely over inequalities. In order, also, to keep the tubs from shifting during their transit, a simply-contrived latch is always applied either on the floor of the cage or at the ends of a rod passing through its upper bar. And when the weight reaches the surface, duly signalled on its approach by a bell ringing in the engine-house, and by some visible mark attached to the rope, the cage is lifted with its floor a little above the plane of the bank at which it is intended to rest, and then allowed to

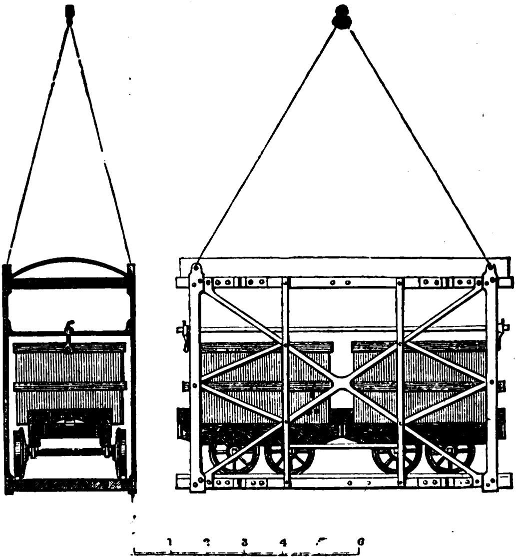


Fig. 37.—Single-deck Iron Cage, Newsham, for rolled iron guides.

drop on to the *keeps*. These latter are the heads of an arrangement of counterbalanced levers, which offer no obstacle to the ascent of the cage, but by a single movement of the hand, or automatically, are made to protrude and catch it in its descent. The moment that, at a lively pit mouth, the cage bottom touches the keeps, the landers have already got hold of the full tubs to pull them on to *terra firma*, or are forcing them out with the empty ones which they are pushing in to take their places. On the

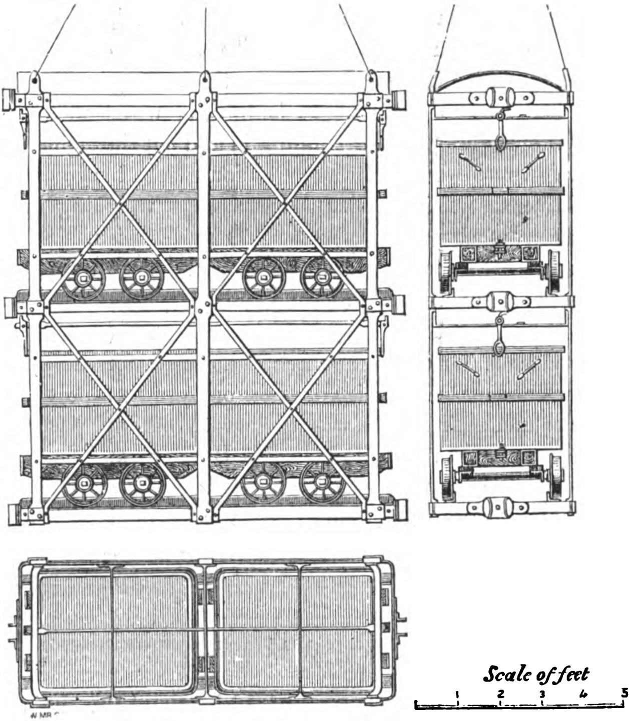


Fig. 38.—Steel Cage, North Seaton, with four tubs, in elevation and plan.

iron plates, with which the staging about the pit top is floored, the waggons are hauled off, up goes the cage with a jerk a few feet, and anon plunges down again into the gloom, whilst the men are rushing forward with the empty tubs prepared for the fellow-cage, which in a few seconds flies up by the other side of the pit.

When the cage is two-decked, or as sometimes in Belgium, has three or four compartments one above the other, the landing process has to be repeated at the same level, or, for the purpose of saving time, may be carried on at two different levels on the staging, whilst the loading is similarly performed at the bottom. It is in this way that a very neat system is adopted for running in and out the eight tubs which form the load of the great four-decked cage of the Grand Hornu Colliery, near Mons, a cage weighing itself with its protecting cover, about 2,692 lbs. English.

The single-link chains, and the round hempen ropes of former days, survive only at rude and petty works. Elsewhere they are succeeded by flat ropes of hemp (bands), by the ponderous flat chains of three links used for the slow drawing in the Staffordshire district, or by wire rope either flat or round. Iron wire was applied to mining purposes in the Hartz Mountains, and then in Hungary and Saxony, before it was tried in England, and its cheapness and lightness, as compared with hemp rope of equal strength, obtained for it a great, but by no means exclusive success. The desirable quality of lightness has been pushed still further by employing ropes of steel wire, but not at first to any great extent, although Mr. Tylden Wright informs me that his flat iron wire ropes, weighing 27 lbs. per fathom, have been replaced by flat steel of 16 lbs., and (in the upcast pit) by round steel rope of 13 lbs. to the fathom, the weight of coal in each case being 28 to 30 cwts.; and that the round ropes have been working for two years, whilst the flat iron and steel ropes seldom admit of more than 14 months' wear.

Steel-wire ropes are now very generally employed. The breaking strain of the best quality of steel rope will vary from 110 to 120 tons per square inch of section of wire used. The safe working load for a winding rope will, by careful viewers, be reckoned at one-tenth the breaking strain.

Charcoal-iron wire ropes will give a breaking strain of only 40 to 45 tons per square inch of section of wire used. In calculating the size of rope required to lift a certain weight from a given depth it must not be forgotten that the weight of the rope itself will require to be taken into account. To lessen the excessive weight of the rope itself at great depths, attempts have been made to manufacture taper ropes, diminishing in size at the lower end, but so far the success attained has been very limited.

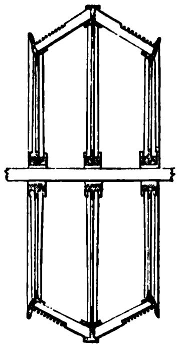


Fig. 39.—Conical Drum in section. Scale—1 inch to 10 feet.

The flat ropes have been largely employed, in consequence of their easing the engine by coiling one lap over the other, and thus forming a counterbalance as the cage ascends or descends, giving the fullest leverage to the engine at the time that the maximum weight is being lifted, *i.e.*, when the loaded cage starts from the bottom of the pit. But the greater wear and tear has given rise within the last few years to the introduction of round wire ropes, coiled, some upon cylindrical, others upon conical drums. In the instance just quoted the drum runs from 16 feet at the small end up to 20 feet diameter, and if due care be taken to wind the rope on at first very tightly, and to give such an inclination as shall guard the coils against slipping, these drums are found to work admirably. In several instances, with a maximum diameter of 24 to 30 feet, conical drums have been constructed with an iron channel or scroll for the reception of the rope.

In the deeper Belgian collieries flat ropes made of the aloe fibre (much employed for the same purposes in Mexico) are preferred. The disadvantage of this material would appear to be the great weight, since, with about 15 per cent. of tar, the ropes used at the Grand Hornu weigh from 12 to 19 lbs. per metre of 3·28 feet English. They are stated, however, to be extremely strong, trustworthy and

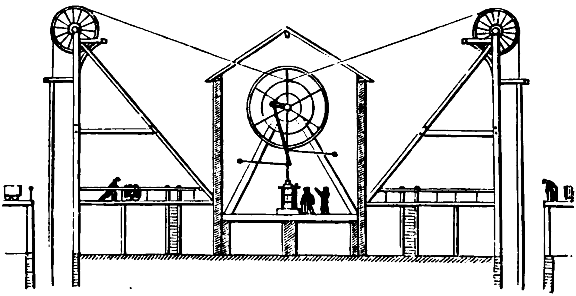


Fig. 40.—Drawing-engine, placed between two Pits. Scale—1 inch to 50 feet.

durable. As a further means of counterbalancing the great weight of rope to be lifted with the full cage, there is in most of the northern collieries a counterbalance chain attached to the drum-shaft, which passes in the reverse direction to the rope over a pulley, and has appended to the end of it a quantity of excessively heavy links of iron, which repose at the bottom of a pit, 30 or 40 yards deep, when not required to be in action. When, however, the descending rope begins to preponderate, they are gradually lifted into the air, and thus, when the full cage begins to be lifted, aid, with their great weight, the effort of the engine in accomplishing the heavier portion of its work. Another mode is a wire rope hanging down the pit and connected to the bottom of the two cages.

The pulley-frames or *head-stocks*, intended for the working of a single *band* down a pit, and thus often placed one on each side of the engine, as sometimes arranged in the Midland districts, are a comparatively simple framing in a triangular form, composed of two uprights and two back-legs, supporting a sheave or pulley of cast iron, 6 to 9 feet

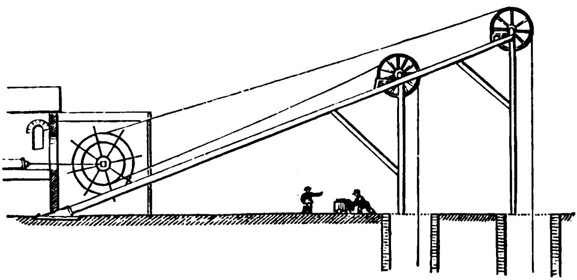


Fig. 41. – Engine on one side of a pair of Pits.
Scale—1 inch to 50 feet.

diameter, at the height of from 20 to 30 feet above the ground. When intended for rapid winding, these latter are generally replaced by pulleys of greater diameter, from 10 to as much as 20 feet, and having the spokes made of light wrought-iron rod and only the socket and rim of cast iron. When two bands are to be worked, the pair of pulleys are set upon a framing of greater breadth, which often has a general rectangular form, steadied by back-legs strutted either against the ground or against the engine-house. But the varieties in form are so numerous that it would carry us beyond our limits to do more than refer generally to them.

A noteworthy, but expensive, modification is that at Seaton Delaval, where the timber framing is replaced by beams of $\frac{3}{8}$ths inch wrought iron, riveted at the corners with angle-iron.

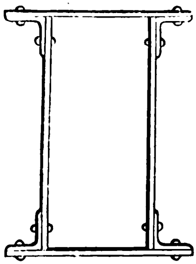
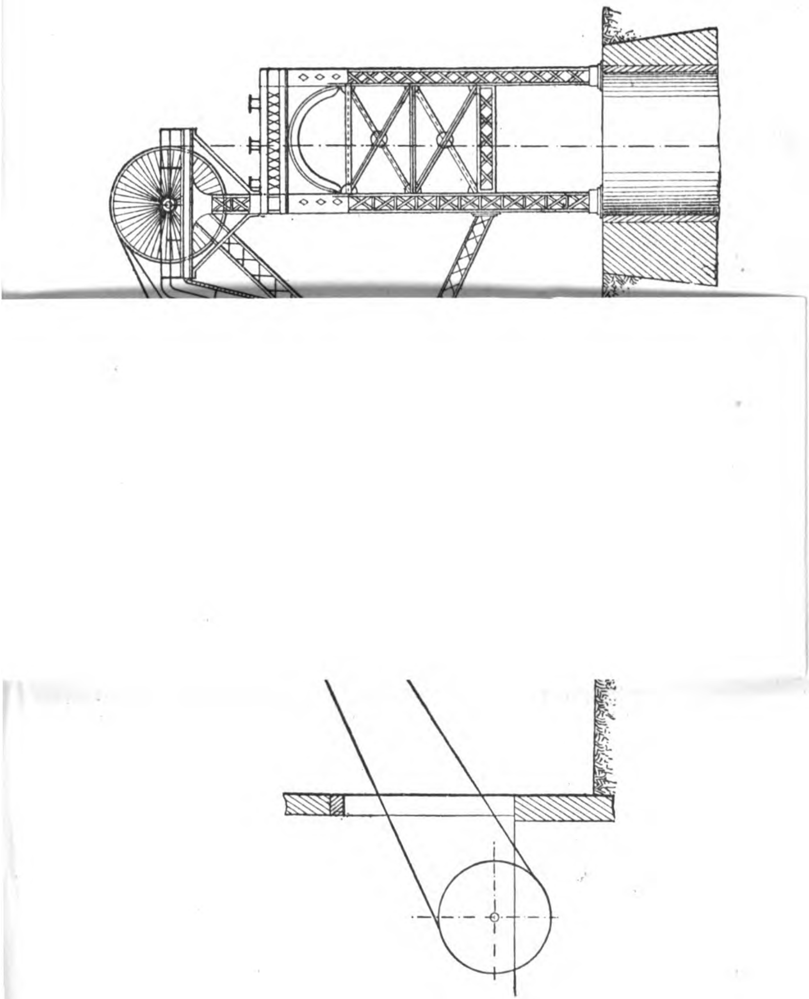


Fig. 42.—Plan of Iron Uprights.

Cast iron has been employed in Staffordshire for small frames, but it is not to be relied upon. Many patterns of iron frames have now been introduced, of which Fig. 43 will serve as an example.

With all the precautions taken to secure good engines, careful men, and trustworthy ropes, two kinds of accidents occasionally occur, which—as in this country the men are invariably lowered and raised by the same machinery—give rise to a peculiarly harrowing loss of life. One of these is the *overwinding*, which brings the cage violently up against the pulleys overhead, and thus breaks the rope. And, as with the large drums now in use, a single stroke of the engine raises the cage 60 or 70 feet, it will be seen how needful it is to have a careful engine-man, and machinery under perfect control. Overwinding is guarded against partly by having the pulley-frame high (from 30 to 60 feet), partly by the signals, which tell the man when to moderate his speed, and partly by efficient brakes; and of late steam brakes have often been added to the engines, which, in some cases, are self-acting, and come into play by admission of steam into a special cylinder as soon as the cage passes a certain point in the guides.*

* See also Chapter XX., p. 320.



The second class of accident is from the simple breakage of the rope, and whilst in most cases it is guarded against only by keeping in employ the best materials, and carefully overhauling the rope, it has been the subject of a number of inventions, to which the name of safety-cage (in French *parachute*), has been applied. As early as 1846 Mr. Fourdrinier had practically tested in North Staffordshire an ingenious arrangement by which, on the breakage of the rope, a wedge was, by the action of a spring, inserted between the wooden guide and a part of a cage, so as to bring the latter immediately to a standstill. In 1850 and 1851 I saw a number of them applied by sundry colliery viewers, who, two or three years later, had, after fair trial, unshipped them all, mainly for the reason that they were apt, in quick winding, when the rope surged or slacked, to come into play when not wanted, and thus to introduce a new source of delay and danger. In fact, to the present day, this same objection holds good, more or less, to all the varieties that have since been proposed; and, along with the common dislike of trusting to a spring for setting it in action, militates against their general adoption by the coal trade.

Two varieties, it is true, were shown at the Exhibition of 1862, which dispensed with springs—Paull's and one of Nyst's, of Belgium; but neither of them was thought satisfactory by the Jury.

The remainder of the safety-cages are chiefly divisible into those where two levers are made to thrust outwards against the conductors, and those where clutches embrace the two sides of the guide-rods. Of the former kind is that of Fontaine, which has been successfully applied in the great collieries of Anzin. Of the latter, we can only mention White and Grant's, largely employed in Scotland; Aytoun's, Nyst's (fitted to trapezoidal guides), Jordan's, which grips firmly without the use of sharp teeth; and Owen's, Fig. 45, which has been applied in many of the Lancashire pits, and has actually saved numerous lives.

The apparatus of Mr. Calow, of Derbyshire, Fig. 46, is noticeable for the ingenious manner in which he brings a single spring to bear on the clutches, not when the rope is merely slacked, so as to run out faster than usual, but only when the cage begins to descend at the velocity of falling. The spiral spring, held in a state of compression between a weighted cap above it and the part of the cage below it, from which the cap is separable, no sooner finds its foundation gone by the commencement of fall, than it flies into action, lifting its cap and pulling the levers which close the clutches.*

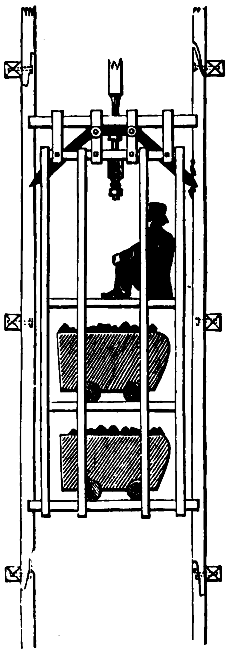


Fig. 44.—Fontaine's parachute as it appeared at the colliery of Boussu, when the flat wire rope broke with a weight of 2 tons.

The question of the advisability of employing any form of safety-clutch yet invented is by no means settled. Many of the most experienced colliery viewers, both at home and abroad, hold to the opinion that they substitute one danger for another; and that, what with the inconvenience

* Models of a great number of the safety-cages which have been in practical operation are open to inspection in the Museum of Practical Geology, Jermyn Street.

of their operating when not required, the danger of trusting to springs amidst the dust and wet and rust of a shaft, and the tendency to induce neglect of the proper condition of the rope, it is safer to trust to careful engine-men,

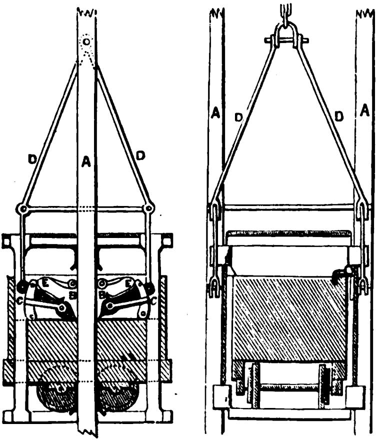


Fig. 45.—Owen's Safety Cage.

A, the conductor rods.
B C, the toothed levers connected by the rods D D with the rope.
B E, the spring which, if the rope breaks, forces down the upper end of the lever.

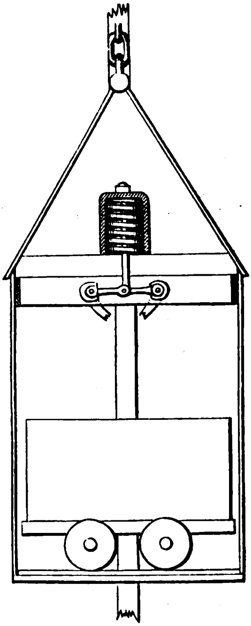


Fig. 46.
Calow's Safety Cage.

the best materials and caution in not running a rope too long, or omitting to have it frequently examined.

Many of the above inventions are coupled with an apparatus for disengaging the cage if overwound, and thus bringing it to a standstill against the guides; and these form, doubtless, a very useful adjunct.

A cover, or *bonnet* of sheet iron, is now very generally added to the cage to protect the men against falling materials; and with the addition of sliding gates at the shaft top, which are lifted when the cage comes up, but guard the brink of the pit when the cage is down, are safeguards against many of the accidents so rife in connection with shafts.

Those who are connected with metalliferous mines would like to see one of the pits of every coal-work fitted with a ladder-way, to give egress to the men is case of accident to the winding machinery; but though commonly employed on the Continent, ladders are quite unusual at our British collieries.

A safe and very economical mode of putting the men up and down the shafts is the Fahrkunst, or man-engine, a reciprocating rod or pair of rods, fitted with steps, by which the traveller is lifted from 8 to 14 feet at a stroke, and by which an entire pit's crew of 400 or 500 men may be conveyed in little more than an hour. In Belgium and Westphalia, as in our Cornish mines, they are in common use; and from a long experience, I can testify to their comfort and security; but in our coal districts a strong feeling in favour of the rope prevails, by which, although one party of men passes through the shaft more rapidly, the passage of the whole complement occupies the engine much longer; whilst the annals of colliery-working supply us with too many sad instances of the dangers which attach to this system.

CHAPTER XV.

DRAINAGE AND PUMPING.

IN no respect do collieries differ more from each other than in the quantities of water which they encounter, either in the winning or in the subsequent working of their mineral. In one case a retentive clay cover may prevent the access of surface water, which in another may pass in abundance through a sandy or a gravel alluvium. In certain districts, water-bearing measures of an almost fluid consistency must be passed through, whilst in others the comparative tight coal-measures may at once be entered. Frequently the strata above and below the coal are so compact as to render the workings actually too dusty and dry; but instances are common enough in which water makes its way through the roof stone, or through the coal itself, and adds difficulties and expense to the whole of the operations. In a former chapter we have seen that, by the process of *tubbing*, the water met with in the shaft may be so effectually excluded as even to admit of a mine being worked dry beneath heavy feeders; but it too often happens that, either from the conditions of the place being unfavourable to the process, or from its not having been attempted, a costly system of pumping has to be unremittingly maintained.

Up to the beginning of the present century there were many districts in which comparatively shallow collieries were drained by means of adit-levels, or *soughs*, often driven for a long distance from lower ground. But, in proportion as the superficial workings have been exhausted, it has become necessary to follow the seams to greater depths, and there are but a few hilly regions left, such as South Wales and Dean Forest, where some of the works still enjoy the advantage of free drainage.

Before the practical introduction of Newcomen's steam engine, the modes of removing the water from under-level excavations were by the application of horse-power or of water-wheels to an endless chain with buckets, to drawing pumps, to the rag-and-chain, or to winding of the water in barrels or ox-skins.

Agricola gives us, in 1550, an accurate description, with drawings, of many varieties of apparatus worked by tread-wheels, by horse-gins, or by water-wheels, of 15 to 30 feet diameter, which show that very little advance was made between the period of his observations and the commencement of the eighteenth century. Nay, it is clear that, until of late years, many of our mines still laboured under the same disadvantage as of old in their pump-work, viz., that it was supposed to be necessary to restrict the height of a lift of pumps to the 22 feet through which water can be raised by atmospheric pressure. The several contrivances above mentioned answered their purpose as long as the pits were very shallow, but their difficulties increased rapidly with depth (a condition of mining work often overlooked by inventors), repairs were constantly needed, and "when a joint-pin gave way, the whole set of chains and buckets fell to the bottom with a most tremendous crash, and every bucket was splintered to pieces." A singular pumping machine, recalling this old apparatus, was still, in 1857, to be seen at the little colliery of Coal Barton, near

Frome, where 50 fathoms lengths of 8-inch pumps were worked by a fall of water passing 26 yards down a pit, and utilised upon a chain with buckets of sheet iron lapping over wheels above and below.

When pumps were employed, of which the one raised water, about 30 feet only, to the next lift above, the moving parts had to be so multiplied that things were unnecessarily crowded in the shaft; first cost and subsequent maintenance were needlessly heavy, and all the difficulties were greatly augmented with the increase in the volume of water to be lifted.

These common drawing or "suction" pumps had to be converted into the more useful drawing or bucket lifts of mines, by the simple expedient of increasing the height of the collar above the piston, or, in other words, making the bucket-rod work inside a column of pumps, or trees (as they are often termed, from being originally of wood), and lift the water above it. Applied in this manner, the length of the lift becomes only a question of strength of materials, and it is commonly extended to 50, 60, or 80 yards.

The woodcut, Fig. 47, will show, in section, the bucket in its *working-barrel*, the rod extending upward with the column, or trees; below it, is the *clack*, or valve-piece, resting in its seat, and capable of being removed either through the *clack-door*, or sometimes, in case of accident, by being fished up with the hook passed down through the column on removal of the bucket-rod. The lowermost portion is the so-called *wind-bore*, or *snore-piece*, where the holes in the bottom, covered by the water of the cistern or the sump, are of such size as to prevent the entry of chips or stone. The joints of the various lengths, and that between the door and the clack-door piece, are made tight by the intervention of a thin layer of some soft material, as tarred

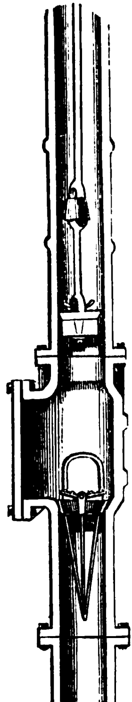


Fig. 47.—Bucket, or Drawing Lift.

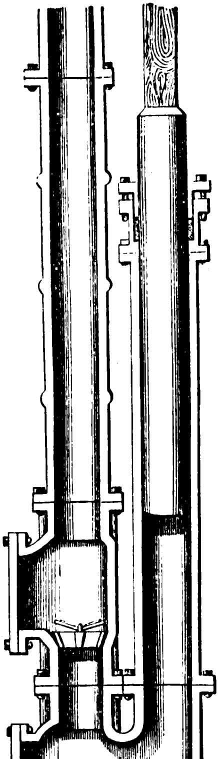


Fig. 48.—Plunger Lift.

flannel, caoutchouc, etc., and screw bolts and nuts. The action of this pump is easy to follow: at every up-stroke of the rod the water will rise through the clack, and the column of it standing above the bucket will be so raised as to deliver, at the top of the lift, a quantity measurable by the diameter of the working barrel and length of the stroke. Should the pumps be going "in fork," or the water have receded below some of the holes of the wind-bore, the ebullition of the water will show that air is being drawn, and that the full quantum of water is not being raised.

A few specialities of the bucket-lift may be noticed. When the water is saline, or acidulous, and corrodes the iron, the working barrel, ordinarily of cast iron newly bored, is sometimes made of brass or gun-metal (as, indeed, it very often was in earlier days); or, as in some of the copper mines in Cornwall, the whole of the pump-work may need to be lined with staves of wood, carefully fitted like an internal cask, to prevent the rapid destruction which otherwise ensues. During the sinking of pits, and where sand finds its way to the sump, the leather with which the bucket is covered is rapidly cut to pieces, and the water ceasing to be properly lifted, the bucket has to be changed. In very bad cases this may take place, not merely several times a week, but even every few hours, and the time and cost expended in the operation are very serious. Metallic and gutta-percha packing have been largely tried, but without establishing a general superiority.

The clack is much more slowly worn, but it is, nevertheless, often a subject of trouble if the water be quick and rises above the clack-door before the change be made. When in such case it refuses to act, and sticks fast in its seat, it must either be drawn out by main force or a second clack may be dropped upon it, and the water thus lowered. In recent instances very important services have been rendered by professional divers, employed to put to rights a lost lift. At Messrs. Fletcher's Clifton Pits, Workington, and in South Wales, the work has been thus satisfactorily done by the aid of the diving apparatus under 30 or 40 feet of water.

To return to the action of the pumps. At every up-stroke it will be seen that the engine has to raise the rods, or *spears*, and their connections, as well as the entire column of water contained in the lifts; and in order to obviate the enormous strain thus occasioned, it was early found desirable in the deep mines of Cornwall to substitute for the buckets a forcing arrangement in all but the bottom lift. This was perfected by Captain Lean in 1801 (the plunger had, however, been at work in the United Mines several years before this date, erected probably by Murdoch) by the introduction of the *plunger-pole* or *ram*, working through a stuffing-box into a plunger case of bored cast iron, and forcing at every down-stroke the water upwards through an upper clack, and the clear column of pipes above it. The working of this method will be evident from the sectional woodcut Fig. 48.

The great advantage hence derived over and above the much smaller degree of wear and tear is that the engine has simply at each stroke to lift the rods and plunger-poles. These, then, in the down-stroke, by their own weight, descend and force the water before them. And inasmuch as the weight of the rods is far more than sufficient in a deep mine for this purpose, they are in part counterbalanced by beams (balance-bobs), placed some at surface and some at intervals in the shaft, each laden with 15 to 20 tons of old iron.

Thus, in the mine Tresavean, at a shaft 348 fathoms deep from surface, the 86-inch cylinder engine raised a weight of rods, plungers, and sets-off, for nine lifts, of 67 tons 3 cwts. The main beam, with its gudgeons, connections, etc., 50 tons; four balance-bobs, 60 tons; the four loaded balance-boxes, 80 tons; or altogether, besides the weight of water in the drawing lifts, about 260 tons, to be set in motion at every stroke of the engine.

The arrangement in Cornwall is universally the same. From the end of the main beam, projecting over the engine shaft, a single rod passes all the way down to the bottom or bucket-lift. Employed in its maximum strength at the surface, where it has the full weight to sustain, it is then tapered or diminished downward, according to the diminution of the strain by which it is affected. Thus, in a deep mine, a main rod of 290 fathoms long is made for the first 120 fathoms of two 12-inch square Riga balk, and afterwards one of 15-inch balk, decreasing to 14-inch and 12-inch. At the requisite intervals the plunger-poles are attached to it by *sets-off*, bound to it by strong staples of iron. The several lengths of rod, generally from 40 to 70 feet in length, are connected by the aid of strapping plates of hammered iron, from 9 to 12 feet long, on opposite sides of the rod, bolted through it with screw bolts. At moderate distances apart, stays are placed across the shaft, which guide the motion of the rod, and iron rollers are added where it deviates from the perpendicular. At intervals, too, very strong beams are fixed in the shaft as *catches*, to prevent the fall of the rods downwards, as well as *indoor catches* to prevent damage to the engine in case of the rod breaking at a shallow point, and thus being suddenly relieved of its great weight. In this manner the gigantic pumps employed in some of the mines are worked with such perfect ease and smoothness of action that you may stand near them in the shaft and not be aware, except by seeing, that they are in motion.

I have thus dwelt especially on the Cornish methods because the necessity for economy and the competition between the engineers in that district have brought the pit work to a higher degree of perfection than is to be seen elsewhere. When tested by the work done for a given sum of money, it contrasts remarkably with the rattle and concussion, the heavy cross-heads, and the greater complication of rods that are often noticeable in other mining regions, even though the excellent invention of the plunger may have been adopted.

We have now to examine into the mode of applying the power which is to keep the pumps in action. I may omit to describe the means of setting water-power to work pumps of the above description, for, although often employed with advantage for metalliferous mines, it seldom comes into play in collieries. Both in the commencement of operations at a difficult sinking and afterwards as a permanency at small or lightly-watered pits, the double-acting rotary engine is commonly used. If the water is to be drawn at times when coal is not to be raised, the usual ropes or chains have attached to them water barrels, *cowls*, or *ringes*, which will carry from 10 cwts. to a ton of water, and are emptied on reaching the surface by means of a self-acting valve placed in their bottom, or by being capsized by the lander. When pumps are to be worked it is usually by sweep-rods passing from the crank on the main shaft to quadrants or bell-cranks at the shaft mouth. Engines of this class, whether worked by high or low pressure steam, are suitable enough for temporary or auxiliary purposes, but must be superseded in deep or heavily-watered mines by special pumping engines.

In some few instances the combination of drawing and pumping may be seen on a large scale, as in Fig. 49, representing an engine of 65-inch cylinder and 7-feet stroke, Cambois, Northumberland, which though ultimately intended for drawing alone, was, in 1865, during the sinking of the shaft, working the pump-rod by the intervention of,

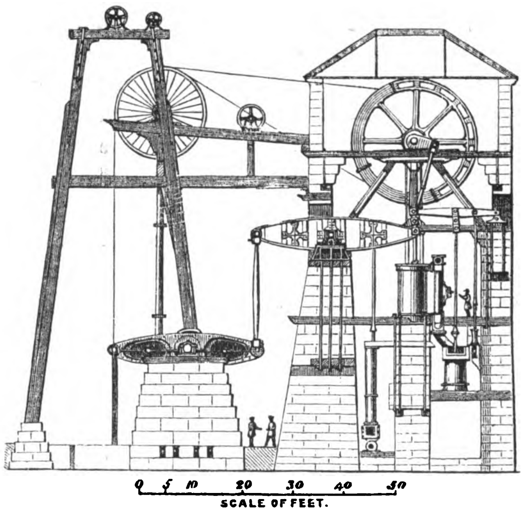


Fig. 49.—Engine and Apparatus for Winding and Pumping, Cambois, Northumberland.

first, a built wrought-iron beam, and, secondly, a beam of cast metal.

The engines intended for serious pumping form a subject of the highest importance in mining, and as the value of the best kinds is still but imperfectly understood, it is desirable to take an accurate view of the results which have been obtained from them.

We have already, in Chapter I., followed the improvements of the steam engine with reference to the employment of coal as a motive power, and have seen that Newcomen's atmospheric engine (of which a very few specimens are still left) was succeeded, soon after Watt's patent of 1769 for the separate condenser, by various improved forms. The comparison between different constructions which then became needful was made by calculating the *duty*, or number of pounds of water raised 1 foot high by a bushel of coal. When Smeaton commenced his modification of the atmospheric engine the average duty about Newcastle was 5,590,000 lbs.; in 1772 he erected one at Wheal Busy, which attained 9,450,000. The same great engineer acknowledged that Watt's engines, which came out between 1776 and 1779, would perform double the duty of his own, and some of them were tested to do nearly 19,000,000. The average, however, of Watt's engine in Cornwall gave a duty of 17,000,000, and when 20,000,000 had been attained in the engine at Herland that shrewd philosopher pronounced the work perfect and stated that further improvement could not be expected. Left, however, to themselves, by the expiration of Watt's patents, and the withdrawal of his agents from the county, the Cornishmen, after a few years, organised, in 1811, a system of monthly reporting the engines, with their conditions of work, and the duty accomplished.

Within a space of some 25 years marvellous results were produced by the emulation thus aroused among mine captains in the arrangement of their pit work, and among engineers in the devising of improvements in boiler and engines.

As some of the modifications to be specially cited are, first, Trevithick's tubular boiler, for generating high-pressure steam where the fire is applied at the large end of the tube, and the heated air made to pass through it, then beneath the boiler or outer tube, and afterwards along its side; secondly, the expansion in the cylinder of the high-pressure steam by closing the inlet valve at ½, ⅓, ¼, or even ⅙ of the stroke, whereby from 41 to 60 per cent. of the fuel is saved; and thirdly, the addition of a steam jacket or outer case to the cylinder, so protected by a brick wall, casing of sawdust, or other clothing, that the internal space is occupied by steam of a temperature but little below that in the cylinder.

From an average duty of 17,000,000 performed in Watt's time, the reports published by Lean show an amount of 28,000,000 attained in 1823, and of no less than 60,000,000 in 1843, whilst the best engine then tested had actually given an average duty of above 96,000,000. The most remarkable case on record is that of Austen's engine, of 80 inches diameter, erected by Mr. William West, at Fowey Consols Mines, and which on being reported in 1834 to give a duty of nearly 98,000,000 was the occasion of a certain investigation and of a practical experiment, conducted by other engineers and mine agents, formed into a committee. (Similar experiments by a committee had shown, in December, 1827, that Woolf's engine, at the Consolidated Mines, gave 63,663,473 lbs. duty, and Grose's engine, at Wheal Towan, St. Agnes, in 1828, 87,209,662 lbs.) The shaft was at that time 131 fathoms below the efflux point of the water, the lifts of 15 inches diameter for the three upper, and 10½ inches for the two lower ones, the length of stroke 9 feet 3 inches, the pressure at the boiler 36½ to 45 lbs. per square inch. The astonishing result was, a declared duty for the 24 hours of experiment of 125,000,000.

On taking the average duty all through the year at 91,672,210, we find that, as burnt in this way, 1 ton of coal will do the work of 5 tons in Watt's engines, and will raise for 100 fathoms in height as much as 367,000 gallons, or 1,638 tons of water; whence, taking coal in Cornwall at an average price of 15s. per ton, the fuel costs one farthing to raise 2¼ tons of water 100 fathoms. The coal consumed for the long single-tube boilers of the Cornish engine is Welsh, shipped from Llanelly and Swansea, mostly small, and weighing 94 lbs. to the bushel. The combustion is very slow, but so perfectly effected that a few years ago scarcely a puff of smoke was to be seen between one end of the county and the other. Of late, it is true that a black pennant is occasionally visible, and the blame is laid upon inferior coals. But at the same time it is observable that a very small number of the engines are reported, and the average duty has deteriorated; and thus, whilst the shareholders grudged the guinea or two per month for engineer's or reporter's fee, they pay heavily in increased coal bills.

Among the most experienced of our mine engineers in Cornwall may be mentioned Captain Grose, Messrs. Harvey & Co., of Hayle, Messrs. Hocking and Loam, and Mr. West, of St. Blazey. Engines on a similar construction have been built elsewhere, at Messrs. Fairbairn's and many other works, both at home and abroad. But there has been wanting a fair system of reporting the results obtained; and when we see the great strides which accompanied the recording and publishing of the details in our western counties, it appears most desirable that such reports should become more general, and should include coal districts in which we too often have to witness miserable exhibitions of neglect, extravagant use of fuel, and great wear and tear of materials. To compare a bad case with a good one, I have watched a large pumping engine in the North, which raises water from 105 fathoms deep, in 12-inch lifts, at 7½ strokes per minute, with a consumption of 20 to 25 tons of slack *per day.* A similar amount of work is done by an average Cornish engine, with from 2 to 2½ tons. The coal is, doubtless, in the former instance inferior, but the result shows that there *are* engines in the country consuming upwards of 10 times the quantity of coal that is needed for the work accomplished.

At the beginning of the century it was proposed, by Bull, to omit the heavy beam, or *bob*, which constitutes a great part of the dead weight of the common pumping engine, to place the cylinder over the shaft, and connect the piston-rod, working through the bottom, directly with the main rod of the pump. The Bull engines have been erected at many mines, but have failed to compete with the others. Of late years several have been established at collieries in this country and abroad, but their effective performance is doubtful. Another modification is just now in fashion in the coal districts, although condemned, after long experience, in Cornwall, viz., that of inverting the cylinder and placing the beam below it; but the piston-rod can hardly upon this system be so well lubricated, nor the stuffing-box kept in equally good condition, and the asserted saving in the building of the engine-house seems at best to be a very questionable piece of economy.

The fearful loss of life occasioned by the fracture of the main beam at the Hartley Colliery has been the cause of further attention paid to that part of the engine, and several methods of substituting wrought for cast iron have been applied. At Clay Cross, the beam of the new 84-inch engine is formed of two slabs of rolled iron, 36 feet long, 7 feet deep in the centre, and 2 inches thick, the two braced by strong cast-iron distance-pieces bolted between them, the whole beam weighing 32 tons.

At North Seaton and Cambois, near Newcastle, and at East Caradon and other mines in the west, beams have been variously built of boiler-plate and angle-iron; but it yet remains to be seen what mode of construction will best ensure that rigidity which cast iron, with all its faults, must be acknowledged in a high degree to possess.

The heavy first cost and amount of shaft room required by the Cornish engine has led to a large number of pumps being devised with the double object of overcoming these objections and also securing greater economy.

Modern mine-pumping machinery may be divided into two distinct classes. That in which the pumping machinery is placed on the surface, as in the Cornish engine, and that in which it is placed in the mine, the motive power conveyed down to it and the water forced up to the surface through pipes.

The advantage of the former type lies in its being possible to place the machinery near the boilers and thus economise the consumption of steam, while, in case of accident, the risk of having the pumping engine drowned out is obviated, added to which the machinery is usually more accessible for repairs; whilst in the second type of pump less room in the shaft is required, the heavy pump-rods are dispensed with, and the foundations necessary are usually less. They can also be constructed to deliver water at both ends of the plungers or rams, or, in other words, be made double-acting, and a smaller pump would be required to pump the same quantity of water than if the former type of pump were employed. Now that improvement in material and type of valves employed enables water to be forced against great heads in one lift or column, this second method of arranging pumping machinery is gaining rapidly in favour.

In the Hathorn-Davey differential pumping engine, which comes under the first type of pump, the heavy pumping beam of the Cornish engine has to a great extent been eliminated, the pump-rods or spears being worked off wrought-iron quadrants. It is a horizontal condensing engine, worked expansively, and does not require expensive foundation. Good results have been obtained from it in practice. Its especial feature is its differential valve and trip gear, which is thus described by Mr. Pamely in his "Colliery Manager's Handbook": "Steam is admitted to the engine in proportion to the resistance to be overcome, and in case of a sudden total loss of load, reverses the steam to catch the piston. The distribution of the steam is affected by coupling the motion of the engine with that of a subsidiary piston, whose velocity is made uniform by its cataract. The engine is made to cut off steam by its motion, while the uniformly-moving subsidiary piston is employed in admitting it. As long as the resistance of the engine is sufficient to prevent its motion from becoming equal to that of the subsidiary piston, steam is admitted up to the fixed point of cut-off, but should a loss of resistance or an increased pressure of steam cause the main engine to acquire a speed relatively greater than the subsidiary piston, the motion of the valve gear is reversed earlier, and the supply of steam is adjusted to the altered condition. In the event of sudden loss of load, the action of the valve is reversed, and the steam thrown against the piston, stopping it before the end of the stroke."

A very varied and large number of direct-acting force pumps are now made; amongst which are the Cameron, Worthington, Riedler, the chief feature of the second of which is a device (of oscillating cylinders on the piston-rod, actuated by compressed air, steam or water) to prevent shocks, and so arranged that at the commencement of the stroke of the main engine, when the steam pressure is at its highest, the action of the oscillating cylinders is opposed to the main engine; as the stroke proceeds, the position of the subsidiary cylinders become reversed, so that after the main engine reaches the centre of its stroke their action helps the engine, their greatest power being exerted at the end of the stroke, when the steam pressure in the main cylinder is at its lowest.

The peculiar feature of the Riedler pump is the type of water-valve employed, designed to give the maximum capacity of out-let with the least friction, and mechanically regulated to shut suddenly, preventing leakage and enabling higher piston speeds to be employed. The results obtained in practice with this pump are stated to be very satisfactory.

An ingenious method of pumping is that of Moore's, in which water is used as the motive power. The water is compressed by steam power at bank to a considerable pressure, and conveyed, through two columns of pipes of small diameter, constructed to resist great pressures, to the underground pump, where it actuates pistons to which the water-rams are attached. The water in these pipes is never changed, either pipe connecting an end of the pump on the surface to an end of the power cylinder underground.

The action of the pump underground follows that of the pump on the surface, the water in the pipes acting as "water-rods," alternately ascending and descending. This type of pump has acquired considerable favour in Scotland and elsewhere.

Electricity is now very generally employed to actuate underground pumping engines, and where no risk of fire-damp is to be feared is an economical and convenient means of transmitting power for these purposes.

The electric current is conveyed from a dynamo at bank to a motor underground, from which direct-acting pumps are driven, either by spur or belt gearing.

CHAPTER XVI.

LIGHTING OF THE WORKINGS.

THE collier, in descending to his work, seldom needs to carry a light through the shaft. A few seconds when the machinery is good, or minutes when it lacks power, are sufficient to land him at the bottom, either in the dense gloom of a pit-eye, rendered barely visible by a candle, or a safety-lamp, or, according to the circumstances of the colliery, in a busy scene of activity, well lighted by oil lamps, gas, or electric light. Here, or at some station not far in-bye, he will light up, and after a little delay, in order to accustom the eye to the darkness, proceed on his inward way.

The lamps of the well-known classical form, of which the Romans have left us numerous examples in bronze and *terra-cotta*, survive in many of our modern underground workings, but especially in the metal mines of the Continent. In the collieries more generally their form has been changed to one with a globular, cylindrical, or conical oil-holder, and with a much smaller wick than would be used in the Roman lamp. The Scotch, and some of the Saxons, employ a little metal oil-lamp with a hook on one side, by which it may be attached to their cap when travelling in low places on hands and feet, or when climbing ladders. In pits about

Mons, in Belgium, an oblate form is preferred, resting upon a strong iron spike, by which it may be fixed into wood, or into the coal itself at the required point of work. Lamps of this kind may be constructed to give a very tolerable light with vegetable oils, at the cost of from three farthings to one penny for 8 hours. Lamps for burning petroleum and paraffin oil have also been devised, and a splendid light has been obtained, but coupled, in the examples which I have tested, with a disagreeable odour very objectionable in narrow excavations.

Our English colliers (as also some of those in Saxony, etc.), have more commonly been lighted at their work by tallow candles, which, for ordinary work, are from 20 to 25 to the pound, but for fiery collieries, used to be so thin as to weigh 30 and even 40 to the pound. The candle is either fixed in a holder, with a spike at the end, or is attached by soft clay to the place whence it best throws a light on the work; if it be used in a draught of air, a shield of wood is placed behind it to prevent its "swealing." Before the successful introduction of the safety-lamp, it was the regular practice to test the presence of fire-damp in the working stalls and in the wastes by the appearances of the flame of a candle; and skilful, steady-handed pitmen acquired such a readiness in thus trying the gas that they would sometimes almost play with it when standing within a hair's-breadth of destruction. The slim candle is for this purpose neatly trimmed, and then held out, shaded by one hand, so that the top of the flame can be more clearly watched. On being advanced gradually upward in a place where fire-damp is lodged, the flame is seen to elongate, and to assume a blue colour, more or less pure, according to the nature of the gases present; sometimes, indeed, if the carburetted hydrogen be much mingled with carbonic acid, nitrogen, etc., the "cap" of the flame will exhibit a grey or brown tint; and such variations will be frequent in the mingled impurities of the "return" air-courses. As some varieties of fiery gas are "quick" in comparison with others, it needs a cool head and unswerving hand to lower the candle again with requisite stillness, when once it had shown too dangerous a cap. It seldom happens that the candle is now used for this purpose, unless to test the presence of the enemy in places capable of storing only a small quantity.

Towards the end of the last century, when it was attempted more and more to work in places infested with fire-damp, various substitutes for the old method of lighting were tried. The reflection of the sun's rays from a mirror was capable of throwing a sufficient light forward for some little distance from the shaft for the accomplishment of certain work about the pit-eye, but was inadequate to penetrate far into the workings. A premium attached to those men who could work best in the dark, for driving some dangerous place into which no candle could be taken. The steel-mill was then invented by Spedding, of Whitehaven, and acquired a considerable popularity. In this instrument a disc, with periphery of steel, is made to rotate rapidly by means of cog-wheels and a handle, whilst a sharp flint is held against the steel edge and a succession of sparks is given off, which yield a feeble, irregular radiance. One person had to turn a mill, whilst another plied the pick; and yet, in spite of its costliness, its miserable glimmer of a light, and its having distinctly caused several explosions, no other means of illumination could be employed; and it made so many friends that even in 1822 it is described by a pitman as "an excellent instrument to travel dead waste with, because, when in the hands of a judge, it discovers, by its various shades of light, where gas is, and where it is not."*

The occurrence of very serious explosions in the county of Durham in the year 1812 led to the establishment of a Society for the Prevention of Accidents in Coal Mines, at whose meetings in Sunderland, in 1813, Dr. Clanny, of Newcastle, exhibited his first lamp, intended to give light in an explosive atmosphere, and of which a description was published in the "Philosophical Transactions."

In October and November, 1815, his lamp was tried in a fiery pit, whilst that of Sir Humphrey Davy is stated to have been first tested in practice only on the 1st January, 1816. But although thus early in the field, Dr. Clanny afterwards judiciously modified his lamp by applying to a part of it the invention of Davy.

This great philosopher first visited some of the collieries in 1815, and after an elaborate series of investigations, during that year and 1816 perfected a lamp which was to be so great a boon to the mining community. It would be out of place here to refer at length to the successive steps of the inquiry which established the fact that flame cannot be passed except under pressure, through a wire gauze containing 600, 700, or 800 holes to the square inch, and that hence the explosive mixture might ignite inside a gauze cylinder without communicating the flame to the gas outside it. The standard which was fixed on as the safe limit was a gauze with 28 iron wires to the linear inch, or 784 apertures to the square inch. A lamp of $1\frac{1}{2}$ to $1\frac{5}{8}$ inches diameter was at once found to be safe in the most inflammable air of the pits so long as attention was paid to the caution, which he inculcated, that it must not be exposed to a rapid current, or allowed to become red-hot from the

* "The Pitman's Infallible Guide." Newcastle, 1822.

combustion of the gas within it. Mr. Buddle showed that it thus became unsafe if exposed to a current of more than 3 or 4 feet per second, and Dr. Pereira proved that flame could be passed through the gauze if the lamp was subjected to a sudden jerk. It is hence manifest, that, as stated by Davy himself, this is an instrument of security only within limited conditions, and that it should be guarded by a complete shield when exposed to a rapid current of explosive air. Anxious attention has been re-directed to this source of risk, and numerous modified lamps have been brought forward in consequence.

In the long series of years that have elapsed since the first safety-lamps were sent down to the Northern coalfields, a very small number of accidents has been traced to the lamp itself, and many of the alleged cases are doubtful. Its thorough efficacy has been daily tested, not only where it is employed for inspecting the working places the first thing in the morning or for travelling places of known risk, but in many instances for the working of a large portion of, or even the entire area, of a pit. And, indeed, it is like an effect of magic to pass, with the safety-lamp in hand, into a fiery stall or along the edge of a goaf, and to walk unscathed in the midst of an explosive compound, whose deadly power would dash you to pieces if there were but a wire awry in the gauze. Abundance of warning is given by it; and as the quantity of gas increases, the flame, at first elongated by a blue cap, flashes into an explosion within the lamp, more or less fierce, according to the mixed nature of the air. When the carburetted hydrogen is mixed with common air in the ratios of from 1 to 6 parts to 1 to 12 parts it is highly explosive; while below and above that proportion it burns quietly. But if the fire-damp burn in it until the gauze becomes red-hot it is time to withdraw the lamp steadily from the place, or to extinguish it, either by dipping it gently into water or by drawing down the wick with the "pricker" and suffocating the gas flame.

A chief objection to the Davy lamp consists in its small amount of light, which leads the colliers, who are paid by the quantity of coal which they cut, to substitute, when they imagine they are safe, the open light of a candle, or of the lamp with the gauze removed. So many serious accidents have arisen from this cause that a vast number of modifications of the original lamp have been brought forward, some for the purpose of obtaining a fuller light, others with the object of so locking the gauze to the lamp that the colliers shall be unable to take them asunder, or shall only do so with the certainty of putting out their light, or of being detected.

It would occupy too much space to describe the various contrivances which have been proposed for these purposes, but it is essential to notice a few of the safety-lamps which have come into extensive use.

1. The ordinary Davy lamp, as most commonly employed in this country, A, Fig. 50. The cylinder of iron wire gauze is fixed to a brass ring, which screws on to the oil-vessel. Its upper portion is double in order to guard against the effect of the heated gases passing off from combustion. It is guarded externally by three strong wires or rods attached at the top to a metal roof, above which the loop is placed for carrying or suspending the lamp. A thin wire for trimming the wick passes up through a close-fitting tube from the bottom of the oil-vessel. It is commonly locked by a bolt, turned by a simple key, till its head is sunk even with, or below, the surface of the metal where it is inserted. A part of the circumference is sometimes protected by a curved shade of tin or horn, made to slide upon the pro-

tecting bars. The usual cost is 6s. 6d. to 7s. 6d., and the weight about 1 lb. 6 ozs.

2. Clanny's lamp. The lower part of the gauze is replaced by a cylinder of thick glass, well protected by vertical bars. The feed air has to enter the lamp through the gauze above the glass; hence, what with the imperfect combustion, and the thickness of the glass, the light given off is not much greater than that of the common Davy, whilst the weight is double; and the risk alleged to attend the use of the glass has added to the objections made to its common employment.

3. Lamp by Dubrulle, of Lille. This is a Davy, provided with a locking-bolt, so connected with an arm which lays hold of the wick that if the oil-vessel be unscrewed from the gauze cylinder the effect is to draw down the wick and extinguish the light. This and other analogous contrivances would be efficacious if the men could be prevented from taking with them lucifer matches; but as long as it is in their power to strike a light at will the only real detection which has been applied seems to be a Belgian method of locking with a pin of lead, which, when put in its place by the lamp trimmer, has a device punched upon it. The lamp cannot then be opened without breaking the pin.

4. Stephenson's lamp, B, Fig. 50. The "Geordie," as it is called, after its inventor, George Stephenson, the engineer, is made of rather larger diameter than the Davy, but has the additional safeguard of a glass cylinder, surmounted by a cap of perforated copper within the wire gauze. The feed air enters by a series of small orifices below the cylinders, and in order that the light may burn well it is important to hold the lamp, or suspend it, when at work, in a perpendicular position, and to guard against these small feed-holes being clogged with oil and coal-dust. The glass is a pre-

servative to the wire gauze, and even should it be broken leaves the lamp a "Davy." It has been thought safe in a still atmosphere, since when the air becomes highly explosive the light goes out. A good many of these lamps are

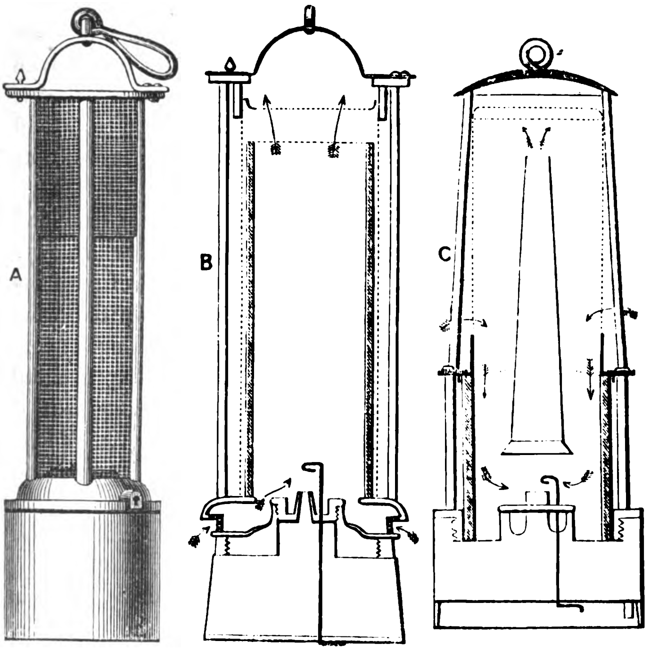


Fig. 50.—Safety-lamps. Scale—One-third true size.

A, Davy's, in elevation. B, Stephenson's, in section. C, Mueseler's.

In the sections the dotted lines are wire gauze, the parts shaded with oblique lines are glass, the strong black lines sheet metal. The arrows represent the direction of the air-currents.

employed in certain British collieries, and when carefully treated and watched give good results, which compensate for the extra weight and cost as compared with the Davy.

5. Boty's lamp, D, Fig. 51. A Royal Commission appointed in Belgium, to take into consideration the means of lighting fiery collieries, recommended, in addition to the simple Davy, this and the three following. In Boty's a good light

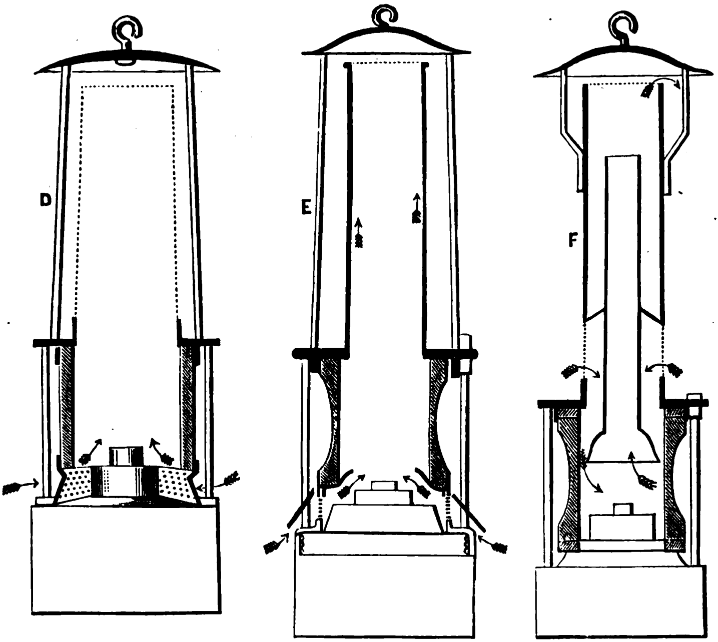


Fig. 51.—Safety-lamps. Scale—One-third true size.

D, Boty's. E, Eloin's. F, Eloin's Mueseler.

The dotted lines are wire gauze, the parts shaded with oblique lines are glass, the strong black lines sheet metal.

is given through a short glass cylinder, surmounted by a wire-gauze chimney, the feed air being admitted through a series of minute perforations a little below the level of the flame. The same precautions must be taken with regard to these minute orifices as in the Stephenson. I have seen these lamps in use near Charleroi, where the agents expressed themselves well satisfied of their security if the cylinder be made of properly annealed glass.

6. Mueseler's lamp, C, Fig. 50. This consists also of a glass cylinder below and wire gauze above; but by the insertion of a central metal chimney, opening a short distance above the flame, so strong an upward draught is produced by the heated gases that the feed air is drawn briskly down from the wire gauze, and passes by the inside of the glass to the wick, thus keeping the glass cool and ensuring a superior combustion. Upwards of 20,000 of these lamps are said to be in daily use in Belgium, and I am assured by M. De Vaux, engineer-in-chief, that no accident has been traceable to their failure, although they have now been introduced for many years. These facts refer to the early introduction of the Mueseler in England, about 1860. The glass is, of course, subject to fracture, and its average life is 18 months. The full light which they give, removing as it does the temptation of opening the safety-lamps, is a strong point in their favour; and they have been employed with success by Mr. Lancaster at the collieries in Lancashire, and by Mr. Tylden Wright at Shireoaks, in Nottinghamshire. At the latter colliery, where they have been introduced for many years, and are charged 5s. 3d. each, I learn that for six months 383 Mueselers had been in daily use, and consumed 1 gallon of refined rape oil each. In that period 69 glasses had been broken. A great convenience is their not being affected by an amount of draught sufficiently strong to blow out the common Davy, and some viewers hold it to be an advantage, whilst others object that it goes out when the air becomes highly explosive.

7. Eloin's lamp, E, Fig. 51. This arrangement, proposed by M. Eloin, of Namur, about 1850, admits the air through a ring of wire gauze, under a curved cap, surrounding the wick. Above this, the light is given off through a glass cylinder, formed in such a curve externally as to diffuse the rays. The upper part of the lamp surmounting the glass is a brass tube, covered at the top with wire gauze. A brass reflector slides up and down the protector bars, serving both to throw the light downward, when needed, and to guard the glass against dropping water. An admirable light is given by the Eloin, but it requires to be carried in careful hands, since it is very apt in rapid movements to be suddenly extinguished.

8. Mueseler's lamp modified by Eloin, F, Fig. 51. The combination of the principles of the two above lamps is clearly seen in the section.

The comparison of the various safety-lamps has acquired a new significance during the last few years. A number of systematic experiments have been carried out at various places in Great Britain, and also on the Continent, to determine the limits of danger when the lamp meets a current of air at too high a rate of velocity. Already Davy and Buddle had pointed out this source of risk, but the question had been allowed to slumber; and now, when it was announced by careful experimenters that the Davy would pass the flame if it were moved with a speed of 8 feet a second, and that all the other lamps hitherto thought safe could not endure a greater velocity than from 8 feet to 12 feet per second, it seemed alarming that no sufficient protection could be relied on in circumstances that must often occur. A rapid current of air in some part of the returns, a person walking hastily against the wind, a fall of the roof, a blower of gas, or even the stumble or jerk of a careless person might ignite the gas and cause explosion. Hence more than ever it seemed needful to take precautions, and at once to attack the problem of rendering the lamp more secure.

A host of new lamps have been brought forward, of which several have withstood successfully the ordeal of high velocity. Among these are Morison's, with two concentric glasses, between which the current of air has to find its way to the wick; Williamson's, also with double glasses, and feed air entering from below, as in the Stephenson's; Hann's and others, in which the typical Davy, Clanny, and Stephenson have been modified with extra safeguards to check the passing of the flame. Some of these, in which glass forms a large part of the construction, give a very good light; others are not approved because the checking of the air current prevents their burning briskly. Some inventors have addressed themselves to the greater security of the lock, as in the ingenious device patented by Craig & Bidder, for the lamp, which can only be opened when placed over the poles of a powerful magnet. Others have, for economy's sake, as well as for a good, clear light, employed mineral oils, or used a spirit under the misleading name of colzaline, as in Teale's "Protector," a lamp now in extensive use, and of which the general form is a modification of the older types, especially of the Mueseler, giving in some respects excellent results.

During later years, electric lamps, capable of burning for a fixed period, have been introduced to a limited extent. The most successful of these is probably that known as the "Swan," consisting of two cells (as a minimum), containing a core of lead wire, surrounded with peroxide of lead; the electrolyte is sulphuric acid.

A lamp of this capacity gives a light somewhat better than one candle for a period of 10 hours; by increasing the number of cells, and the weight in consequence, a better light can be obtained. The lamp is recharged by placing it upon a charging bench, through which the electric current from a dynamo is led. The incandescent wire burns in a vacuum, and is protected from external injury by a strong glass bulb. The cost of charging and maintenance is given by the inventor from 1½d. to 2d. per ton per week.

The method of relighting safety-lamps without the need of unlocking by means of an electrical current led through a charging bench, which may be situated at different fixed points in the mine, thus lessening the time required and distance which the workman has to traverse to relight his lamp, constitutes a great improvement, tending as it does to lessen the temptation to unscrupulous colliers to open the lamp in the working face. Some objection exists to this method, as it necessitates the use of more volatile lamp-oils than would otherwise be necessary, but if suitable precautions be taken that the flashing point of the oil in use is not below a certain fixed safe flashing point, these objections should disappear.

Originally a form of screw lock, which could be opened with a suitable key, was generally adopted, but is now rapidly giving way either to the lead lock, which cannot be opened without cutting, or to some form of electric magnet lock, both of which cannot be tampered with so readily as a screw lock, and are in consequence considerably safer.

Meanwhile the Belgian Government has repeatedly given consideration to the subject, and the King, in June, 1876, issued a decree in which the Mueseler lamp alone is permitted to be used in fiery collieries. The employment of mineral oils is interdicted, and only three modifications of the typical lamp are to be allowed. This important document is completed by a series of full-sized figures of the several lamps which are thus sanctioned by authority.

Experiments on various lamps are recorded in the *Ann. des Travaux publiques*, tome 31, in the "Trans. No. Inst., 1868," and in those of the Midland and other Institutions.

It is worthy of notice that, whilst at present a great diversity of opinion obtains among our British colliery managers as to which is the best safety-lamp, a very large majority adhere to the Davy as being the most sensitive lamp by which to test the presence of fire-damp.

To detect this gas when in minute quantity, Prof. Forbes renders it observable by the instrumentality of the sound given by a tuning-fork,* and E. H. Liveing has exhibited to the engineers at Newcastle a beautiful little apparatus, in which the comparative illumination of a screen by a coil of platinum wire, acted on by a magneto-electric machine, will indicate $\frac{1}{2}$ or even $\frac{1}{4}$ per cent. of gas.

With regard to the employment of safety-lamps, there can be but one opinion of their value, in testing the condition of the working-places before the men are admitted to them of a morning, and in the examination of those parts of a colliery not visited by the ordinary collier, where fire-damp may be expected to be present.† But as respects their introduction throughout the workings of a pit, the question is somewhat complex. It is apt to be the case that if one precautionary measure be fully installed another is neglected; that when safety-lamps are adopted for the entire operations of a mine, the ventilation is no longer a subject of the same attention; and, unless there exist good

* British Association, Dublin, 1878.

† Though not applicable in practice, I would mention the "fire-damp indicator" of Mr. Ansell, of the Royal Mint, in which the *diffusion* of gases is made to indicate by an index hand on a dial.

local reason for it, it is obvious that the protection by wire-gauze against present fire-damp is a less desirable kind of security than that of drowning the enemy in a full ventilating current, and sweeping him bodily away. Where the gas, however, is not merely given off continuously from the surfaces of freshly-cut coal, but bursts out from time to time in sudden blowers, the general use of safety-lamps is imperative; and on such occasions, when for a short time the best ventilated workings may be "fouled," or rendered explosive, the lives of all in the pit will depend on the proper condition of the lamps, and on the obedience to discipline of those men who are interposed between the point of outburst and the exit to the surface. Similarly, in the working of pillars, where, with the movement of the ground, fire-damp may exude either from the roof or floor, or may be forced by a fall from the magazine in which it has been collecting, safety-lamps are indispensable. It commonly occurs that although such may be the case in portions of a colliery, other parts, and especially the ordinary narrow work in whole coal, may be safely conducted with open lights. Here it will be necessary to fix on certain limits within which safety-lamps alone are to be employed, and to make it a stringent rule that no naked light be allowed to pass beyond a definite point in the roads. In Fig. 26, the bords, in the North, are worked with candles, the pillars adjoining the goaf with safety lamps; a special door is fixed upon as the place beyond which no open light is allowed to be carried; and the course of the ventilating current, led backward and forward three times, as seen by the arrows in the figure, is so contrived as to guard against any communication of gas from the dangerous portions to the bords.

In no department of mining is a strict discipline and attention to orders so momentous as in this—the question of lighting. The misplaced confidence, which is the result either of ignorance, of hardihood, or of long impunity, has led to the sacrifice of thousands of colliers, the innocent often suffering with the guilty; and among the most useful of the innovations of the Governmental inspection is that of giving authority to the code of rules to be established for every pit, and thus of protecting the majority of the men, the steadier workers against the few reckless ones, who, choosing to act for themselves, steal in secret the luxury of their pipe, or some extra light at the risk of their own and their comrades' lives.

CHAPTER XVII.

VENTILATION.

It needs no argument to impress on those who know the necessity of ventilating our public and private rooms that it is in a high degree essential to take thought for the replacement of vitiated by fresh air in the low and often-complicated chambers of coal mines, where many men and horses are engaged in hard work, and where numerous lights, with gunpowder smoke and dust, aid in contaminating the atmosphere. But in the workings of a colliery additional causes come into play; a slow, yet constant, change takes place in the surface of the substances exposed to the air, and the general result is the absorption of oxygen; a large amount of watery vapour requires removal; the poisonous gas, carbonic acid, is frequently given off, and more commonly the insiduous fire-damp, or carburetted hydrogen, exudes from the surfaces of the bared coal, or sometimes bursts from it in violent jets. The amount of air required for the health and safety of the men will, therefore, vary much in different localities, according to these unequal conditions; and whilst, in some cases, the slightest movement of air may suffice to keep a small colliery salubrious, in fiery coals, worked over a large area, an actual whirlwind must be forced through the principal passages in order to sweep away the noxious exhalations.

Notwithstanding the undoubted phenomena of the diffusion of gases, their intermingling in the chambers and drifts of mines is only partial, and the specific gravity of the gaseous bodies is practically a very important guide in testing their presence and enabling them to be dealt with. Thus, carbonic acid (CO_2), with a specific gravity as compared with air of 1·524, tends to occupy the deeper parts of excavations, rendering it unsafe, when they have been disused, to enter them without precaution. Sulphuretted hydrogen (HS), here and there evolved continuously, very poisonous, but readily detected by its offensive smell, is also slightly heavier than air; carbonic oxide (CO), most deadly, but occurring rarely from natural causes, is 0·970. Fire-damp, or light carburetted hydrogen, (CH_4), the *grisou* of the French miners, has a specific gravity of 0·555, and is, therefore, commonly found to float along the upper portion of levels, to escape of itself from workings carried downhill, and to lodge in hollows or the higher parts of excavations. If mingled with air in the proportion of $\frac{1}{30}$th to $\frac{1}{15}$th, it may be detected by the "cap" on the flame of a candle or lamp. If in larger proportions, it becomes explosive, and is most violent when it forms $\frac{1}{8}$th to $\frac{1}{10}$th of the mixture. The presence of carbonic acid greatly reduces the explosive property. When there is as much as $\frac{1}{4}$th of the gas, it burns without explosion, and a still larger proportion causes suffocation. In fiery seams it may be observed exuding from the freshly-broken surfaces with a hissing sound; and if in large quantity, as with "blowers," or sometimes near faults, with a rushing noise like the steam from a high-pressure boiler. Under these last circumstances it will rise through a column many yards high of water, and numerous accidents have occurred through a forgetfulness of this property. Some of these blowers will be exhausted in a few minutes, others will last for years—like that at Wallsend, which gave off 120 feet of gas per minute —and may then be piped off and burned at the pit bottom. The expansion of the gases collected in open spaces is affected by the pressure of the atmosphere, a notably larger amount being emitted when the barometer is low; and hence that instrument becomes a useful adjunct in judging of the amount of ventilation needed at different times.

For the due ventilation of a colliery, it is, therefore, not sufficient to supply air enough for the breathing of men and horses and the burning of lights; but we must provide for the sweeping away of the products of breathing and combustion, for the removal of the gaseous results of blasting, and of the decomposition of vegetable and animal matter; for the cooling of the excavations where the temperature is high, partly from depth and partly from chemical change; and, lastly, for the dilution of the gases exuding from the coal.

In round numbers, 100 cubic feet of air per minute may be required for the health and comfort of each person underground, or for 100 men 10,000 cubic feet; but if fire-damp be given off—say at the rate of 200 cubic feet per minute—we should need at the very least thirty times that amount of fresh air to dilute it, or 6,000 cubic feet in addition. Increase the number of men and liability to gas, and 40,000 or 60,000 cubic feet of air may be indispensable for safety. Hence we may point out once for all that no system of pipes can ventilate a mine, and that the large volumes of air required must be introduced through the drifts or workings themselves.

The subject now divides itself into two parts—first, the production of a current or "draught"; secondly, the distribution through the workings of the current so produced.

A spontaneous ventilation is produced by natural causes, which may always greatly assist, and in some cases may be sufficient for all purposes. To account for this on the simplest principles, let us observe what happens in summer and in winter with a diagrammatic working connecting two shafts of different depths.

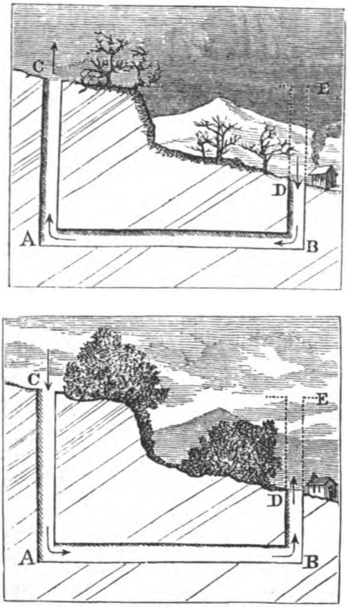


Fig. 52.—Diagrams illustrating Natural Ventilation.

The temperature of the rock is found, as we descend, to increase 1 degree Fahr. for about 60 feet of depth. Hence the air in workings of moderate depth will be in summer cooler, and in winter warmer, than the air at the surface. And, as air expands in warming—and we know by Mariotte's law that the pressures of the gases are in an inverse ratio to their volumes—the colder column will press upon and displace the warmer. If, then, we compare the two cases, we shall find that in summer (Fig. 52) the deep shaft A C compared with a column, B E, of equal height in and above the shallower shaft will be the cooler and heavier of the two, and will establish a current in the direction of the arrows. In winter the effect will be reversed, and the warmer air will be expelled from the top of the deeper shaft. But at certain seasons—and especially if the shafts are not very different in depth—there will be equilibrium between the two, or in other words, the ventilation will be checked or cease.

Under these circumstances we may artificially increase the difference of temperature—which is, in fact, the measure of the ventilating power—either by building a tower to lengthen the column of one of the shafts, or by lighting a fire in it for the purpose of expanding and lightening the air.

Air, in passing through the confined passages of a mine, is retarded by friction against the sides, roof, and floor of the passage, and the quantity of air that it will be possible to pass, and the amount of power required to produce a certain ventilating current in a mine, will largely depend on the length and dimensions of the air-ways and consequent rubbing surface. The pressure required to overcome the friction of the air rubbing on the roof, sides, and floor of an air-way, assuming the velocity of the air and area of roadway to remain constant, increases and decreases in direct proportion to the increase and decrease of the extent of rubbing surface, *i.e.*, that if we double the extent of rubbing surface we also double the pressure required to overcome the friction of the air. If, on the other hand, we double the velocity of the air passing through the same air-way, we shall require four times the pressure to overcome the friction; and this second rule is expressed by the late Mr. Atkinson in his able treatise on "General Principles of Mine Ventilation," as follows:—The pressure required to overcome the friction in the same air-ways varies in the same proportions that the square of the velocity of the air increases or decreases.

Again, if we assume the extent of the rubbing surface to be the same, and it is required to double the quantity of air passing, we shall need to burn eight times the quantity of coal on the fire-grate of the furnace or in the boilers supplying steam to the ventilating fan, or in other words, the quantity of air varies as the cube root of the power or coal burnt to produce it. A due appreciation of these three laws governing the friction of air in mines will make it evident that it is of importance to maintain the air-ways of a mine of as large dimensions and free from obstruction as practicable; it will also be evident that the extent of rubbing surface will be affected by the shape of the air-way; thus, a circular air-way of 8 feet diameter has a periphery of a little over 25 feet, whilst an air-way 8 feet square, 32 feet.

In early days it was usual to build a stack over the pit, and to attach to it a furnace accessible at the surface through doors; and in small pits, either this mode, or that of suspending a fire-lamp in the shaft, may perform useful service; but if a really large volume of air be required we must heat the full height of the column in the upcast shaft, and by good brick lining, and prevention of the dropping of water, obtain a maximum effect in the greatest possible difference of temperature between the upcast and downcast shafts. Under favourable circumstances, spontaneous ventilation may be made to pass many thousands of cubic feet of air per minute through a colliery; but where the pits are deep and in good order the quantity may be enormously increased by the application of a furnace at the bottom, or, if it be needed, by two, or even three ventilating fires playing into the same shaft. For this purpose a furnace is usually placed in the plane of the seam, from 5 to 10 feet in width, and with fire-bars about 6 feet in length; the arch is built in fire-brick, and well isolated from the coal, the height above the bars being 3 to 5 feet, and below them, 3 to 4 feet.

From the furnace to the shaft a gently-inclined passage —the *furnace drift*—leads the flame and heated air upwards; whilst, if the return air be apt to be *foul*, it may be led through a higher passage—the *dumb drift*—into the

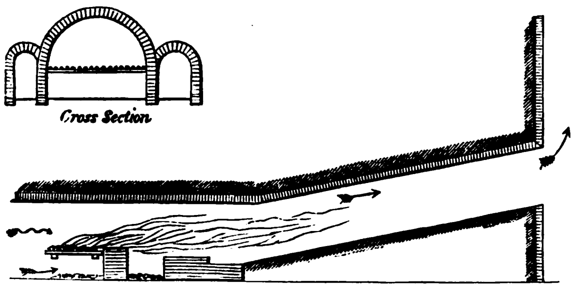


Fig. 53.—Ventilating Furnace, in longitudinal and cross-section. Scale—½-inch to 1 foot.

shaft at such a height above the mouth of the furnace drift as to secure the gas from firing, and the furnace will then be fed either with a safe portion of the returns, or with a "scale" (a small current of fresh air) from the downcast shaft. For perfect combustion, the coal should be thrown on frequently, and should form a thin fire; and thus an average temperature of 140 to 160 degrees Fahr. may be obtained in the upcast shaft, which, if we take an average of 60 degrees in the downcast, will give a difference of 60 or 80 degrees Fahr., on which the ventilating power may be calculated. The quantity of small coal consumed in such furnaces varies from 2 to 5 tons per 24 hours; and the volume of air passed—which may be from 15,000 to 150,000 cubic feet per minute—depends in a great measure on the diminution of the resistance offered by friction in the workings.

In order to obviate some of the shortcomings of the common furnace, such as the difficulty of increasing its power when circumstances demand it, and the interruption of its work caused by cleaning, new furnaces have been erected at Hetton, at the suggestion of Mr. John Daglish, which are 26 feet in length, so as to allow either the shifting of the place of the fire, or its increase, whilst by a series of doors the admission of the air may be regulated according to the conditions, either above or below the fire-bars.

The uncertainty of where sudden outbursts of gas may be met with, which may foul the air-current of a colliery and be carried on to the furnace, is steadily leading colliery owners to discard the furnace in favour of some mechanical means of producing the ventilating current.

A vast number of mechanical contrivances have been employed in mines, sometimes for forcing in air, but more commonly for drawing it out from the workings, and thus establishing a constant current. It would need a volume fairly to describe them, and we can here only glance at a few of those which have been most largely applied in practice.

The waterfall, formed by turning a special stream into the downcast shaft, or by allowing the pump cisterns to run over, is a useful auxiliary, especially for driving in air after an accident.

The air-pump—employed at a very early period in the mines of the Hartz—was, on a magnified scale, adopted at many collieries, especially in Belgium. It generally had pistons working in cylinders of from 6 to 10 feet in diameter, placed sometimes vertically, sometimes horizontally. The valves had to be complicated from being very numerous, and from being fitted with counterbalances,

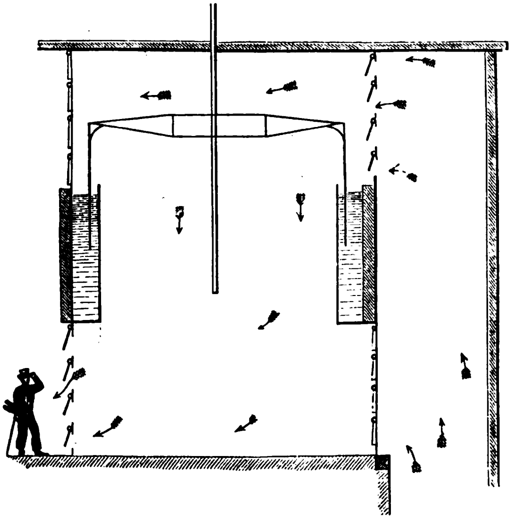


Fig. 54.—Struvé's Ventilator. Scale—¼-inch to 10 feet.

attached by light levers, in order to diminish the resistance. A great diminution in friction was obtained by making the piston in the form of a gasometer, plunging with its sides in a ring of water. This latter plan was carried out on the largest scale by Mr. Struvé's ventilator. His piston was a close-topped wrought-iron bell, of 12 to 22 feet in diameter, working up and down in water; and by means of ranges of valves above it and below, placed in the walls of the piston chamber, drawing in and forcing out air at each up and each down stroke. The action will readily be seen from the adjoining figure (Fig. 54), in which the piston is making its down stroke. These machines are usually composed of two such pumps, worked by a steam-engine, and are capable of giving a theoretical amount of 20,000 to 100,000 cubic feet of air per minute. Their cost is about £200 per calculated 10,000 cubic feet. Horizontally-working pistons in prismatic chambers were erected in 1828, by M. Brisco, near Charleroi, and on a

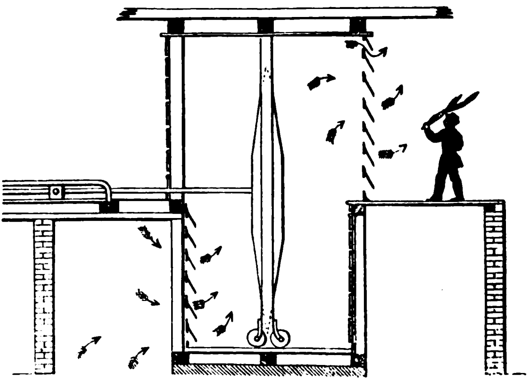


Fig. 55.—Nixon's Ventilator, Aberdare. Scale—¾-inch to 10 feet.

larger scale by M. Mahaux, in 1861. One applied to the colliery of Monceau Fontaine, by Scohy, in 1861, was capable of extracting 45,000 cubic feet per minute. These are all greatly exceeded by Nixon's ventilator, now working at the Navigation Pit, near Aberdare. Its sheet-iron pistons—30 feet by 22 feet, or no less than 660 feet area each—are supported on wheels traversing on rails a stroke of 7 feet. The chambers are fitted, as in Struvé's machine, with flap valves 16 inches by 24 inches, and 672 in number. At 9 strokes per minute, the theoretical quantity of air expelled would be 166,000 cubic feet per minute; but a large reduction has to be allowed for leakage.

Fans, constructed with straight radial vanes, were abundantly used in the German mines in Agricola's time, about

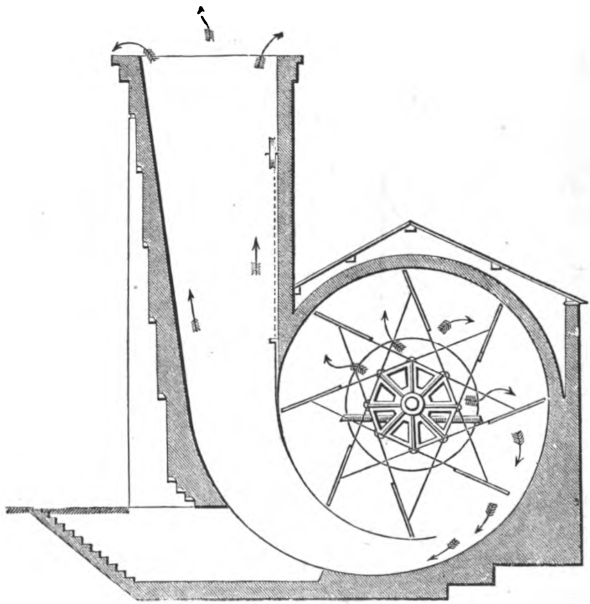


Fig. 56.—Guibal's Ventilating Fan. Scale—1 inch to 20 feet.

1550. Similar machines on a larger scale, 8 to 22 feet in diameter, vertical or horizontal, have been applied at several collieries; but from their leakage, and the considerable velocity needed, have not given very good results.

M. Guibal, of Belgium, commencing about the year 1860, devised and erected several examples of an improved fan, of from 20 to 28 feet diameter, and 6 to 10 feet wide. The figure shows its form and the great improvement of casing it in and providing a slide valve to a part of the casing, to meet the varying conditions of a mine. The stack expanding outwards is stated to counteract to a great

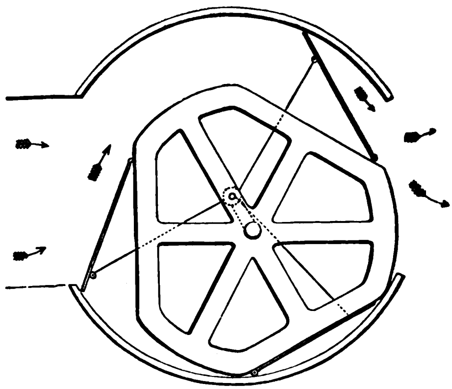


Fig. 57.—Lemielle's Ventilator.

extent the loss due to the high velocity given to the air by the vanes; and experiments made on the machines erected at Bully-Grenay, near Bethune, and Monceau-Fontaine, near Charleroi, have shown a useful effect of 30 to 50 per cent. from the steam in the cylinder, and 60 to 70 per cent. of the force transmitted to the axle. Between 1863 and 1880 upwards of 200 of these fans, some up to 40 and 50 feet diameter, have been put to work in this country.

M. Lemielle has devised a very ingenious ventilator, now at work in many Belgian and French pits, and at Ashton Vale, near Bristol, where it has acted satisfactorily for some years, with very little necessity for repairs. Within a large cylinder of brick, wood, or sheet iron, a smaller drum is placed eccentrically, and made to revolve. On the surface of this drum are two or more valves or shutters, which, by means of iron rods moving freely round an elbowed axis in the centre of a large cylinder, lie close to the drum in one part of the revolution and open out in another. The section shows by the arrows how the air will thus be expelled by the shutters as they approach the point of outlet.

Fabry's machine is another—on the fan principle—much approved on the Continent. Two axes, each fitted with three very broad blades (6 to 10 feet), revolve in opposite directions, and each blade is formed with a cross-arm so curved as to give close contact during revolution, and thus prevent communication from within to the external air. Above half of the circumference of these fans fits closely within a casing of brick or wood, and the foul air, when the machine is employed for exhaustion, is taken by the blades on approaching the lower part of their circles of revolution, is carried on each side outward and ejected on passing the upper limit of the curved casing. The moderate velocity at which it may be driven, and its durability, have obtained this machine a good name.

The Waddle fan, shown in Fig. 58, consists of a fan of diameters from 20 to 50 feet. Air is received at the centres of the fan, on one side only, and delivered all round the periphery direct into the atmosphere. It is driven direct from the main shaft of a vertical or horizontal engine. A large number of these fans are in operation at the present day and are giving good results.

The Schiele Fan, of which Fig. 59 is a representation, is a fan of small diameter, with blades curved backwards, made to revolve at a very rapid rate by means of rope or belt

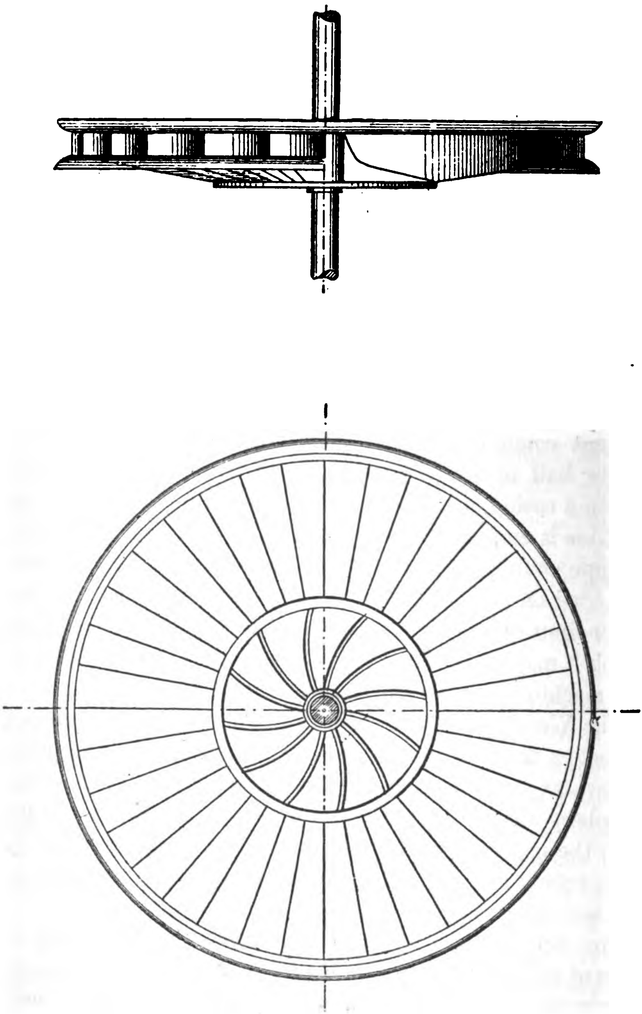


Fig. 58.—The Waddle Ventilating Fan.

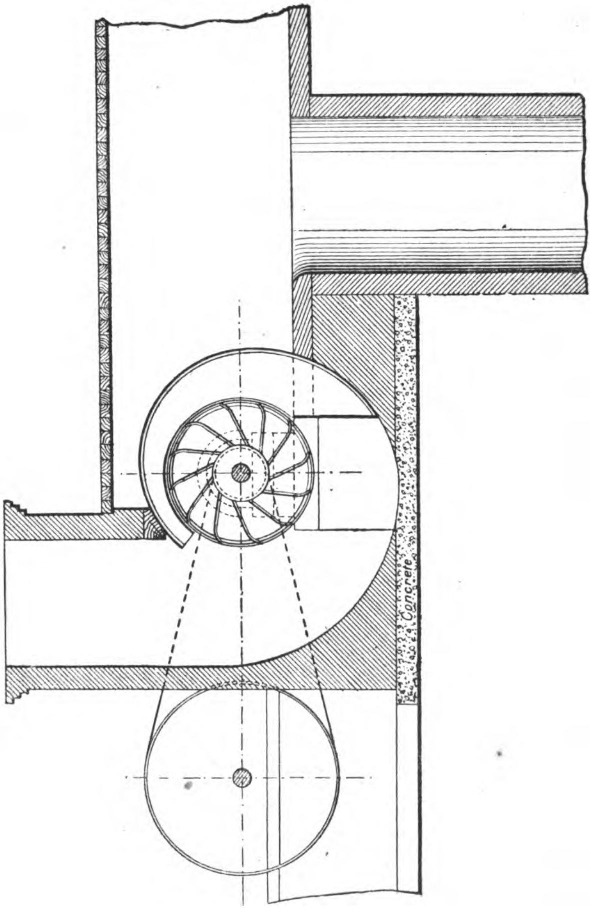


Fig. 59.—The Schiele Ventilating Fan.

gearing from a large pulley on the engine shaft. In this fan air is received on both sides. The results obtained from it have been excellent and it enjoys considerable favour.

Amongst several newer fans may be mentioned "Walker's Indestructible" and the "Capell"; the former a modification of the Schiele and Guibal combined, which has given very good results in practice; the latter, a small, quick-running fan, for which a high efficiency is claimed.

Several years have now elapsed since a vigorous attempt was made, under the impulse of a most injudicious Parliamentary Committee, to substitute for the furnace the mechanical action of steam jets. The subject was elaborately tested in practice by Messrs. T. E. Forster, Nicholas Wood, and others, and it was clearly shown that high-pressure steam, generated either at surface or underground, and allowed to escape from a series of small jets—say, 30 to 40 in number, and from $\frac{1}{16}$th to $\frac{1}{8}$th of an inch in diameter—was capable of doing good service, especially as an auxiliary at times of accident; but was utterly unable to compete in economy with the furnace.

In selecting our ventilating power it must be remembered that the great object is to obtain a large volume of air at moderate velocity, and that on this account most of the simple fans, and certain other classes of machine which have to force the air through insufficient valve room, give it an unnecessary velocity, which, in other words, means increased resistance or diminished ventilation.

Furthermore, that whilst the furnace exerts its fullest advantages in deep and dry upcasts, to which the air travels through roomy wind-ways, the mechanical ventilators may be most properly applied at pits where these conditions are reversed.

Let us now consider the distribution of the air through the workings, remembering that without due attention to its details we may have a storm of ventilating wind in the shafts and yet a deadly stagnation in the interior; or one portion of the pit safe and wholesome, another foul and verging on explosion.

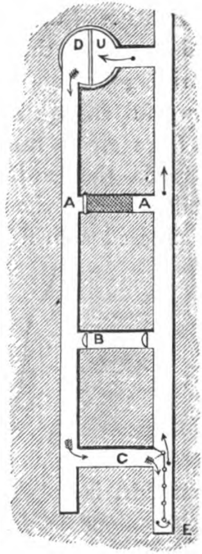


Fig. 60.—Diagram illustrating Distribution of Air.
Scale—1 inch to 80 feet.

First of all, the means of carrying the air current up to or near the place where the men are employed consists in cutting a drift or wind-way across from one working spot to another, and, as we advance, closing the old openings by doors or *stoppings*, so as to force the air through the required passage only. To take a simple case: Fig 60 represents a pair of levels driven a short way out from a shaft divided by brattice into D and U, the downcast and upcast portions. The pillar between the levels is holed through by a "thirl" at A, when the drift-ends are advanced but little beyond that point. Subsequently, when B has been thirled, a *stopping* is put into A, either by brick and mortar, or stowed rubbish, or both; and similarly, when C has been opened, B will be closed. If, however, a thoroughfare for the men be required, so that a stopping is inadmissible, a door or—where the ventilation is important—two doors, or even three, are put up, so far apart that a horse and tram can pass the one and have it closed after them before the second is opened. Thus loss of air is avoided, and the tendency of the current to take the shortest way to the upcast is checked. Indeed, a watchful eye must always be kept on the *intake* current D C, which constantly presses upon the barriers which divide it from the return E U, and leaks through all available openings to the diminution of the ventilation in the inner workings. Doors and stoppages, therefore, require constant attention, or, by a trifling leakage at each of them, a ventilating current, powerful enough at the beginning of its run, may lose all its force ere it reaches, at half a mile or a mile or two distance, the locality where it is really needed. If, meanwhile, the coal should be so fiery as to render it dangerous to proceed above 4 or 5 yards without extra precaution,

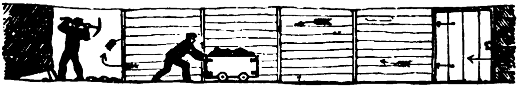


Fig. 61.—Diagram illustrating Circulation of Air.

bratticing is employed as a temporary measure until the next thirl is holed. Thus, supposing in the Fig. 60 the end E alone is dangerous, a range of upright posts is erected between roof and floor, from the side of the pillar B C to within a short distance of the face at E, and brattice boards are nailed to them, dividing the level into two parts, and making the current travel as represented by the arrows. A light door is generally added for the passage of the men or horses and trams. These features are shown in the section of the working of a 7-foot seam, Fig. 61, where the air passes up close to the man on the left and then turns behind the brattice.

A single current may thus be carried to the various working places, and brought back to the same or to another shaft; whilst if the power be great, the air-ways roomy, and the doors and stoppings in good order, it will be maintained for a length of several miles without serious loss. If the form of the works be such as that shown in Fig. 28, as a variety of "long-wall," a stream of air starting each way from the downcast shaft will simply and effectually ventilate the mine. But the same method, generally applied as it used to be years ago, to more complicated workings, is highly objectionable; it would leave the mass of the openings inside of the working "bords" *dead* or stagnant; it would needlessly carry fire-damp from dangerous to otherwise safe places, and the body of air which in the morning went down into the pit fresh and pure would take till night to drag itself along some 20 or 30 miles of drift, and would visit all its later scenes of work overheated, clogged with dust and smoke, and laden with impurities.

Spedding, about 1760, introduced the *coursing of the air* by twos or threes through the whole of the opened passages, and soon afterwards all the chief Northern viewers recognised the importance of shortening the runs, and obtaining larger volumes. For this it would be needful either to have more shafts, and work, as it were, several separate mines, or—what is more suitable when the shafts are ample enough—to *split the air*. This latter plan, by which a number of separate currents are obtained, is perhaps the greatest improvement effected in the airing of pits, and when combined with the division of the area into panels or districts, has the advantage of confining danger or the results of accident within narrow limits. Take the case of a colliery having 12-feet shafts, and air-ways of 4 feet by 5 feet, or 20 feet area; the shaft having 113 feet area will be fully adequate to pass the air required not for one or two such air-ways, but for at least five. Each may then ventilate a different district, and they may be brought together again either at the upcast shaft, or into certain roomy return air-ways approaching it. As we increase the area or number or power of the shafts, so the number of the splits may be increased, and since the resistance varies directly with the length of the road which the air current has to travel, and inversely as the sectional area of the passage, it is manifest that if the runs are shortened, and the air-ways increased in size, the same ventilating power will pass a larger volume of air. Reference to Fig. 26 will show this arrangement in a portion of the working of a large colliery. But the balancing of these splits requires nice management, or the air would tend to desert the longer for the shorter runs, and where inequalities in length exist it is necessary to put in regulators, which, checking the entry of the air into the shorter, may force it into the longer runs. It is upon such principles that our large collieries succeed in passing through their workings the enormous volumes of from 150,000 to 300,000 cubic feet per minute.

When the workings assume this complicated form, the number of doors to be tended by trappers is, nevertheless, greatly diminished; but frequent *crossings* have to be made where one air current is carried across the course of another (*see* Fig. 26 C). Thus, the "returns" are generally made to mount over the intake drifts, and are divided from them either by timber or brick arching, or boiler-plate (as at Kirkless Hall), or occasionally—for extra security—by being carried up to some height in the solid measures, so as, in the event of explosion, to prevent the risk of one passage being blown open into the other.

It is observable that in the more serious accidents from explosion a great majority of the sufferers lose their lives not from the actual violence or fire of the blast, but from suffocation by the deadly after-damp, consisting of the products of combustion. Most fearful is this when dependence has been placed on a bratticed shaft, the brattice is shattered, and the air, passing down one portion and up the other, leaves the workings *dead* or without air, and the poor fellows who may have escaped the force of the actual explosion fall victims to suffocation. But independently of bratticed shafts, the same evil occurs in a modified form in every colliery, and due attention has very rarely been shown to so laying out the works that in case of a blast sufficiently heavy to blow out the doors and shake down the lighter class of stoppings, there may still remain be-

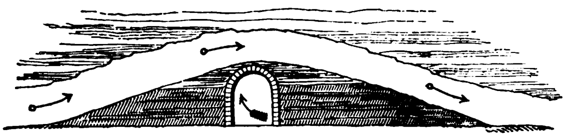


Fig. 62.—Air-crossing.

tween the downcast and upcast shafts a sufficiently long course of unbroken air current to afford a better chance of escape to the colliers, who can flee thus far from their working places. In Fig. 60 it may be seen how, if the stopping at A, or the doors at B, are blown out by explosion, the air would take that shorter course and the inner workings be laid dead; and an examination of Fig. 26 will show the same result more forcibly. The further the two important shafts can be separated, the longer will be such independent air-course to which the men may escape. An upcast pit to the rise may often come in usefully in this way; but no general rule can be laid down, because a shaft so situate may often be so much shallower than the other as to form a less efficient furnace shaft; and in cases of this kind—if the depth of the rise pit be too small for good ventilation by this means—it becomes a question whether a mechanical method would not be preferable.

The quantity of air which passes is measured by taking the sectional area of a drift, and multiplying it by the velocity in feet per minute, to obtain the number of cubic feet circulating in that time. The velocity is obtained either by observing the rate at which a puff of powder or tobacco smoke travels along a measured distance, or by an anemometer. The instrument most frequently used in collieries is that of Biram, made in various sizes, from 3 to 12 inches in diameter, by Davis, of Derby, which by wheel-work and index hands registers the number of feet of air in tens, hundreds, and thousands, which have passed through it in a given time. M. Combes, and more recently Mr. Casella, and other makers, have devised for this purpose a smaller and more delicate instrument, depending for its results, like the former, on the revolution of a wheel fitted with light vanes.

In order to test the different densities of the currents on opposite sides of a brattice, a door or stopping, a manometer or water-gauge is employed. This, although it gives no criterion of the amount of ventilation, is very useful for comparisons, as giving a measure of the resistances, or of what is technically called the *drag* of the mine, and distinctly pointing out any unusual obstruction such as may be caused by a fall of roof in the air-ways.

The above brief sketch, although not pretending to go into the details of exceptional circumstances, may, I trust, be sufficient in a general way to set forth the principles and practice upon which the ventilation of our larger collieries has been brought into so high a position of effectiveness by the skill and perseverance of the leading coal-viewers.

CHAPTER XVIII.

BLASTING AND EXPLOSIVES.

SINCE the discovery that coal-dust when in a finely-divided state is capable of being exploded, and of spreading and increasing the effects over long distances of what perhaps would have been merely a local explosion, the subject of blasting in collieries, and the nature of the explosive to be used, has received a great deal of attention at the hands of mining and scientific men.

As early as 1803, in the inquiry into an explosion at the Wallsend Colliery, attention was called to the part coal-dust might have played in spreading the effects of the explosion, but it was not until 1844, in which year an explosion occurred at the Haswell Colliery, that serious attention was turned to this subject, the importance of which, in connection with blasting operations in collieries, becomes greater with every new light thrown upon it.

It is now generally admitted that fine coal-dust in suspension may be ignited and exploded with great violence by the flame from a shot-hole where no fire-damp is present, and that the dustier the mine the greater the violence of the explosion, which increases in force as it spreads through the workings.

Until recent years ordinary gunpowder, containing 75 per cent. of nitre, 13 per cent. of charcoal, and 12 per cent.

of sulphur was the usual explosive employed in coal-getting, and is even now used to a considerable extent. It has been found that, owing to its rending rather than shattering action, gunpowder is the most effective explosive in procuring round coal, but, owing to the large flame which accompanies its explosion, its use in fiery and dusty mines is attended with grave risk. To eliminate this risk, the efforts of explosives manufacturers have been directed towards producing a high explosive which, by reason of its rapid explosion, should produce little or no flame. The first step in this direction was the introduction of dynamite, composed of 75 parts of nitro-glycerine (a liquid explosive of great violence which, by reason of the danger of handling and storing it, prohibits its use in its natural state), absorbed into 25 parts of a silicious earth called kiesalguhr, found in Hanover. Dynamite has an explosive force from 5 to 10 times as powerful as ordinary blasting powder. It is unaffected by water, and hence is a very valuable explosive in damp situations, though it is by no means flameless. Recently many new so-called flameless explosives, composed for the most part of varying proportions of nitro-glycerine, or nitrate of ammonia mixed with foreign substances, have been introduced, having in view the production of a non-flameless explosive.

The safety explosives may be divided into two classes, those having nitro-glycerine for their base and those with nitrate of ammonia. The hereto appended (see folding plate) gives the majority of these with their reputed composition.

In these efforts manufacturers have been only partially successful up to the present time. Whilst it has been found that the greater number of these so-called safety explosives are considerably safer than ordinary blasting powder or dynamite, they all of them, under certain conditions, may f Amyse.

...or melt below 200° Fahr.r)	...oodmeal & Charcoal mixed (the latter not to exceed by weight 3% of Explosive)	Carbonate of Magnesium	Nitrate of B...	Chalk.	Nitro Cotton.	Wood Meal.	Saltpetre	Sulphur (pure)	Nitrate of Potassium.	Charcoal	Oxalate of Ammonium.
				6-9			26-34				
							28-31				
				8-10			25-31				
					74-76	9-11		14.5-15.5			
							69-73	12-15.5	13.5-16.5		

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ignite coal-dust, or mixtures of fire-damp and coal-dust in suspension, and they cannot be considered absolutely safe.

The quality of safety in them appears to be dependent for the most part on the temperature of detonation, and this fact has been placed on record by the decree of the French Government in 1890, which forbids any explosive being used in blasting stone in a dangerous mine which has detonating temperature greater than 1900 degrees centigrade, or 4,060 degrees Fahr., and if in coal the temperature shall not exceed 1,500 degrees centigrade, or 3,212 degrees Fahr., the products of detonation not to contain combustible matter.

Many and various experiments have been made in Germany, France, and this country to determine the relative safety and efficiency of these explosives. Among those carried out in England may be mentioned those by Mr. Henry Hall, Her Majesty's Inspector of Mines for Lancashire, and also those by a Committee of the North of England Institute of Mining and Mechanical Engineers, who, after a large number of elaborate experiments, have made the following recommendations as to the use of these explosives :—

"That the precautions usually adopted when using ordinary blasting power should not be relaxed in any way when using these higher explosives, seeing that the risk of explosion is not eliminated but only lessened by their use.

"That the name of the explosive should be printed on the wrapper of each cartridge, and that the date of manufacture and proportion of ingredients should be printed on each case of cartridges.

"That owing to many of these explosives altering in character if improperly kept, it is necessary that every care should be taken in the storage to ensure their being maintained in good condition."

The use of explosives in coal-mines is strictly regulated by the Coal Mines Regulation Act, and we would refer our readers to General Rule 12, quoted in Chapter XX., for an abstract of the regulations imposed.

The fact that the composition of different samples of the same explosive often vary may account to some extent for the uncertainty, as far as regards production of flame, in them. Attempts have also been made by surrounding the explosive with some form of fire extinguisher to prevent the production of flame. As an example of this class may be quoted Settle's water-cartridge, in which the explosive is placed in a water-tight cartridge enclosed in water, contained in a varnished paper case or metal case. The water is retained by means of a cork through which the fuse or electric wires are taken. In use the results from this cartridge have been fairly satisfactory, but it is open to the objection that the water-bag may be perforated, and the water leak away during the process of tamping.

Substitutes for explosives have come into use to a limited extent in working coal. The lime cartridge, which depends for its action on the great expansion of lime by increase in bulk in slakeing. Carbonate of lime is calcined and ground to a powder, and made into cartridges 2½ inches diameter and about 4½ inches long. After the shot-hole has been drilled, a perforated iron tube ½-inch diameter is inserted, after which these cartridges (of which there may be several in one hole) are put in, and pushed to the far extremity of the hole and stemmed. Water is then forced into the perforated pipe by means of a force-pump attached to the end of the tube, the water escapes into the lime through the perforated holes, steam is evolved and the lime expanded sufficiently, if successful, to bring down the coal. In practice this cartridge has been found to be of some use in certain coal-seams, but its action is very uncertain, and consequently its use is not economical. The advantages claimed for it are absolute immunity from the risk of igniting fire-damp, the heat evolved in slakeing lime being 700 degrees Fahr., while 2,000 degrees is stated by Sir F. Abel to be the temperature at which fire-damp will ignite.

The ordinary wedge, Macdermott's multiple wedge, and the Haswell mechanical coal-cutter, are all attempts to provide substitutes for explosives, and are well described in the "Transactions of the North of England Institute," vols. ii., xii., xiv., xix., xxiii., and xxxiii. Their use, however, is, and can be, only very limited, and can never be considered as serious competitors with explosives.

It therefore behoves mine managers in dusty mines, wherever possible, to allow no shot firing. Where this, owing to the physical condition of the seams, is not possible, every possible precaution should be used, in addition to the regulations enforced by the Mines Regulation Act, such as the regular and systematic watering and cleaning of the dust off the roadways, the use of suitable stemming, such as damp clay, moss, etc., and the employment of thoroughly competent men to supervise the firing of shots.

Several systems of watering the roadways of a mine are employed. Sometimes it is done by water-tub or tank, in which a cask or special water-tub is attached to the set of coal-tubs, hauled along the underground engine-planes, or drawn by horse in a similar manner to surface road-watering; but this, owing to its too often intermittent character, cannot be considered satisfactory. A system often employed is to lay 1½ or 2-inch pipes along the main roadways of the mine, connected to a surface reservoir or shaft-feeder. On these pipes, at stated intervals, are fixed standpipes with fine sprays. In a large colliery it is advisable to keep special men to see that these sprays are regularly turned on.

When the system is carried out in its entirety, the pipes are carried into the face of the main gateways, and india-rubber piping, capable of reaching the neighbouring main gateway, is attached to cocks placed near the end of the

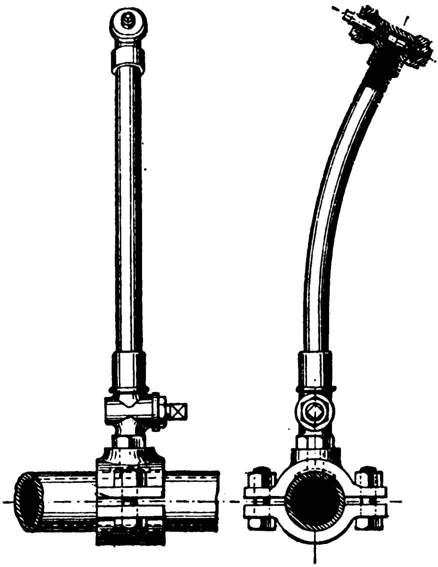

Fig. 63.—Appliance for Watering Roadways.

pipes, thus ensuring the watering of the whole working face if necessary.

Fig. 63 shows such a spray, which is both cheap and effective. The objects to be aimed at in the construction of a spray are the production of as fine a spray of water as possible, which will be carried for long distances by the ventilating current, and thoroughly damp the dust without making the roadway unnecessarily wet. If too large a spray be used great difficulty will be incurred in maintaining them, owing to the inconvenience occasioned to the workmen in passing them. In some collieries compressed air is employed in conjunction with water to form a fine spray, the disadvantage of this system being that the pressure of the compressed air is not constant, the spray thus at times throwing out too much air, and at others too much water.

Whether blasting be carried on with powder or any other explosive, the first step is to clean out the shot-hole. This is done by means of a ¼-inch round iron bar, flattened into a small hook at the end, called a "scraper"; this is inserted to the extremity of the hole and drawn out several times, until all the *débris* made in drilling it has been removed; the charge is then placed in the shot-hole in the form of a cartridge, with fuse and detonator attached, and pushed by means of a rammer (made of some material which will not produce sparks, such as wood, copper, or phosphor-bronze) to the far end; suitable stemming, such as clay, rock, curlings, etc., is then inserted, the use of coal-dust for this purpose being strictly forbidden by the Coal Mines Regulation Act, 1887, sec. 12, sub-sec. *d.* By means of the rammer the stemming is rammed tight against the cartridge, until the hole is filled up; the fuse is then lighted, after which the shotman retires to a place of safety. Should the old system of firing by straw be in vogue, it is carried out as follows: A straw containing a train of gunpowder is inserted through the stemming, and a piece of touch-paper attached to the end, to which a light is applied, and allows of the shotman retiring before the flame communicates with the straw, and then with the explosive. An ordinary safety-fuse burns at the rate of 30 inches a minute; a man is thus better able to calculate the length required to give him sufficient time to reach a place of safety than by the straw system. A far better way of firing shots than either of the above, is by means of an electric hand-battery, to which the ends of the electric wires are attached, the other ends being connected with a detonator inserted in the explosive. The advantages of this system are the avoidance of risk in approaching any shot which has missed fire, as by disconnecting the wire from the battery all risk of the shot exploding unexpectedly is removed. In blasting rock by this system several shots can be fired simultaneously, largely increasing the efficiency of them.

Considerable skill is required in actual blasting to obtain the best results, and to avoid the frequency of blown-out shots, in which the whole force of the explosion is exerted, along the line of bore-hole, and does not act on the rock. In sinking or drifting, the centre of the drift or shaft is kept in advance by drilling, in the first place, what are called sump holes, bored at angles slightly converging and fired simultaneously by electric battery.

"Canch," or side-holes, are then drilled in the remaining portions of the rock, the central hollow formed by the firing of the sump-holes allows of it being readily dislodged.

The shaft or drift is then dressed by hacks or heavy picks to the required size, and the drilling of the sump-holes resumed.

The question of handling and storing explosives is one on which too much care cannot be bestowed, and it is strictly regulated by the Explosives' Act, 1875, of which the following general regulations, amongst others, may be noted:—

No explosive may be kept for sale without a licence. Blasting cartridges shall not be manufactured in a private house.

Not more than 20 lbs. of gunpowder and 150 lbs. of safety-cartridges, or 15 lbs. of any other explosive, may be kept for private use without a licence.

The store in which explosives are kept shall be situated at certain distances from any house, workshop, etc., ranging from a distance of 25 yards to, in certain special cases, over 2 miles, dependent on the quantity for which the store is licensed, etc., and must be either underground or built on the surface of stone, brick, etc., but no iron must be used in the construction.

No person under the age of 16 is allowed to enter the magazine.

The store must be kept exclusively for explosives, the quantity so kept varying up to 4,000 lbs. of gunpowder, maximum, and 20,000 lbs. safety-cartridges in addition.

No smoking is, of course, allowed.

By the Explosives in Coal Mines Order, of the 11th July, 1898, the use of any explosives other than those on a permitted list, which have satisfactorily passed the tests imposed by the Home Office, are prohibited in seams in which inflammable gas has been found within the previous three months to a dangerous extent.

In such a case, in any coal-mines which are not naturally wet throughout, the use of any explosive is entirely prohibited in all roads, and in every dry and dusty part of the mine.

In all coal-mines coming under the above regulations the following conditions are to be observed in using permitted explosives :—

(*a*) Every charge of the explosive shall be placed in a properly drilled shot-hole, and shall have sufficient stemming.

(*b*) Every charge shall be fired by an efficient electrical apparatus, or by some other means equally secure against the ignition of inflammable gas or coal-dust.

(*c*) Every charge shall be fired by a competent person appointed, in writing, for this duty by the owner, agent, or manager of the mine, and not being a person whose wages depend on the amount of mineral gotten.

(*d*) Each explosive shall be used in the manner and subject to the conditions prescribed in the schedule hereto.

Provided that nothing in this order shall prohibit the use of a safety-fuse in any mine in which inflammable gas has not been found within the previous three months in such quantity as to be indicative of danger.

3. In every coal mine the use of any explosive is prohibited in the main haulage roads, and in the intakes, unless all workmen have been removed from the seam in which the shot is to be fired, and from all seams communicating with the shaft on the same level, except the men engaged in firing the shot, and, in addition, such other persons, not exceeding 10 in number, as are necessarily employed in attending to the ventilating furnaces, steam boilers, engines, machinery, winding apparatus, signals or horses, or in inspecting the mine; unless a permitted explosive is used, and every part of the roof, floor, and sides, of the main haulage road or intake, within a distance of 20 yards from the place where it is used, is at the time of firing thoroughly wet, either naturally or from the application of water thereto.

This section shall not apply to such portions of the main haulage roads and intakes as are within 100 yards of the coal face.

This section shall not authorise the use of any explosive in any case where the use of such explosive is prohibited by section 1 or 2 of this Order.

4. This Order shall not apply to mines of clay, or stratified or nodular ironstone, nor shall it apply to shafts in course of being sunk from the surface, or deepened, or to drifts and other outlets being driven from the surface, if such shafts, drifts, or outlets are not ventilated by return air.

Where a mine contains several separate seams, this Order shall apply to each seam as if it were a separate mine.

5. In this Order the term "permitted explosives" means such explosives as are named and defined in the schedule hereto: provided that where the composition, quality, or character of any explosive is defined in such schedule, any article alleged to be such explosive which differs therefrom in composition, quality, or character, whether by reason of deterioration or otherwise, shall not be deemed to be the explosives so defined: provided further that an owner, agent, or manager shall not be responsible for the composition, quality, or character of an explosive, if he shows that he has in good faith obtained a written certificate from the maker of the explosive that it complies with the terms of the schedule, and that he has taken all reasonable means to prevent deterioration of the explosive while stored.

The term "road" includes all roads of any description extending from the shaft or outlet to within 10 yards of the coal face.

The term "main haulage road" means a road which has been, or for the time being is, in use for moving trams by gravity or by steam or other mechanical power.

6. This order shall come into force on the 18th day of July, 1898, from which date the Explosives in Coal Mines Order of the 4th February, 1898, is revoked.

7. This order may be cited as the Explosives in Coal Mines Order of the 11th July, 1898.

CHAPTER XIX.

WASHING AND COKE-MAKING.

THIS branch of mine-engineering, which has for its object the converting of coal into coke, an essential product for the manufacture of iron and steel, has been the object of much attention.

Coal, when filled by the collier and brought to bank, contains a certain quantity of foreign substances mechanically mixed with it, derived from the surrounding strata. The proportion of these substances contained will vary according to circumstances, such as the hardness or softness of the roof and floor, the number of bands of dirt running through the seams, the carefulness or otherwise exercised by the collier in loading his tub.

It is essential in procuring a pure coke that as great a proportion as possible of this dirt should be eliminated. Resort is, therefore, usually had to washing the coal previous to converting it into coke. The first step is to separate the large lumps from the small or "duff"; and the usual practice is to coke the latter only. Where it is intended to coke the whole of the produce of the colliery, the large coal is converted into small by being passed through some form of crusher. The small coal is then conveyed to a washing machine, of which there are many in the market, claiming their several points of advantage.

WASHING.—The process of washing depends upon the difference in the specific gravity of the coal and that of the foreign substances mixed with it; the more nearly the specific gravity of the former approaches that of the latter the more difficulty will there be found in washing the coal satisfactorily.

Coal-washing machines may be said to be constructed on two principles, that in which the coal is separated from the rubbish directly by the action of water only, and that in which a foreign substance, of a specific gravity between that of coal and the rubbish to be separated, is introduced, combined with the agitation of water between the two substances.

In the former the small coal is usually washed through shallow troughs lying at a slight inclination, along the bottom of which small obstructions are placed; the heavier substances have a tendency to accumulate against these obstructions, whilst the lighter particles of coal are carried over by the rush of water, much on the same principle as alluvial deposits containing gold are dealt with.

In the second type of machines, felspar, which possesses a specific gravity of 2·6 as compared with 1·28 for coal, and an average probably of 2·80 to 3·00 for the shale and rubbish usually intermixed, is the usual substance introduced. The coal is conveyed into water-tanks containing felspar, placed upon a perforated trap or grating. The water in these tanks is continuously agitated by vertical plungers worked off cranks on a revolving shaft driven by gearing from a suitable steam-engine. The continual agitation results in the several substances forming themselves in layers according to their specific gravity, the coal rising to the top and being washed into troughs and elevated into bunkers, from which it is conveyed, when sufficiently dry, to the coke ovens. The rubbish being the heavier sinks through the felspar, and is drawn off at the bottom of the tanks. In Fig. 64 a type of this class of washing-machine is shown.

Some coals are found to be sufficiently clean in the state in which they are brought out of the mine for coking, in which case they are conveyed direct to the bunkers from which the coke ovens are charged.

The percentage of dirt contained in coal varies very largely, and the quantity that may be expected to be washed out by a good machine may be considered to be 10 per cent., depending naturally upon the suitability of the plant and the care exercised in washing.

The process of coking consists of burning coal, in a sealed oven, to a sufficient extent to drive off the volatile constituents of the coal, leaving behind the non-volatile products, consisting chiefly of carbon, ash, and sulphur, and in some cases phosphorus, it being the object of the coke manufacturer to eliminate, as far as possible, these three latter constituents, which are all detrimental to the quality of the coke.

The following analysis of coal previous to coking and the resulting coke will illustrate the change that takes place:—

	Coal. Per cent.	Coke. Per cent.
Fixed carbon	71·12	93·06
Volatile matter	24·92	—
Sulphur	1·11	·91
Ash	1·78	5·33
Moisture	1·07	·70

The volatile gases driven off in coking are, in some cases, utilised to heat boilers, resulting in an economical production of steam. On the Continent more especially, and in

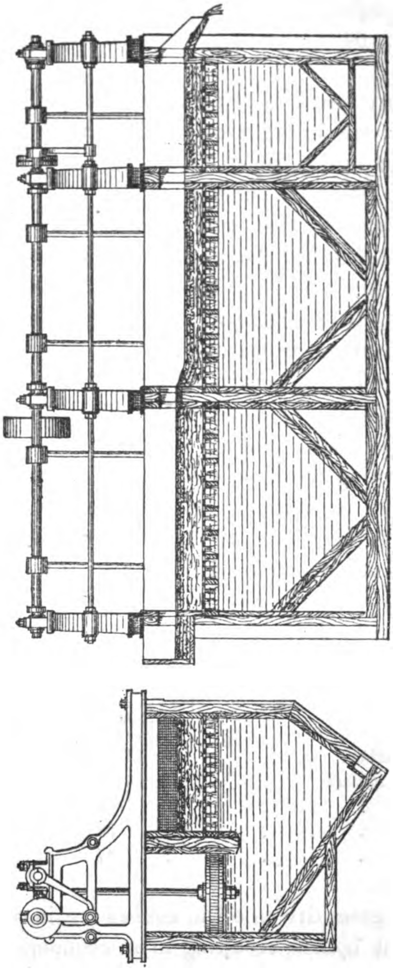

Fig. 64.—Coal-washing Machine.

some few cases in this country, these gases are condensed and made to yield up the several constituents contained in them, such as ammonia, tar, benzol, amongst others.

COKING.—The types of coke ovens in use are varied, but that known as the "Beehive," of which Fig. 65 is an example, may be considered to be one of the oldest and most generally used. Amongst others of old type may be enumerated the Welsh rectangular oven; and among newer ovens, which have for their object the more rapid coking and the saving of labour, as also in some cases the recovery of bye-products, such as ammonia, tar, and benzol, are the Coppée, Simon-Carvés, Otto, Semet-Solvay, etc., varying in the arrangement of the flues for heating the ovens.

A beehive oven of the dimensions given in Fig. 65—viz., a diameter of 11 feet and height of 8 feet—would require a charge of 11 tons of small coal, and would cost approximately £60 to build. The oven being charged, it remains sealed up for a period of 72 hours, after which time the coal should be found to be sufficiently coked. The door is then unsealed and the heated mass is thoroughly watered by means of a water hydrant, after which the coke is drawn and is ready for use.

The Welsh rectangular oven (Fig. 66) consists of an arched brick chamber, 14 to 16 feet long, by 5 to 6 feet wide at the back, and 6 to 6½ feet at the front end, and a height of 5 feet to 5 feet 6 inches to the top of the arch.

The door is built of firebrick, held together by an iron frame, counterbalanced by weights connected with it by a chain passing over a pulley above the door. The ovens hold a charge of 4½ tons for the first three days of the week and 5 tons for the remaining four (including Sundays); 72 hours are allowed for coking the smaller charge and 96 for

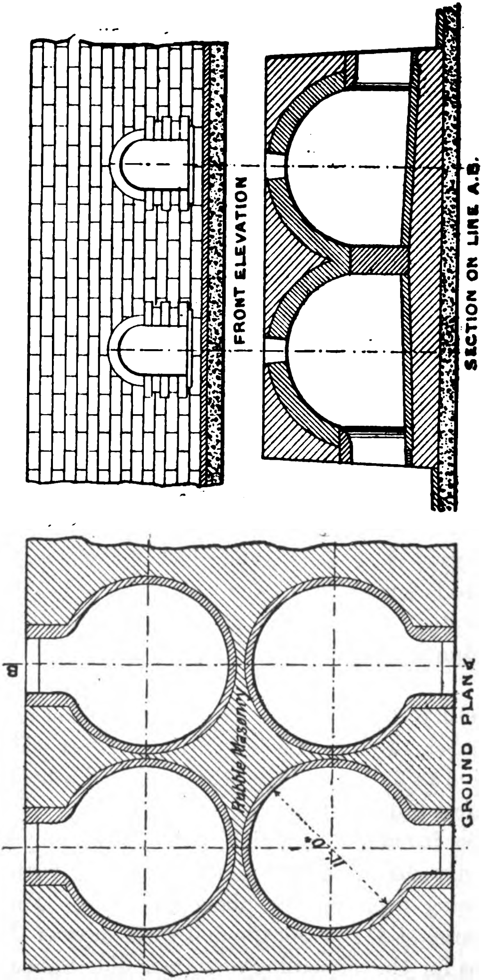

Fig. 65.—Beehive Coke Oven.

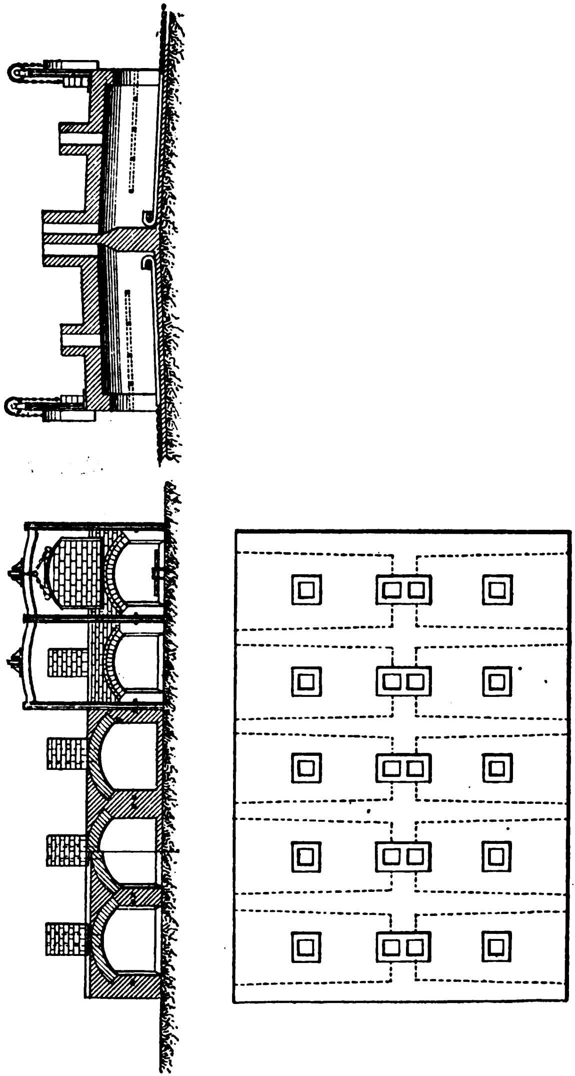

Fig. 66.—Welsh Rectangular Coke Oven.

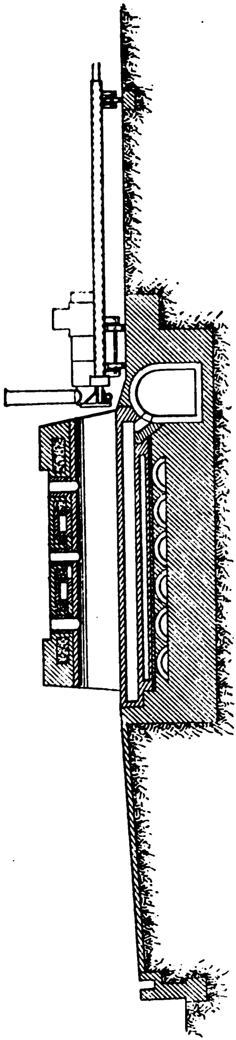

Fig. 67.—Coppée Coke Oven.

the larger. The ovens are usually filled from holes in the top of the ovens. Before filling, a heavy iron rail, bent at one end, is placed on the floor of the oven, with a short one laid across it.

At the back end of the oven, when the charge is ready for drawing, a chain is attached to these rails and the whole charge is pulled out by means of a crab winch. In some cases the coke is watered in the oven and in others after it has been withdrawn.

Fig. 67 shows an ordinary type of the Coppée oven, of a length of 30 feet, a width of 17 inches, and a height of 5 feet 4 inches, which will serve to illustrate the general features of the retort ovens. The oven is filled from the top, three openings, which are kept covered with iron doors, being provided for the purpose. The charge consists of 2 tons 10 cwts. of coal, and the length of time occupied is 24 hours, producing 32 to 35 cwts. of coke. Iron doors are provided at each end.

When the charge is ready for drawing, a ram or pusher is inserted at the back end of the oven, driven by a small steam-engine, and is forced through the length of the oven, pushing the red-hot contents on to a platform, where it is quenched with water. The ram or pusher engine travels on rails to enable it to be brought opposite any oven as required.

In the case of a coal containing a large quantity of volatile constituents this oven is constructed of a greater width, up to 24 inches in width.

Coke made in this and other classes of what are known as retort ovens is usually shorter and of a duller colour, and lacks much of that silvery appearance so noticeable in coke made in the older type of oven; but so long as the coke be pure, hard, and dense, iron and steel manufacturers now generally admit that its appearance, on which so much store was set in past days, is a matter of little moment.

The percentage of coke yielded will vary both with the nature of the coal and the type of oven adopted, but generally it may be taken to vary from 60 to 75 per cent., the latter usually in coking coal containing the minimum quantity of volatile matter, and where retort ovens are adopted.

Where it is the intention to recover the bye-products, such as ammonia, tar, and benzol, from the waste gases driven off in the process of coking, they are drawn off by exhausters and subjected to the following processes:—

1. Cooling, resulting in the condensation of tar and water.
2. Washing with water to absorb the ammonia gas.
3. Washing with creosote to recover benzol.

The gases are first passed through coolers, which consist, in the case of the Simon-Carvés ovens, of long serpentine pipes upon which a spray of water plays. The gases in passing through the cooler will be reduced in temperature some 100 degrees centigrade. The tar and ammonia liquor (resulting from this condensation) are collected in a tank. In this tank the tar, being the heavier, sinks to the bottom, whilst the ammonia liquor floats uppermost. Both are then pumped into separate tanks, the ammonia liquor tank being erected overhead. The gases after being cooled and yielding up the above products, are passed upwards, through four towers filled with coke or other suitable substance. A stream of weak ammonia liquor from the overhead tank already mentioned is allowed to trickle down these towers, meeting the gases coming upwards, the result being the concentration of the ammonia. To extract all traces of ammonia, the gases are then washed by being passed through water.

The concentrated ammonia liquor, together with the water used in this last washing, which will contain a certain quantity of ammonia, is returned to the overhead tank and thoroughly circulated. The gases thus freed from ammonia are passed through similar towers in which creosote oils are circulated. These latter dissolve the benzol contained in the gases and the latter are then passed through a condenser to recover any creosote oil which they have absorbed, after which they are passed through sulphuric acid to extract any ammonia which has escaped condensation. The gases are then returned to the ovens and utilised to heat them.

The ammonia liquor recovered in the process thus described is run into stills heated with steam, and lime is here mixed with it, resulting in the ammonia gas being driven off, which is passed through strong sulphuric acid. Solid sulphate of ammonia, used as a manure, is thus formed, whilst the creosote oils containing the benzol are distilled in retorts, and crude benzol is thus obtained which is distilled one or more times until the requisite purity is obtained. The quantity of the several bye-products yielded will depend upon the nature of the coal used.

The recovery of bye-products is at the present day a remunerative process, and has made very much greater progress on the Continent than in our country, largely due to the fear that their recovery would deteriorate the quality of the coke. This is rapidly being found not to be the case, and this branch of the coal industry may, therefore, be expected to become more generally adopted in the future.

CHAPTER XX.

COLLIERY ACCIDENTS AND THEIR PREVENTION.

THE melancholy fact that from 900 to 1,200 persons are every year killed in our British coal-mines forcibly attracts attention to the inquiry, what proportion of these numerous accidents are due to preventable causes, and how far a part of them are inseparable from the dangerous nature of the collier's occupation. When a catastrophe of unusual magnitude occurs, public feeling is aroused, newspaper articles are written, and Parliamentary inquiries are set on foot; but the majority of the accidents are little noticed, except in the immediate vicinity, and they take place at points so remote and so widely distributed, as to show that the main difficulty in dealing with them rests in the necessity of keeping up an unceasing watchfulness among many thousands of men, workmen as well as managers.

It has resulted, chiefly from the excitement caused by the more destructive explosions, that several volumes have been published, filled with important evidence given before Committees of the Lords and Commons in 1835, 1848, 1852, and 1854. Furthermore, since the Mine Inspection Act in 1850, and the appointment of inspectors under the Home Office, now 13 in number, besides assistant-inspectors and those appointed for the metalliferous mines, a vast amount of valuable information is afforded in their published reports, especially in the analysis of the chief accidents which have taken place in the year. By this means not only are principles and details of practice laid down and confirmed, but many of what may be termed accidents from unforeseen causes are so set before us that a diligent study of their descriptions ought year by year to diminish their occurrence. It is sometimes objected to Government inspection that the number of casualties is not diminished; but it should be borne in mind that the quantity of coal annually extracted has been so largely on the increase that if, with a nearly doubled production, and, of course, with a much greater number of hands, the sum total of deaths has not increased, the results of the system cannot but be considered as successful.

The careful perusal of these documents is strongly recommended to all who are interested in colliery operations, and from their detailed explanations it will be seen that not a year passes without accidents arising from an infraction, wilful or accidental, of rules which have been laid down as being generally applicable.

The following are the General Rules to be observed under the Coal Mines Regulation Act, 1887:—

(1) An adequate amount of ventilation shall be constantly produced in every mine to dilute and render harmless noxious gases to such an extent that the working places of the shafts, levels, stables, and workings of the mine, and the travelling roads to and from those working places, shall be in a fit state for working and passing therein.

In the case of mines required by this Act to be under the control of a certificated manager, the quantity of air in the respective splits or currents shall at least once in every month be measured and entered in a book to be kept for the purpose at the mine.

(2) Where a fire is used for ventilation in any mine newly opened after the passing of this Act, the return air, unless it be so diluted as

not to be inflammable, shall be carried off clear of the fire by means of a dumb drift or air-way.

(3) Where a mechanical contrivance for ventilation is introduced in any mine after the commencement of this Act, it shall be in such position, and placed under such conditions, as will tend to ensure its being uninjured by an explosion.

(4) A station or stations shall be appointed at the entrance to the mine, or to different parts of the mine, as the case may require; and the following provisions shall have effect:

(i) As to inspection before commencing work:

A competent person or competent persons appointed by the owner, agent, or manager, for the purpose, not being contractors for getting minerals in the mine, shall, within such time immediately before the commencement of each shift as shall be fixed by special rules made under this Act, inspect every part of the mine situate beyond the station or each of the stations, and in which workmen are to work or pass during that shift, and shall ascertain the condition thereof so far as the presence of gas ventilation, roof and sides, and general safety are concerned.

No workman shall pass beyond any such station until the part of the mine beyond that station has been so examined and stated by such competent person to be safe.

The inspection shall be made with a locked safety-lamp, except in the case of any mine in which inflammable gas has not been found within the preceding twelve months.

A report specifying where noxious or inflammable gas, if any, was found present, and what defects, if any, in roofs or sides, and what, if any, other source of danger were or was observed, shall be recorded without delay in a book to be kept at the mine for the purpose, and accessible to the workmen, and such report shall be signed by and, so far as the same does not consist of printed matter, shall be in the handwriting of the person who made the inspection.

For the purpose of the foregoing provisions of this rule, two or more shifts succeeding one another without any interval are to be deemed to be one shift.

(ii) As to inspection during shifts:

A similar inspection shall be made in the course of each shift of all parts of the mine in which workmen are to work or pass during that shift, but it shall not be necesary to record a report of the same in a book: Provided that, in the case of a mine worked continuously throughout the twenty-four hours by a succession of shifts, the report of one of such inspections shall be recorded in manner above required.

(5) A competent person or competent persons appointed by the owner, agent, or manager for the purpose, shall once at least in every twenty-four hours examine the state of the external parts of the machinery, the state of the guides and conductors in the shafts, and the state of the head-gear, ropes, chains and other similar appliances of the mine which are in actual use both above ground and below ground, and shall once at least in every week examine the state of the shafts by which persons ascend or descend; and shall make a true report of the result of such examination, and every such report shall be recorded without delay in a book to be kept at the mine for the purpose, and shall be signed by the person who made the inspection.

(6) Every entrance to any place which is not in actual use or course of working and extension, shall be properly fenced across the whole width of the entrance, so as to prevent persons inadvertently entering the same.

(7) If at any time it is found by the person for the time being in charge of the mine, or any part thereof, that by reason of inflammable gases prevailing in the mine, or that part thereof, or of any cause whatever, the mine or that part is dangerous, every workman shall be withdrawn from the mine or part so found dangerous, and a competent person appointed for the purpose shall inspect the mine or part so found dangerous, and if the danger arises from inflammable gas shall inspect the mine or part with a locked safety-lamp, and in every case shall make a true report of the condition of the mine or part; and a workman shall not, except in so far as is necessary for inquiring into the cause of danger, or for the removal thereof, or for exploration, be readmitted into the mine or part so found dangerous, until the same is stated by the person appointed as aforesaid not to be dangerous. Every such report shall be recorded in a book which shall be kept at the mine for the purpose, and shall be signed by the person who made the inspection.

(8) No lamp or light other than a locked safety-lamp shall be allowed or used:

(*a*) In any place in a mine in which there is likely to be any such quantity of inflammable gas as to render the use of naked lights dangerous; or

(*b*) In any working approaching near a place in which there is likely to be an accumulation of inflammable gas.

And when it is necessary to work the coal in any part of a ventilating district with safety-lamps it shall not be allowable to work the coal with naked lights in another part of the same ventilating district situated between the place where such lamps are being used and the return air-way.

(9) Wherever safety-lamps are used they shall be so constructed that they may be safely carried against the air current ordinarily prevailing in that part of the mine in which the lamps are for the time being in use, even though such current should be inflammable.

(10) In any mine or part of a mine in which safety-lamps are required by this Act, or by the special rules made in pursuance of this Act, to be used—

(i) A competent person appointed by the owner, agent, or manager for the purpose shall, either at the surface or at the appointed lamp station, examine every safety-lamp immediately before it is taken into the workings for use, and ascertain it to be in safe working order and securely locked; and such lamps shall not be used until they have been so examined and found in safe working order and securely locked:

(ii) A safety-lamp shall not be unlocked except either at the appointed lamp station or for the purpose of firing a shot, in conformity with the provisions hereinafter contained:

(iii) A person, unless he has been appointed either for the purpose of examining safety-lamps, or for the purpose of firing shots, shall not have in his possession any contrivance for opening the lock of any safety-lamp:

(iv) A person shall not have in his possession any lucifer match or apparatus of any kind for striking a light, except within a completely closed chamber attached to the fuse of the shot.

(11) Where safety-lamps are required to be used, the position of the lamp stations for lighting or re-lighting the lamps shall not be in the return air.

(12) Any explosive substance shall only be used in the mine below ground as follows:

(*a*) It shall not be stored in the mine:

(*b*) It shall not be taken into the mine, except in cartridges in a secure case or canister containing not more than five pounds:

Provided that on the application of the owner, agent, or manager of any mine, the Secretary of State may by order exempt such mine from so much of this rule as forbids taking an explosive substance into the mine except in cartridges.

(*c*) A workman shall not have in use at one time in any one place more than one of such cases or canisters:

(*d*) In the process of charging or stemming for blasting, a person shall not use or have in his possession any iron or steel pricker, scraper, charger, tamping-rod, or stemmer, nor shall coal or coal-dust be used for tamping:

(*e*) No explosive shall be forcibly pressed into a hole of insufficient size, and, when a hole has been charged, the explosive shall not be unrammed, and no hole shall be bored for a charge at a distance of less than six inches from any hole where the charged has missed fire:

(*f*) In any place in which the use of a locked safety-lamp is for the time being required by or in pursuance of this Act, or which is dry and dusty, no shot shall be fired except by or under the direction of a competent person appointed by the owner, agent, or manager of the mine, and such person shall not fire the shot or allow it to be fired until he has examined both the place itself where the shot is to be fired and all contiguous accessible places of the same seam within a radius of twenty yards, and has found such place safe for firing:

(*g*) If in any mine, at either of the four inspections under Rule 4 recorded last before a shot is to be fired, inflammable gas has been reported to be present in the ventilating district in which the shot is to be fired, the shot shall not be fired—

(1) Unless a competent person appointed as aforesaid has examined the place where gas has been so reported to be present, and has found that such gas has been cleared away, and that there is not at or near such place sufficient gas issuing or accumulated to render it unsafe to fire the shot; or

(2) Unless the explosive employed in firing the shot is so used with water or other contrivance as to prevent it from inflaming gas, or is of such a nature that it cannot inflame gas:

(*h*) If the place where a shot is to be fired is dry and dusty, then the shot shall not be fired unless one of the following conditions is observed, that is to say—

(1) Unless the place of firing and all contiguous accessible places within a radius of twenty yards therefrom are

at the time of firing in a wet state from thorough watering or other treatment equivalent to watering in all parts where dust s lodged, whether roof, floor, or sides; or

(2) In the case of places in which watering would inure the roof or floor, unless the explosive is so used with water or other contrivance as to prevent it from inflaming gas or dust, or is of such a nature that it cannot inflame gas or dust:

(*i*) If such dry and dusty place is part of a main haulage road, or is a place contiguous thereto, and showing dust adhering to the roof and sides, no shot shall be fired there unless—

(1) Both the conditions mentioned in sub-head (*h*) have been observed; or

(2) Unless such one of the conditions mentioned in sub-head (*h*) as may be applicable to the particular place has been observed, and moreover all workmen have been removed from the seam in which the shot is be fired, and from all seams communicating with the shaft on the same level, except the men engaged in firing the shot, and such other persons, not exceeding ten, as are necessarily employed in attending to the ventilating furnaces, steam boilers, engines, machinery, winding apparatus, signals, or horses, or in inspecting the mine:

(*k*) In this Act "ventilating district" means such part of a seam as has an independent intake commencing from a main intake air-course, and an independent return air-way terminating at a main return air-course; and "main haulage road" means a road which has been, or for the time being is, in use for moving trams by steam or other mechanical power:

(*l*) Where a seam of a mine is not divided into a separate ventilating district the provisions in this Act relating to ventilating districts shall be read as though the word "seam" were substituted for the words "ventilating district":

(*m*) So much of this rule as requires the explosive substance taken into the mine to be in cartridges, and so much of the provisions of sub-head (*f*) as relates to a dry and dusty place, and the provisions (*g*), (*h*), (*i*), (*k*), and (*l*), shall not apply to seams of clay or stratified ironstone which are not worked in connection with any coal seam, and which contain no coal in the working.

(13) Where a place is likely to contain a dangerous accumulation of water, the working approaching that place shall not at any point within forty yards of that place exceed eight feet in width, and there shall be constantly kept at a sufficient distance, not being less than five yards in advance, at least one borehole near the centre of the working, and sufficient flank boreholes on each side.

(14) Every underground plane on which persons travel which is self-acting or worked by an engine, windlass, or gin, shall be provided (if exceeding thirty yards in length) with some proper means of communicating distinct and definite signals between the stopping places and the ends of the plane, and shall be provided in every case with sufficient man-holes for places of refuge at intervals of not more than twenty yards; or if there is not room for a person to stand between the side of a tub and the side of a plane, then (unless the tubs are moved by an endless chain or rope) at intervals of not more than ten yards.

(15) Every road on which persons travel underground where the load is drawn by a horse or other animal shall be provided, at intervals of not more than fifty yards, with sufficient man-holes, or with places of refuge, and every such place of refuge shall be of sufficient length, and at least three feet in width, between the waggons running on the road and the side of such road. There shall be at least two proper travelling ways into every steam-engine room and boiler gallery.

(16) Every man-hole and every place of refuge shall be constantly kept clear, and no person shall place anything in any such man-hole or place of refuge.

(17) Every travelling road on which a horse or other draft animal is used underground shall be of sufficient dimensions to allow the horse or other animal to pass without rubbing against the roof or timbering.

(18) The top of every shaft which for the time being is out of use, or used only as an air-shaft, shall be, and shall be kept, securely fenced.

(19) The top, and all entrances between the top and bottom, including the sump, if any, of every working, ventilating, or pumping shaft shall be properly fenced, but this shall not be taken to forbid the temporary removal of the fence for the purpose of repairs or other operations, if proper precautions are used.

(20) Where the natural strata are not safe, every working or pumping shaft shall be securely cased, lined, or otherwise made secure.

(21) The roof and sides of every travelling road and working place shall be made secure, and a person shall not, unless appointed for the

purpose of exploring or repairing, travel, or work in any such travelling road, or working place, which is not so made secure.

(22) Where the timbering of the working places is done by the workmen employed therein, suitable timber shall be provided at the working place, gate-end, pass-bye, siding, or other similar place in the mine convenient to the workmen, and the distance between the sprags or holing-props, where they are required, shall not exeeed six feet, or such less distance as may be ordered by the owner, agent, or manager.

(23) Where there is a downcast and furnace shaft to the same seam, and both such shafts are provided with apparatus in use for raising and lowering persons, every person employed in the mine shall, on giving reasonable notice, have the option of using the downcast shaft.

(24) In any mine which is usually entered by means of machinery, a competent male person, not less than twenty-two years of age, shall be appointed for the purpose of working the machinery which is employed in lowering and raising persons therein, and shall attend for that purpose during the whole time that any person is below ground in the mine.

Where any shaft, plane, or level is used for the purpose of communication from one part to another part of a mine, and persons are taken up or down or along such shaft, plane, or level, by means of any engine, windlass, or gin, driven or worked by steam, or any mechanical power, or by an animal, or by manual labour, the person in charge of such engine, windlass, or gin, or of any part of the machinery, ropes, chains, or tackle connected therewith, must be a competent male person not less than eighteen years of age.

Where the machinery is worked by an animal, the person under whose direction the driver of the animal acts shall, for the purposes of this rule, be deemed to be the person in charge of the machinery.

(25) Every working shaft used for the purpose of drawing minerals or for the lowering or raising of persons shall, if exceeding fifty yards in depth, and not exempted in writing by the inspector of the district, be provided with guides and some proper means of communicating distinct and definite signals from the bottom of the shaft and from every entrance for the time being in use between the surface and the bottom of the shaft to the surface, and from the surface to the bottom

of the shaft, and to every entrance for the time being in use between the surface and the bottom of the shaft.

(26) If in any mine the winding apparatus is not provided with some automatic contrivance to prevent over-winding, then the cage, when men are being raised, shall not be wound up at a speed exceeding three miles an hour after the cage has reached a point in the shaft to be fixed by the special rule.

(27) A sufficient cover overhead shall be used for every cage or tub employed in lowering or raising persons in any working shaft, except where the cage or tub is worked by a windlass, or where persons are employed at work in the shaft, or where a written exemption is given by the inspector of the district.

(28) A single-linked chain shall not be used for lowering or raising persons in any working shaft or plane, except for the short coupling chain attached to the cage or tub.

(29) There shall be on the drum of every machine used for lowering or raising persons such flanges or horns, and also if the drum is conical, such other appliances as may be sufficient to prevent the rope from slipping.

(30) There shall be attached to every machine worked by steam, water, or mechanical power, and used for lowering or raising persons, an adequate brake, or brakes, and a proper indicator (in addition to any mark on the rope) showing to the person who works the machine the position of the cage or tub in the shaft. If the drum is not on the crank-shaft, there shall be an adequate brake on the drum-shaft.

(31) Every fly-wheel, and all exposed and dangerous parts of the machinery used in or about the mine, shall be and shall be kept securely fenced.

(32) Each steam boiler, whether separate or one of a range, shall have attached to it a proper safety valve, and also a proper steam gauge and water gauge, to show respectively the pressure of steam and the height of water in each boiler.

(33) A barometer and thermometer shall be placed above ground in a conspicuous position near the entrance to the mine.

(34) Where persons are employed underground, ambulances or stretchers, with splints and bandages, shall be kept at the mine ready for immediate use in case of accident.

(35) No person shall wilfully damage, or, without proper authority, remove or render useless, any fence, fencing, man-hole, place of refuge, casing, ining, guide, means of signalling, signal, cover, chain, flange, horn, brake, indicator, steam gauge, water gauge, safety valve, or

other appliance or thing provided in any mine in compliance with this Act.

(36) Every person shall observe such directions with respect to working as may be given to him with a view to comply with this Act or the special rules in force in the mine.

(37) The books mentioned in these rules shall be provided by the owner, agent, or manager, and the books, or a correct copy thereof, shall be kept at the office at the mine, and any inspector under this Act, and any person employed at the mine, or anyone having the written authority of any inspector or person so employed, may at all reasonable times inspect and take copies of and extracts from any such books: but nothing in these rules shall be construed to impose the obligation of keeping any such book or a copy thereof for more than twelve months after the book has ceased to be used for entries therein under this Act.

Any report by this Act required to be recorded in a book may be partly in print (including lithograph) and partly in writing.

(38) The persons employed in a mine may from time to time appoint two of their number, or any two persons, not being mining engineers, who are practical working miners, to inspect the mine at their own cost, and the persons so appointed shall be allowed, once at least in every month, accompanied, if the owner, agent, or manager of the mine thinks fit, by himself or one or more officers of the mine, to go to every part of the mine, and to inspect the shafts, levels, planes, working places, return air-ways, ventilating apparatus, old workings, and machinery. Every facility shall be afforded by the owner, agent, and manager, and all persons in the mine, for the purpose of the inspection, and the persons appointed shall forthwith make a true report of the result of the inspection, and that report shall be recorded in a book to be kept at the mine for the purpose, and shall be signed by the persons who made the inspection; and if the report state the existence or apprehended existence of any danger, the owner, agent, or manager shall forthwith cause a true copy of the report to be sent to the inspector of the district.

(39) No person not now employed as a coal or ironstone getter shall be allowed to work alone as a coal or ironstone getter in the face of the workings until he has had two years' experience of such work under the supervision of skilled workmen, or unless he shall have been previously employed for two years in or about the face of the workings in a mine.

The various districts are more or less subject to different kinds of accident, according to local conditions, and the causes are shown in the table of deaths for 1897.

Name of District.	Explosions.	Falls of Roof and Coal.	Deaths in Shafts.	Miscellaneous, underground.	On Surface.	Total.
1. East Scotland . .	4	41	8	22	13	88
2. West Scotland . .	2	31	5	10	6	54
3. Newcastle . . .	—	47	6	21	6	80
4. Durham	—	51	6	39	11	107
5. Yorkshire and Lincolnshire	3	51	2	29	12	97
6. Manchester . . .	—	28	1	26	4	59
7. Liverpool . . .	—	47	3	26	10	86
8. Midland	1	32	2	15	7	57
10. North Staffordshire	—	14	4	9	4	31
11. South Staffordshire	2	15	4	9	3	33
12. South-Western . .	1	39	1	16	5	62
13. South Wales . .	6	84	15	55	16	176
Lives lost in coal pits in 1897	19	480	57	277	97	930
Total in year 1896 . .	173	424	68	237	123	1,025

Let us pass to a review of the more prolific sources of accident :—

1. *Falls of Roof.*—These are occasioned, especially in high seams, by the removal of the upper portions of the coal, more particularly when the whole thickness, as for the most part in South Staffordshire, is taken at one working. In other cases they arise from careless holing or undercutting, without due attention to sprags or props, or from the sudden detaching of bell-moulds, or lumps of ironstone, or masses of shale from the roof. In general, these falls can only be guarded against by limiting the size of the excavations, and setting timber in sufficient quantity, and in the most judicious manner. When the ordinary colliers are not practised or apt at this work, it is

important that it should be carried out by duly qualified deputies. In some parts of the country an unfortunate system prevails of employing *butties*, or contractors, who, intent on getting the coal at a certain price, are prone to neglect the precautions which cost money, and which thus diminish their profits. In the long-wall workings, where the fall of the roof has for a stranger a most threatening appearance, nogs and pack-walls as well as single punch-props aid in giving the men security; but when the roof is treacherous, hourly caution needs to be exercised by the managers and supervisors; and whilst in some cases the premature removal of props may be dangerous, in others the omission to remove some of them will cause an irregular fracture, often attended with serious results. Whatever the method of work, let there be no lack of prop-wood; and to prevent neglect caused by the colliers grudging the time which would have been devoted to it, let such wood be cut for them in proper lengths, and carried near to their places of work. It is no less lamentable to note the great loss of life from supineness and blind confidence with respect to the roof than it is wonderful to see what may be done for a limited time by a few well-set sticks of timber in the midst of crush and pressure that appear overwhelming.

2. *Explosions of Fire-damp.*—According to the abundance of gas, the form of the excavations, and the efficiency of the ventilation, explosions may be either quite harmless, or may injure only one man, or a few men in a single locality, or in the worst cases may flash forth with such lightning speed and fury as to leave not a man alive.

The safety-lamp is, however, now commonly used under most circumstances; and yet, even with this safeguard, when, for economy's sake, the coal is got by blasting, there is great risk of a flame being lighted which may communicate with other places or set fire to the coal. Presence of mind—a virtue often wanting—may in the outset extinguish a flash of this kind, which if not instantly combated may soon become very serious. A fire produced in this manner, or by the spontaneous combustion which arises in the small coal of certain seams, in a short time produces such a smoke and "stythe" that it can only be approached on the windward side, and frequently makes it needful to retire to some distance, and bar off or isolate the district. In such cases dam-doors, the frames of which have been prepared beforehand at suitable spots in the main drifts, may perform excellent service. Perhaps these are nowhere seen to greater advantage or more practically useful than in the great under-sea collieries of Whitehaven, where the Earl of Lonsdale has judiciously had the lintels, etc., of dam-doors prepared in the stone drifts between faulted districts of coal.*

In Chapter XVII. we have treated of the methods of ventilation in practice where due attention is paid to that vital subject; but we have here two questions to answer, viz., why is it, that with so many examples of what can be well done, a large part of our collieries should be in a condition far from satisfactory? and how does it come to pass that every now and then a hecatomb of victims has been sacrificed in a pit supposed to be a model of efficiency? To these we may reply: first, that thoughtlessness and opposition to discipline among the men, and ignorance of principles and of good practice, with parsimoniousness, among the masters and managers, are far too common; and secondly,

* In August, 1864, I had the opportunity of seeing how promptly efficient dams were thus put in to isolate the workings of the new, or Forster's district, where the gas had fired in the dip drifts.

that the sources of accident are so numerous, and often so obscure, that no amount of precaution can be expected to obtain perfect security.

My own experience on this latter head, obtained from close inquiry for the Government into the causes of several heavy explosions, before the system of inspection was commenced, and from frequent visits to collieries in most of our districts, is strongly confirmed by the often-repeated statements of the inspectors, that a great amount of good would be effected by local schools having a technical aim. And yet, strange to say, although it is a subject involving the health and life of 600,000 persons directly employed in our coal-mines, until late years no approach was made, except at Bristol, Wigan, and an abortive attempt at Glasgow, to supply that kind of knowledge on mechanics, the nature of gases, etc., which is so desirable for the overmen and their deputies.

In what concerns the ventilation, a dangerous state of the mine may arise as follows:—

1. Absence or deficiency of ventilating power in the shaft.

2. Injudicious plan of working, or inattention to doors, stoppings, size of air-courses, etc., whereby an abundant current at the shafts is lost before it gets to the faces of work.

3. The insecure position of goafs or wastes, or even small lodgments for gas, with reference to the air currents which have to travel past men who are using open lights.

4. The absence of sufficient bratticing in the bords or drift-ends.

5. Dependence upon too many doors.

6. The occurrence of falls in the air-ways or working drifts. Presence of much fine coal-dust.

7. The interruption of the ventilating current, by repairs in the shaft, by drawing water, or by the furnace or wind machine going wrong.

8. A sudden change of weather, especially a turn of wind to the south-west, with lower barometer and higher temperature.

9. The emission of gas by blowers, or by bursting in from roof or floor, in such quantity as to overpower the ventilation.

In this latter case the use of safety-lamps can alone give security, and since their introduction brings into play a new set of conditions it is imperatively needful to draw up special rules regarding them, and in the interest of the owners and the bulk of the men to visit severely all the infringements of regulations which close surveillance can detect. We cannot do better, in order to show what are the requirements in connection with the use of safety-lamps, than quote the special rules as laid down for the extensive colliery of Seaton Delaval, under the able management of Mr. T. E. Forster :—

1. In every part of the said colliery, where the pillar working or broken is in operation, stations will be fixed upon by the viewer, where each workman's safety-lamp will be examined and securely locked.

From those stations no workman is to take a safety-lamp for use in the pillar working or broken without its having been examined and securely locked by the overman, inspector, or deputy.

The overman and inspector to have full power to direct the workmen how to use their safety-lamps during the time of working ; and it is particularly enjoined that every workman strictly attend to such directions. No lamp to be used on which there is not a tin shield. None but the overman, or similar officer in authority, to be allowed to carry a lamp-key.

2. Should any accident happen to a lamp whilst in use, by which the oil is spilt upon the gauze, or it be in any other way rendered unsafe, the light to be immediately extinguished by drawing the wick

down within the tube with the pricker; such lamp to be directly taken out to the station where the lamps are examined, and not to be again used until after having been properly examined by the overman, or other responsible person, on the in-bye side of which station towards the broken workings no candles are to be taken.

3. Should any workman using a safety lamp detect, by the usual indications, the appearance or presence of fire-damp, he is first to pull down the wick with the pricker, as before mentioned, and then to retreat to the lamp station and give information of the same to the nearest responsible person, it being strictly forbidden for any workman to continue to work in a place where such indications have been observed by him; and should the flame continue in the interior of the lamp after the wick has been drawn down, the lamp then to be cautiously removed, and no attempt whatever to extinguish the flame by any other means to be adopted by the workman.

4. Every hewer, putter, or other person, to whom a safety-lamp is entrusted is hereby strictly prohibited from interfering in any way whatever with the lamp, beyond the necessary trimming of the wick with the pricker. The lamp in no case to be hung upon the row of props next the goaf or old work, and not to be nearer the swing of the gear on any occasion than two feet.

5. Should any hewer, putter, or any other person whatever, in charge of a safety-lamp, in any case lose his light, he is to take it himself to the station where the lamps are examined, to be relighted, examined, and locked by the overman, or some other responsible person, before being again used.

6. It is expressly directed that any person witnessing any improper treatment of the safety-lamps by anyone, shall give immediate information to the overman in charge of the pit, so that a recurrence of such conduct may be prevented by the offending party being brought to justice.

7. Any person found smoking tobacco in any part of the said colliery where the safety-lamp is used, or with a tobacco pipe found in his possession, will be liable to be taken before a magistrate. No matches, under any pretence whatever, to be taken down the pit.

8. No putter, pony-driver, helper-up, or other person, is, under any pretext, to carry a lamp during his work, except in special cases, where the parties have leave to do so from the viewer. Lamps will be hung along the going-roads, to afford sufficient light for the performance of the work.

9. Every person using a safety-lamp to receive the bottom part of

the same himself from the hands of the lamp keeper then in the pit. The gauze to be taken home at the end of each shift, by the person using it, for the purpose of having it properly cleaned before being again used.

10. Any person acting contrary to the above instructions will be liable to be taken before a magistrate, in order that the lives of the workmen employed therein may be duly protected. And any person informing against any offending party or parties will, in every case, be handsomely rewarded. No riding on loaded cages except under special arrangement. Signals, see Act of Parliament.

11. The hewer that keeps his safety-lamp in the best order for a quarter of a year will be entitled to a premium of 5s.; and for the second best, 2s. 6d. The putter to be entitled to 2s. 6d. for the same length of time.

It is a moot point whether the men should take home the lamp gauzes to clean, or whether it should be done for them by the colliery, now the usual course adopted. But we cannot fail to reprobate the neglectful plan which was until the last few years pursued in some mines of throwing upon the colliers the burden of purchasing their lamps, and thus exposing them to the temptation of buying cheap and unsafe gauze. Nor can one think without ire of the dirty, oily state of the battered Davy that one has seen in some of the colliery offices of central districts, kept for a safeguard (?) in case of fire-damp being feared as an occasional visitor.

3. *Accidents in Shafts.*—The breakage of the rope or chain takes place rarely from bad quality, more often from too long wear and tear of the material. Sometimes a want of proper horns or arms to the drum, or a settlement of the ground at the shaft top, may throw the rope on to the axle, and thus sever it. Any inequality in the surface of the rope-roll which makes the rope lap irregularly, and thus communicates a heavy jerk to the weight in the shaft, is dangerous, especially with wire rope. So also is the adherence to small-size drum and pulleys. Many lives, again, are

lost under the old system of raising the men in skips or boxes hanging free, particularly if they be suspended by two chains only. The introduction of cages and guides in the several districts has greatly lessened the liability to this class of accident. Against the falling of stone, bricks, etc., from the sides, a good walling and occasionally overhauling and clearing from rubbish, with a bonnet or cover over the cage, are efficient protections. The numerous deaths from falling into the shaft, either from surface or from mouthings opening into upper seams, may be in great measure prevented by the use of light, railed doors or wickets which guard the orifice until the cage comes up and lifts them out of the way for the time only during which access is needed. Overwinding, one of the most frightful of accidents, where the cage with its human freight is carried up violently against the pulleys overhead, is to be avoided by the employment of only the most trustworthy engine-drivers, the use of the steam-brake, a sufficient height of pulley-frame, and perhaps in some cases the use of the safety apparatus referred to above in Chapter XIV.

The carefully-prepared statistics of Her Majesty's Inspectors of Coal-mines group the accidents under different heads, and among other valuable results show that the casualties in shafts have in the last 30 years been greatly reduced. Whilst in the years 1851 to 1855 one death per annum occurred by shaft accidents out of 1,000 persons, the ratio has of late years, and by a steady process of improvement, been reduced to one death out of 5,017 persons employed. Greater caution has come to be exercised by all parties, superior tackling is used, and close attention is given to its examination; but as a rule the ingenious contrivances for arresting the cage when the rope breaks have not met with extended favour. The comparatively very small number of accidents from "overwinding" redounds to the credit of the engine-men of the country, and the condition of their appliances; but some recent cases, accompanied by a sad loss of life, have drawn more attention to the subject of special contrivances for arresting the load when it is raised too high.

Detaching links or hooks were proposed 30 years ago, but in some, at least, of the forms suggested there were positive sources of danger. Of late a number of others have come to the fore, and, what with popular pressure, and the suggestions of Government officials, are being adopted in great numbers. Whether this is altogether a wholesome way of advancing, and whether the introduction into the winding gear of any piece of complication is not a new source of danger, are questions upon which opinions will differ. Most of these disengaging or safety links and hooks are patented, and run a close race of rivalry: some few have been offered freely as a boon to the mining world.

Mr. Aytoun, W.S., of Edinburgh, in 1860 proposed a hook formed of three parallel plates of steel, the central one of which, standing out in its normal position beyond the side pieces, should, on overwinding, be drawn through a narrow ring, and thus cause the central plate to push the shackle by which the load is suspended off its usual seat, so that it falls through a vertical slot and disconnects the cage from the rope. Mr. J. Bryham, of the Rosebridge colliery, nearly about the same time introduced the hook, on a similar principle, which is shown in Fig. 68 under three aspects. Here *a a* are two parallel plates of wrought iron, with vertical slot *b*; *d* is a central plate, *f* a brass pin, which keeps it in a projecting position till the pin is sheared by *d* coming in contact with the iron plate *g*, when the shackle will be pushed from its bearing to the slot *b*.

The cage is then arrested by strong cams or catches attached to the pit-head framework.

King's, Ormerod's, Walker's, and Ramsay & Fisher's hooks involve the additional feature of throwing out clutches when overwinding, which suspend the cage to the framing. They are all fairly before the public, abundantly advertised; and it may be hoped that the selection of the best of them may aid in the good work already done by

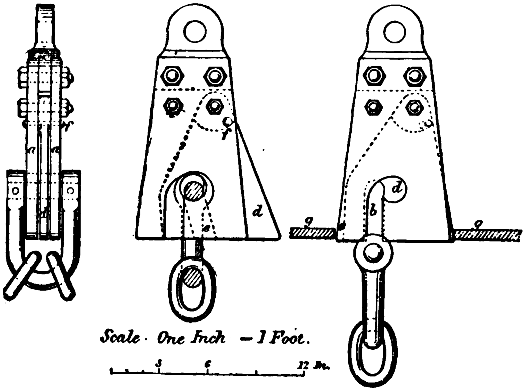

Fig. 68.—Bryham's Safety-hooks.

the rooting out of the neglect and slovenliness which were once too common.

4. *Holing into Old Works.*—A great risk is incurred in approaching old abandoned workings, sometimes from their containing fire-damp or carbonic acid, but more commonly from their having reservoirs of water ready to escape under great pressure, and certain, if incautiously tapped, to occasion a disastrous inundation. The danger is often sadly magnified from the lamentable and unbusiness-like

unfrequented places, and improved ventilation, must be looked to for the reduction of this class of perils.

It may excite surprise that men should be found willing to confront so many dangers, coupled with hard work in cheerless gloom. But familiarity with subterraneous works shows a different side to the picture, and although plenty of bad cases might be cited, the larger well-managed collieries offer, as the life-statistics prove, by no means unhealthy working places. The gaseous enemies which invade them are invisible, and are therefore even too readily forgotten; and the work, though heavy, is simple, and requires very little expenditure of thought. Moreover, the wages are, in spite of strikes and associations, as a rule very good; nay, in some cases exceedingly high, if men only choose to work, and have acquired the degree of skill which we find, even in coal-cutting, will greatly distinguish certain hewers above others. Our Cornish miners, fagged by climbing, and by high temperature, contending with rocks of excessive hardness, and, after all, earning rarely more than £3 10s. or £3 15s. per month, offer a strange contrast to colliers of the North, who can commonly make their 6s. per day, and have often houses free of rent, and coals, and schooling for their children at a nominal charge; and to the Welsh colliers, who in a good stall of the rich Aberdare coal will get their 8s. or even 10s. a day.

Truly, as contrasted with other men, the colliers in well-conducted pits have not so much to grumble over as they are made by their interested friends to believe; nor do the

* To quote a special instance, the highest wage made in March, 1866, at the Navigation Colliery, Mountain Ash, was no less than 12s. 8d. per day for 23 days. It must be noted that the figures above given belong to a prosperous period, and that in the depression of trade between 1874 and the end of 1879 wages have also fallen.

CHAPTER XXI.

DURATION OF THE BRITISH COALFIELDS.

THE astonishing increase in the consumption of coal within the last half-century has kept pace with the advancement of various arts and sciences, and has necessitated a constant improvement in the methods and appliances used in its extraction. Our knowledge of the mineral resources of this and other countries has, during the same time, been placed on a footing so much more definite than formerly, as to excite in the reflecting mind conversant with the heavy drain now making on our coalfields, a reasonably-founded anxiety as to their duration.

Contented security may in its ignorance of the facts assume, and persons interested in maintaining their own special trade may represent that the coal-seams are "practically inexhaustible," and may stigmatise as "alarmists" those who would invite attention to the bearings of a question so vital to our immediate posterity; but a fair examination of the statistics above set forth, and of the local conditions of our coal-bearing districts, will show that at least the time for prudent forethought has arrived.

In the last few years, accurate surveys have shown the certain boundaries of most of our coalfields, formed by the actual rise to the surface of the ground of the foundation rocks, in and under which no coal at all is contained.

In some other instances they exhibit a surface boundary, beyond which much may be hoped for, but where in many cases the uncertainty and expense will greatly reduce the value of the extended territory, or, in other words, increase the average charge at which the coal will be raised.

Knowing, therefore, most of the edges, and pretty nearly the depth of all our recognised stores of coal, let us remember at what rate we are now digging them out. The amount of coal raised in this country in 1864 shows that, supposing 1,300 tons be obtained per foot thick per acre, out of 1,600 which it actually contains, there are now clearing out in every hour, day and night, for every day in the year, 4 acres of coal of 2 feet thick—1 acre every quarter of an hour. There can here be no reproduction, nothing to grow again; "we are drawing," as an able writer* has well put it, "more and more upon a capital which yields no annual interest, but once turned to light, and heat, and force, is gone for ever into space." How fares it with some of our best-known districts? Do they, or do they not, show symptoms of a change? In Shropshire, the workings have passed away from the exhausted western side of the field to group themselves along the eastern; in Staffordshire, the famous Dudley seam will, in a few years, be as a tale that is told; in the great northern coalfield almost every available "royalty" is taken up, large tracts have been cleared out, and already progress is made in leaving *terra-firma*, and working out under the North Sea.

It must, then, be understood that the rapid exhaustion of certain districts, and the calculation of what coal remains, are not the speculations of theorists, but the fair deductions from weights and measures, ascertained with a great amount of practical care and discrimination.

* Mr. Jevons, on "The Coal Question."

I need not refer to the older estimates of the duration of our coalfields, for neither had the early writers any idea of the enormous future increase of demand, nor were they provided with the requisite data for reasonable approximations. It was only in the classical coalfield of Durham and Northumberland that the position and character of the seams were so well known to the viewers as to admit, many years ago, of approach to accuracy.

Mr. Greenwell, a colliery viewer thoroughly acquainted with the district, taking the quantity producible from each several seam, including what lies below the magnesian limestone, as well as *a width of two miles under the sea*, calculated, in 1846 that 331 years would, at the then existing rate, exhaust the whole area. At that time only 10,000,000 of tons per annum of round coal were raised. In 1854, when the amount had reached 14,000,000, and a larger proportion of small coal came to be available, Mr. T. Y. Hall, also a member of the Northern Institute of Mining Engineers, estimated the duration at 365 years, but stated that it would be reduced to 256 years if the demand were to increase to 20,000,000. And, now, since the output in 1897 reached upwards of 43,000,000 of tons, and there is every reason to expect a constant increase of production, it is obvious that the time thus estimated must be greatly abbreviated, and that Sir William Armstrong, in calling attention to the rapid exhaustion of coal, in his address at Newcastle in 1863, based his argument on no unsound foundation.

In 1859 Mr. Edward Hull attempted the more ambitious task of making a similar calculation for the whole of the British coalfields. As a laborious geologist on the Government Survey, Mr. Hull had enjoyed excellent opportunities of learning the structure of several of the coal disworked out; and shou spect to others, had to rely on data of over 200,000,000 to . In each case he has measured the 250,000,000 tons a has adopted from the sections an average pect, a period o workable coal, and deducted from the total their exhausti us obtained an allowance (no doubt difficult to more expen on) for the denudation of the upper seams. A such as fraction is then allowed for quantity worked out and cheaply n future workings, leaving us a total amount in stock It is bout 80,000,000,000 tons for the entire kingdom. All the of pr al lying at a greater depth than 4,000 feet is excluded not from this estimate, as being beyond reach, but a very large li area, amounting to an increase of one-third, is added to the coalfields, for extension beneath newer formations.

We may cavil at some of Mr. Hull's numbers, and disagree with his notions about the limit of depth, but his little book is a creditable summary of the chief features of our coal resources, and his approximate general estimate the only one which is so founded on facts as to deserve attention; whilst, especially on the subject of reaching coal beneath the Permian and Trias formations, no previous author has approached it with the same amount of practical knowledge. When we pass from the descriptive part to the reasoning on the coal supply, we find arguments of more questionable character, some of which have since been combated by Mr. Jevons in his clear and forcible work, "On the Coal Question," whilst others appear to have led to false conclusions as to the rate of progression of the consumption.

It seems that, in 20 years, ending 1860, the quantity of coal raised in Great Britain was more than doubled; but are we thence justified in believing that in the next following 20 years it will be again doubled, and so on in geometrical progression? On this view of the subject little more than a century will see this country utterly deprived of the mainspring of its mercantile greatness. Manufactories without their motive powder, iron furnaces blown out, railway trains brought to a standstill, steamers replaced by sailing ships, our streets left to the gloom of oil-lamps, and our fire-grates empty—such would be the dismal prospect of a nearly approaching time could we give credit to such an inference!

I think, however, that the assumption is based on a fallacy, and that, although the number for certain years appeared to fit such a conclusion, the increase to our production of from 2,000,000 to 3,000,000 of tons annually, serious as it undoubtedly is, will keep us within comparatively moderate figures for a long time to come, and, at all events, defer, as regards the country at large, the evil day for two or three centuries.*

But although the day which will see the whole of our coal resources exhausted is as yet far distant, those cheaply-worked coals, which have enabled this country to produce cheap manufactures, and brought about our commercial supremacy, are within measurable distance of becoming

* In France the production of coal was similarly doubled, after every period of 12 to 14 years, up to 1872, but from that year onwards the ratio of production shows a decided decrease—

Year.	Tons.
1789	250,000
1815	950,000
1830	1,800,000
1843	3,700,000
1857	7,900,000
1872	15,800,000
1884	19,527,120
1896	27,704,900

but the Comité des Houillères Françaises think that the same rate of increase cannot possibly be kept up (1875).

worked out; and should the present extraction of coal of over 200,000,000 tons a year continue to increase to 250,000,000 tons a year, of which there seems every prospect, a period of from 50 to 70 years will probably see their exhaustion, and we shall become dependent upon more expensive fuel, and be rapidly outstripped by countries such as America, China, and Japan, possessing large and cheaply-worked coal resources.

It is a question whether even the present rate of increase of production can long be continued, and whether there are not causes at work which will tend to raise the price and limit the consumption. Our special position as the first manufacturing people depends, in great part, upon the cheapness of our fuel, and any considerable increase in price, as compared with that of other countries, would soon be deeply felt.* At present Belgium, France, and Westphalia are unable fully to compete with us, and English coal takes possession of the seaboard of the Continent, and in numerous cases ascends the rivers for long distances towards the centre of the coal production of those countries. And sundry reasons may account for the fact. Nature has been bountiful to England, not only in the quantity, but in the comparative regularity of the coal-seams. In the best pits in France and Belgium the large, or *round*, coal is seldom more than 45 per cent. of the whole, and the general average is far less. The disturbed position of the beds also renders them more difficult to work, and involves an expense, in the mere item of prop-wood alone, of 9d. to 1s. per ton, whilst in many of our districts 2d., in others 3d., on the ton may be the average.

But if we are to be checked in the race, the mischief is

* For a masterly treatment of this important argument see Jevons's "Coal Question."

likely to proceed, in great part, from an internal canker, from the irregularity and combativeness of the men. What with the peculiar socialistic views so common among them, and the facility with which their organisation, under skilful delegates, enables them to threaten their masters, the interferences, stoppages and interruptions to the working of collieries are becoming an evil of such weight as to constitute an additional charge on the ton of coal. It would be quite out of place here to discuss the subject at any length; but it must obviously be taken into account in forming an estimate of our power of production. It might be supposed from the frequent recurrence of strikes that the colliers, as a class, are ill-paid; but when we find wages of from 5s. to 12s. a day—the rate for good hewers from Newcastle down to South Wales—we cannot but see that there are other large classes of working men in the kingdom, bringing equal skill and labour to bear upon their task, with a much less satisfactory result. The rate of payment is fairly brought to the test of experiment, being in most districts so much per tub or cart of known capacity; in the North so much per score or per ton, and each pit having a weighing machine, at which a man is commonly stationed to watch the weighing on behalf of the colliers.

If, therefore, with these inducements to steadiness of work, a skilful collier nevertheless joins in the strikes and agitation for short hours, weekly pays, with all the concomitant idleness, limitation of quantity to be got, exclusion from the pits of boys under a certain age, and various other interferences which may be more or less objectionable in different districts—that man is adding a weight against his own nation in the balance between ourselves and the foreign coal-producer.

In a discussion on the duration of coal, we should bear in mind that it is one thing to obtain a certain amount of fossil fuel tolerable in quality, but dear from being wrought under difficulties, and another thing to occupy our present position of raising the best qualities at lowest prices. Most of our best districts are being stripped at a fearful rate*—the purest household coal of the North, the "Wallsend" of the London trade, the Dudley thick coal, the Wigan cannel, the Aberdare steam coal—where will they be 50 years hence? And yet there is no help for this; and all we have to see to is that they are made away with to the best advantage. But the question follows: When the cream of our coalfields has thus been enjoyed, what have we to fall back upon to maintain, at least, our large production, even if we are unable to keep up a marked lead? There will be the seams that are coarser in quality, that are thinner or deeper, and those about which there may be much uncertainty, as, for example, where it may be required to sink through overlying formations. A cloud of difficulties arises, but there are rays of light around it: "dirty" coals will be more commonly treated by washing processes—thin seams now neglected will turn out useful; for if we can already work 12 and 14-inch coals in Somersetshire, why should 2 feet be elsewhere called unworkable? And then as to depth: the improvement of both pumping and winding engines is rendering that element of difficulty—within moderate limits—a matter of no very great import.

Here, however, we arrive at a topic fraught with much interest. In South Wales and Lancashire, in the coal-measures, and in certain districts where the surface is occu-

* In order rightly to appreciate the rate of exhaustion of the coal, we must add to the 202 millions of tons returned as raised, a further amount for wasted slack, barriers, faulty coal, etc., of probably not less than 50 millions of tons.

pied by the red sandstones of the Trias, we may have coal-seams below us at 5,000, 8,000, or 10,000 feet deep. Some of the authors above quoted think that the limit of accessible depth is 4,000 feet, beyond which the increase of temperature would prevent the possibility of working; but a considerable experience of deep mines induces me to believe that the difficulty of temperature may, by due appliances, be overcome to a much greater depth.

It is sufficiently well known that experiments made in the mines of various countries show that below a certain point of invariable temperature generally reached at 10 to 20 yards, the temperature of the rock and of water contained in it increases at the rate of 1 degree Fahr. for every 60 or 70 feet descent.* The air which travels down into the workings is soon heated; but passing off, and thus cooling the walls of the excavations, and constantly replaced by fresh air from above, it enables work to be done with comfort in our deepest present mines. It must be admitted that the first opening of the levels or drifts at a depth of 1,500 to 2,000 feet deep is a hot task; but after finding the thermometer in such cases at from 75 degrees to 88 degrees in a close end, I have observed that when the air has once circulated beyond such points for a period of a few weeks or months the temperature has sunk by so many degrees as to admit of further working with facility. The most remarkable case of this rapid cooling with which I am acquainted is at the Clifford Amalgamated Mines in Cornwall, where, in the 230-fathom level (1,650 feet from surface) the air (July, 1864) was 104 degrees Fahr., and close to the issue of a hot spring of 122 degrees even higher; but where in the 220-fathom level (1,590 feet deep) it was only 83

* The extreme variations of increment, except where thermal springs are present, are 58 to 88 feet for 1 degree Fahr.

degrees, although when first opening, a year or two before, it had been at 100 degrees.

The late Mr. Rogers, at Abercarn Colliery, in sinking a shaft in 1851, supplied compressed air to within a few feet of the men at work, which—as I tested at the time—in its escape from the pipe, cooled the pit bottom several degrees. No doubt, therefore, that what with a good ventilating power, and occasionally, it may be, by the aid of compressed air, the first winning works may be quickly reduced below the normal temperature due to the depth, and the subsequent workings be rendered comparatively cool.

It is not commonly known that in the province of Hainault, in Belgium, coal is working at a depth of 2,820 feet (860 metres) at the colliery des Viviers, at Gilly, near Charleroy, and that one pit at the same place has been sunk to the serious depth of 3,411 feet (1,040 metres).*

With regard to other difficulties offered by great depths, our present best methods of raising the water and coal are no doubt capable of dealing with a considerably greater depth than has yet been attained. For still deeper pits it may be suggested either that a plant of engines be established halfway down, and the work thus effected by two lifts, or that reciprocating rods, as in the *Fahrkunst* or Cornish man-engine, may be fitted, as proposed by Méhu and by Guibal, to bring up a constant succession of coal-tubs; and although such modes have not as yet been made practically economical, we may rest assured that the same art of mining, to which the public is mainly indebted for

* Visiting this pit in 1871, the author found the depth to the bottom of a trial staple was 1,064 metres, or 3,489 feet.

In Mr. Caleb Pamely's "Colliery Manager's Handbook" (Fourth Edition, 1898, p. 96,) will be found a list of shafts over 1,500 feet in depth, some of which show even deeper sinkings than those of the Belgian mines here referred to.

the improvement of the steam-engine and for the railway, will not rest without further development of its appliances.

If, then, as we have reason to assert, our better and more accessible coals are being so fast wrought out as to threaten an early change of conditions, what, it may be asked, can be done to prevent their exhaustion? Our home consumption *must* increase, if we are as a nation to advance in prosperity, and its only check will be from an increase of the price at which it can be delivered to the consumer. This, however, as compared with the cost of production abroad, will be the turning-point in our progress. As regards our exports, which have risen since 1841 from 1½ to over 27 millions of tons, constituting about a sixth of our production, it has often been suggested, and by grave authorities, that a tax should act as a check; but such an impost would undoubtedly be open to serious objections. Other suggestions have been made that the State should, during the present prosperous years, set aside an annual sum to acquire the reversion of the railways, docks, etc., within the next 50 years, and also pay off the large capital invested in public works, and by this means diminish the cost of production by reducing the cost of transit and living, and enabling thinner and inferior coals to be worked at a reasonable cost, and prolonging the period of prosperity due to our cheaply-worked coal resources. Whatever may be the proper solution of this problem, there can be but one opinion amongst thinking men, that the time has arrived when a thorough investigation of this problem should be undertaken with a view to minimise the disastrous effects to the commercial prosperity of the country that will surely arise from a neglect to consider and take steps to provide against a contingency which is already within measurable distance.

It has been held by certain writers that the exports are sure to diminish, because other nations are developing their own coalfields; but a little attention to the statistics given above will show that during the very period of the multiplication tenfold of our exports, France, Belgium, and Germany have been increasing their output no less remarkably than ourselves. The fact is, that all the active nations of the world are every year requiring more coal than before; and a fair inference is that the amount going abroad, as well as what is consumed at home, will be an increasing quantity, until a higher price per ton operates as a check.

But although we are thus carried away by the stream, it behoves us to take every precaution to navigate our craft in the best manner. There are many things, both in our individual and our collective mode of treating coal-mines, which should be better looked to in the interest of those who will follow us. We must admit that amid the pressure of competition it is hardly possible to do otherwise than take out in the cheapest way whatever pays best: hence the strictures sometimes passed upon our wasteful procedure are, however true as regards the nation at large, scarcely just to individual workers.

The great waste of small coal, although of late years less flagitious than formerly, is still a lamentable extravagance; for it is not too much to say that millions of tons of small, but none the less valuable coal, are buried up annually, in gobs, stowage, crushed pillars, etc.

The remedies which we may hope to see gradually applied are as follows:—

1. The best selected mode of laying out collieries, both as regards freedom from crush and creep, avoidance of an excess of narrow or *strait* openings, and judicious direction of the bords of working faces;

2. The more general washing of smalls;
3. The extended use, partly by means of new forms of furnace, of slack and the smaller varieties of screened coal (*pease* and *duff*), for manufacturing purposes;
4. Employment of the best methods of coking;
5. Improvement in the making of coal-bricks or "patent fuel";* and,
6. Last, but not least, the application of coal-cutting machines, some of which appear to be verging close on practical utility, will be the advent of a saving that may give us years of prosperity.

A miserable sight it is to see a part of a seam, the "roofs" or "benches," as the case may be, when a parting becomes so thick as to prevent the whole group of beds from being conveniently worked together, abandoned and left uncared for, with the probability that when the present generation has died out there will be no sign to show that there is still lying there, neglected, a tract of what at some future day might offer a profitable working.

And intolerable, again, is it to observe corners and plots of ground sacrificed on account of the inconvenient division of properties on the surface. Oftentimes the avarice or ineptitude of some holder of the surface fields operates as a bar to the regular working of colliery properties, and, of course, as an obstacle to the development of the national store.

It appears hardly credible, when we consider how easily

* The large proportion of "small" in the Belgian and French coal has led Continental colliery proprietors and machinists to devote much attention to the manufacture of *briquettes* or *agglomérés*, which, when well made, meet with a large sale. Opinions at present vary as to the best method of cementing the coal fragments, and much stress is laid on the substitution, for pitch or tar, of farinaceous matter, as first, I believe, practised at Fünfkirchen, in Hungary.

these sources of sheer waste might be indicated in the maps, and when we remember the uncertainty and the danger to human life of approaching old workings, that until 1872 no arrangement was made compulsory for the registration and preservation of proper mining plans.

In no other country in Europe was there so great a laxity in a matter of vital importance to our successors. Under the first Inspection Act every colliery was bound to keep up plans on a certain scale; but how partial was the advantage, when at the end of a lease the documents were subject to be lost or destroyed. Under the new Act the Government, when a mine is abandoned, insists on the deposition of "accurate plans," to be preserved under the care of the Secretary of State. And if lessors and lessees, alive to the national importance of these documents, co-operate in rendering available at a future day those tracts which it may be difficult to turn to present account, we shall no longer remain open to the charge of an unworthy stewardship of the riches which a bountiful Nature has committed to our care.

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