PRACTICAL TREATISE
ON
MINE ENGINEERING.
BY
G. C. GREENWELL.

Bought from M Lewis 10/505.

George William Southern
Mount House, Nr Gatesh

June 16th 1855

Thomas. A. Southern
Penshaw Colliery. Fence H

June 16th 1877

George William Southern
Mount House, Nr Gatesh[...]

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June 16th 1877

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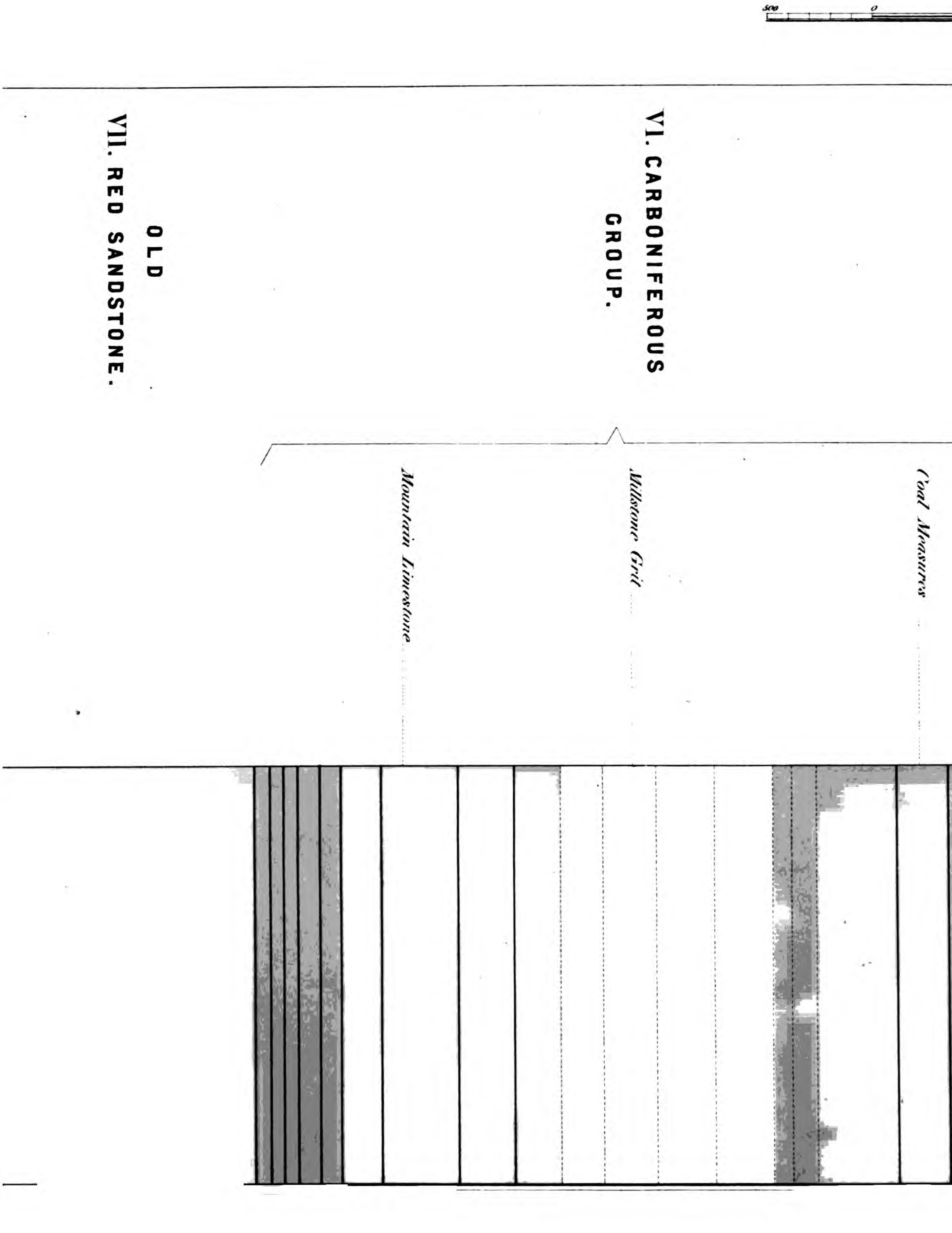

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VI. CARBONIFEROUS GROUP.
OLD VII. RED SANDSTONE.
Coal Measures
Millstone Grit
Mountain Limestone

OF STRATA.

OF FEET.

000 1500 2000 2500

INDURATED ROCKS.

Yorkshire.

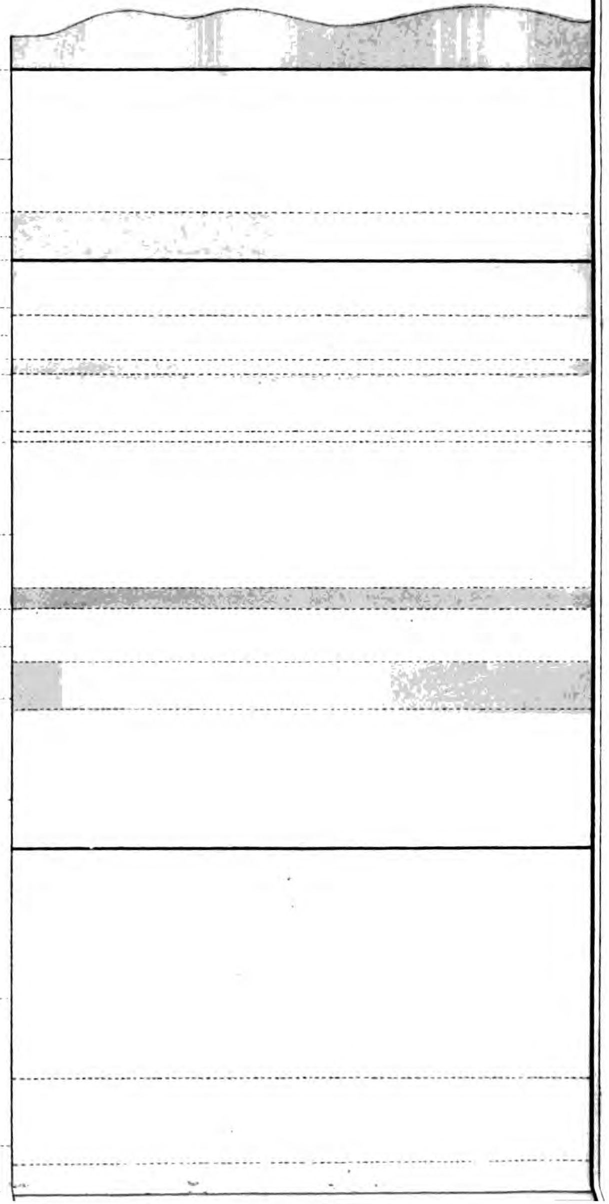
I. ALLUVIAL
- *Gravel &c.*

II. CHALK AND GREENSAND
- *Chalk*
- *Red Chalk*
- *Speeton Clay* { *Gault* / *Kimmeridge Clay*

(III. WEALDEN absent)

IV. OOLITE AND LIAS.
- *Coralline Oolite*
- *Oxford Clay*
- *Kelloways Rock*
- *Cornbrash*
- *Upper Carboniferous Shale*
- *Great Oolite*
- *Lower Carbon. Shale*
- *Inferior Oolite*
- *Upper Lias Shale*
- *Lias Marlstone*
- *Lower Lias Shale*

V. NEW RED SANDSTONE.
- *Red Marl with Gypsum & Red Sandstone*
- *Magnesian Limestone*
- *Lower Red Sandstone*



Lamberts Lith.

A

PRACTICAL TREATISE

ON

MINE ENGINEERING.

BY

G. C. GREENWELL,

COLLIERY VIEWER,

MEMBER OF THE NORTH OF ENGLAND INSTITUTE OF MINING ENGINEERS.

"WE ONLY DESIRE THAT ALL INTERESTED SHOULD HAVE THE POWER TO DISCRIMINATE BETWEEN SOUND AND UNSOUND VIEWS, SO FAR AS EXISTING KNOWLEDGE MAY BE AVAILABLE."

—SIR H. T. DE LA BECHE.

Newcastle-upon-Tyne:

M. & M. W. LAMBERT, GREY STREET.

MDCCCLV.

(1855)

TO

SIR HENRY T. DE LA BECHE, C.B., F.R.S.,

WHOSE EXERTIONS IN THE CAUSE OF

INDUSTRIAL EDUCATION

THE AUTHOR TAKES THIS OPPORTUNITY OF PLACING UPON RECORD,

This present Volume

IS

(BY PERMISSION)

MOST RESPECTFULLY DEDICATED.

THE READER IS REQUESTED TO MAKE THE FOLLOWING CORRECTIONS:—

PAGE 13.—For Droitwich in Staffordshire, *read* Droitwich in Worcestershire.

PAGE 15.—For quartzoze, *read* quartzose.

PAGE 62.—For turretella, *read* turritella.

PAGE 168, &c.—For Byhydruret, *read* Bihydruret.

PAGE 171.—For wire-gauge, *read* wire-gauze.

CONTENTS.

PREFACE.

ALTHOUGH, as indicated on the title page of this work, a very short time has elapsed since the delivery of the course of Lectures there alluded to, it is many years since the Author was first impressed with the necessity that existed for some practical work on Mining generally, but more especially on Coal Mining.

This conviction induced the commencement of an Essay on the subject, a considerable portion of which is embodied in the Treatise now published, in accordance in some degree with a pledge implied in the Author's Preface to a "Glossary of Terms used in the Coal Trade of Northumberland and Durham," which was printed in 1849.

The great advantage of the diffusion of information of a scientific, as well as of a practical character, is in no branch of industry more clearly apparent than in that of Mining. Its object may be considered as twofold: the first being the instruction of those who are studying Mining as a profession, and also of those who are at present placed in situations of responsibility, but who, though possessed of valuable practical knowledge, are in many instances almost totally uninformed upon the first principles of subjects with which they ought to be thoroughly conversant.

As regards the class last named, the advantage of a better system is even greater than appears at first sight; for when we consider the moral superiority which education gives to every one, we cannot avoid the conclusion that the orders given by its possessor will be much more readily obeyed than those of one who, in point of intelligence, is in no degree superior to those over whom he has the control. The value of prompt and unhesitating obedience, where neglect of orders may produce fatal results, is too palpable to require comment here.

Another object attained by the diffusion of such information (more particularly its practical part) is not to be lost sight of. We have already seen the benefits conferred upon the Miner by talent and education, when directed into a useful course, in days when to the general public very little knowledge of Mining was laid open; it is, therefore, but reasonable to hope, that when they are brought to bear upon the basis of fact and experience, many difficulties at present besetting the Miner, and many dangers which now make his life a scene of constant hazard, may in a great measure be averted. The following works have been consulted, and in some instances largely drawn from, the Author preferring in the less practical portion of the subject the adoption of standard opinions to the adventure of new ones :—

Artis' Antediluvian Phytology.
Combes' Traité de l'exploitation des Mines.
Dunn on the Coal Trade.
Dunn on the Winning and Working of Collieries.
Forster's Section of the Strata.
Lindley and Hutton's Fossil Flora.
Lyell's Elements of Geology.
Lyell's Principles of Geology.
Mahan's Civil Engineering.
Péclet's Traité de la Chaleur.
Phillips' Geology.
Phillips' Geology of the Yorkshire Coast.
Phillips' Mineralogy.
Taylor's Statistics of Coal.
Thompson's Chemistry.
Tredgold on Warming and Ventilating of Buildings.
Turner's Chemistry.
Transactions of the Natural History Society of Newcastle-upon-Tyne.
Parliamentary Reports; Local Pamphlets, &c., &c.
Young and Bird's Geological Survey of the Yorkshire Coast.
Williams' Mineral Kingdom, &c.

During the progress of the work the Author has received from several of his friends much kind aid, and many valuable hints, which he takes this opportunity of gratefully acknowledging.

Marley Hill, May 31*st*, 1853.

CHAPTER I.

Application of Geology to Mining: Alluvial Deposits: Chalk and Green Sand Formation: Wealden: Oolite and Lias: Oolite Coal: Alum Shale: Ironstone: New Red Sandstone: Salt Mines: Magnesian Limestone: Lower New Red Sandstone: Coal Measures: various Coal Fields: Newcastle Coal Field: Millstone Grit: Mountain Limestone: Berwick Coal Field: Lead and Copper: Old Red Sandstone: Silurian and Cambrian Rocks: Granite: Building Stone.

THE variation of the prominent rocks of one locality, from those of another, we find to be represented on a geological map by a difference of colouring: thus, in the Newcastle or Staffordshire district, coloured black, we have the coal-bearing strata; in the neighbourhood of Derby we have the mountain limestone; in Cornwall, granite, and so on. From this it is not necessarily to be inferred, that because in any given locality a particular species of formation is shewn on the map to be prevalent, other formations are not to be found as well. The contrary, as a general rule, is the case; and the chief points to which it is necessary to attend are,—firstly, the relative positions of the various series, so that the great mistake of passing through an inferior in search of a superior rock may not, as has sometimes been the case, be fallen into; and, secondly, whether a formation which we might naturally expect to find, beneath that which we have at the surface, does actually exist in an available form, or whether as a mere type, or whether it is altogether extinct.

According to Sir C. Lyell (Elements of Geology, p. 19), there are four great classes of rocks considered in reference to their origin,—the aqueous, volcanic, plutonic, and metamorphic, all of which may be conceived to have been formed contemporaneously at every geological period, and to be now in progress of formation. By referring to plate 1, we perceive what relative positions the members of these four great classes, A, B, C, and D, may occupy in the earth's crust while in the course of simultaneous production. Thus, while the aqueous deposits, A, which are expressed by the yellow colour, have been accumluating in successive strata at the bottom of the sea, the volcanic cone, B, has been piled up during a long series of eruptions, and the other igneous rocks, coloured purple, have also ascended from below in a fluid state. Some of these last have been poured forth into the sea and mingled with the aqueous sediment. On pursuing downwards either the small dykes or large masses of volcanic rock, we find them pass gradually into plutonic formations, D, which are coloured red, and which underlie all the rest. These last again are seen to be in contact with a zone of contemporaneous metamorphic strata, C, coloured blue, which they penetrate in numerous veins.

In that part of the section which is uncoloured, a more ancient series of mineral masses is seen, belonging also to the four great divisions of rocks. The strata from *a* to *i* represent as many distinct aqueous formations, which have originated at different periods, and are each distinguished by their peculiar fossils. The mass, *v*, *v*, is of volcanic origin, and was formed at one of those periods, viz., when the strata, *g*, were deposited. The strata, *m*, *m*, are ancient metamorphic formations, and the rocks 1, 2, are plutonic, also ancient, but of different dates. With the whole of these great classes we are brought more or less into contact. Among the aqueous we find coal, ironstone, and salt; in the aqueous, metamorphic, and plutonic, where traversed by the volcanic, as in veins and dykes, we find copper, lead, and tin; and among the metamorphic we find statuary marble, which is merely oolite limestone, altered by the action of heat.—(Lyell, Elements, page 514.)

It will be necessary for us, however, to enter into more detail of the formations constituting the classes mentioned above, and on referring to the synoptical table of equivalent formations, by Sir H. de la Beche, contained in his selection of Geological Memoirs, we find the whole at length, from which I have selected the following as being, I think, all that is required for our present purpose.

The following then are the formations in their order, commencing from the highest: the whole require attention, for a reason assigned above, but those most especially which have annexed to them the names of the minerals which the practice of mining enables us to extract from them.—(Frontispiece.)

			PRODUCTS.
1	Fresh-water and Marine Formations, Sands, Gravels, Clays, &c.		
2	Chalk, Green Sand, and Iron Sand.		
3	Wealden.		
4	Oolite and Lias		Ironstone, Coal.
5	New Red Sandstone.	*a* New Red Sandstone	Salt.
		b Magnesian Limestone.	
		c Lower New Red Sandstone.	
6	Carboniferous	*a* Coal Measures	Coal, Ironstone.
		b Millstone Grit.	
		c Mountain Limestone	Coal, Lead, Copper.
7	Old Red Sandstone.	*a* Old Red Sandstone	Copper.
		b Slates, Submedial and Primitive Limestone, Clay Slate, Gneiss, &c.	Copper, Tin.
8	Granite		Ditto.

1. *Alluvial Deposits:*—

Beneath the soil or vegetable earth of which the surface usually consists, we seldom find an immediate change into the rocks commonly found in the district; if we have not a deposit of alluvial matter, we have, almost in every instance, a few feet of the debris of the stratum first met with in prosecuting our further search downwards.

We have, however, most frequently what is termed an alluvial deposit, which consists of various clays, loam, and sand; the result of either the subsidence of the mud, suspended in the waters of rivers which have overflowed their banks, or of the conveyance by such rivers of similar mud, gravel, &c,, into their estuaries, or into lakes or inland seas.

In order to examine into the appearances of some of these deposits, we may take the example of that in the valley of the Team, towards its confluence with the Tyne, in our own neighbourhood.

The following is the section of the clays, &c., passed through in sinking at the Norwood new pit:—

Soil	17 Fathoms.
Dark mud, with vegetable matter in abundance	
Clay, with loam	
Strong clay, with gravel	
Sand, with gravel	
Gravel, with tumblers	
Sand and stones	
Rambly slate...	

We may observe, generally speaking, the coarse nature of the materials here as we descend, some of these stones being three feet in diameter, and without the appearance of much rolling; and infer from this that at the period of the formation of the lower part of this deposit, the fall of the river must have been much more rapid than it is at present. At this period it has probably poured its waters into a lake, the valley of the Tyne in fact, the ancient bottom of which is now upwards of 100 feet beneath the level of the sea.

We might here speculate upon the changes which have taken place since this era; we might find it necessary, in order to account for them, to theorize upon upheavals, landslips, earthquakes, &c.; but as I think our time will be more usefully spent if we confine ourselves to the result of actual observation, we shall proceed with our subject.

These clays and layers of loam and sand present usually a sort of semi-stratification, particularly seen in the partings or natural divisions between the beds of clay, and also very prettily developed in the lamination of dry clay. This alluvial clay is the well known brown clay used in the manufacture of common bricks.

The layer of mud near the surface is a deposit from still and sluggish waters. In some parts it slightly borders upon peat, and, in proof of its recent formation, a piece of oak that was found at a depth of ten feet from the surface, when cut through, was found to be perfectly sound; indeed, these low grounds are flooded several times in the course of the year, and therefore must receive an augmentation at a rapid rate. I may also mention another instance, viz., at the Prudhoe Main new colliery, near the Tyne, and eight miles west of Newcastle, where nuts, arrow heads, and pistol bullets were said to have been found buried at some depth beneath the surface.

These alluvial beds are not peculiar to the lower grounds; the surface of a deposit in the neighbourhood of Durham, near Shincliffe, of the thickness of 180 feet, being 190 feet above the level of the river Wear.—Plates 2 and 3 illustrate these deposits.

The whole of these may be called recent alluvial formations, and distinct from the ancient fresh-water and marine formations of which the clays of the south-east part of Yorkshire, at Holderness, and those of the London Basin, &c., form such striking examples. Plate 4 is a section of the ancient alluvium of the Isle of Wight, where it exists of the enormous thickness of 1639 feet.

2. We now pass on to the *Chalk and Green Sand, &c.:*—

The chalk abounds in the southern counties: its first appearance in the cliffs of the east coast of England in pursuing a southerly direction from here, is near Sowerby Hall, a little to the south of Flambro' Head. It consists of nearly pure carbonate of lime, and abounds in organic remains. Chalk is usually soft, but is occasionally found sufficiently hard to be used for building, much of the foundation work at Grimsby new docks being composed of this substance.

The miner of this country has little acquaintance with the chalk in the search for those substances which he has to extract from the bowels of the earth. In the neighbouring country of Belgium however, in sinking for coal, the chalk, in some instances to the thickness of 70 fathoms, has to be passed through before the coal is reached.

The upper part of the chalk abounds in flints. Metallic ores are rarely met with in chalk; martial pyrites (a compound of iron and sulphur) and iron ochre are the only metallic substances which it affords.—(Williams' Mineral Kingdom.)

Beneath the chalk are the green sand, gault, iron sand, &c., found in Kent, Hertfordshire, &c.

The thickness of the cretaceous group is from 150 to 250 fathoms.*

3. *The Wealden Group* follows next beneath the chalk:—

It is a fresh-water formation, of the thickness of not less than 800 feet in some places.—(Dr. Fitton, Geological Transactions, vol. 1, p. 320, second series.)

It consists of thin beds of sand, shelly limestones, clays, and calcareous grits.

The wealden beds contain many organic remains of both the animal and vegetable world: among the former, with crocodiles, &c., are plesiosauri, and some other gigantic reptiles, different from anything yet discovered upon our globe in a living state.

Although in the tertiary strata we have fossilized wood in large quantities, forming lignites, as at Bovey, in Devonshire, yet we do not find any coal until we come to the wealden beds.

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*Cretaceous group	1. Chalk formation	*a* Soft white chalk, with flints	United thickness, 600 to 1000 feet.
		b Hard white chalk, with few or no flints ...	
		c Chalk marl	
	2. Green sand ditto...	*a* Upper green sand	Thickness, 30 to 100 ft.
		b Gault, or blue marl	Ditto 10 to 150 ft.
		c Lower green sand and iron sand, with occasional limestone	Ditto 250 feet.

Lyell's Geology, Elements, p. 314.

The sinkings at Bexhill, in Sussex, in search of coal, at a great expense, were conducted in beds of this formation. It is said that a kind of cannel coal, extending for a quarter of a mile in beds of from two to ten inches thick, occurs on the banks of a stream in this county.—(Outlines of the Geology of England, p. 137.)

According to the opinion of Dr. Mantell, the Hanoverian coal fields are situated in deposits of the wealden period.—(Wonders of Geology, p. 688.)

Dr. Beck assigns the same period for the coal of Bornholm, in Denmark.

We observe by the geological map that the country occupied in England by the wealden group is very limited, which, in a mining point of view, is of little moment so far as we are concerned, as it neither contains any minerals of value, nor is it passed through in progress of searching for others situated beneath.

4. *The Oolite and Lias* are classed by many geologists as portions of the same group, yet can scarcely be so considered, as though usually the lias is conformable with the oolite, it is not always so.—(Lyell's Elements, p. 387.)

The oolite, which consists of a series of clays and limestones, derives its name from the egg-shaped grains of which the limestones belonging to it were observed, when first examined, to consist.

The lias is a term generally adopted for a formation of argillaceous limestone, marl, and clay, lying beneath oolitic beds. The characteristic fossils of these formations may be well examined on the coast of Yorkshire, between Scarborough and Whitby, and specimens obtained in abundance.

Among the lower beds of oolite, north of Scarborough, is found a seam of coal from twelve to seventeen inches in thickness, of inferior quality to the true coal, but occasionally worked for ordinary purposes in the neighbourhood.

According to the Rev. George Young, this coal formation extends about forty miles in length, and about four miles in breadth. This author states that the coal is of very variable character, there being sometimes numerous thin seams, sometimes a single seam, and sometimes none at all. In quality the coal is equally variable, being sometimes slaty, but at others of excellent quality, breaking with a smooth, shining cubical fracture. The seams appear thinnest next to the sea coast; in the interior the seams are more considerable, and have been worked for 120 years at the Danby pit. The quantity worked at the time of Mr. Young's survey was about 200 or 300 bushels per day on an average.

Another coal field, viz., that of Brora, in Sutherlandshire, belongs to the oolitic period, and corresponds with that last named.

The first pit in this coal field was opened by Jane, Countess of Sutherland, in 1598.

From the sections published it appears there are two seams, besides some thin beds not workable. The quality is bituminous, of a cubical fracture, burning to a white ash, but subject to spontaneous combustion unless excluded from the pyrites which abounds in the shale.

From the main seam, 3½ feet thick, about 70,000 tons of coal were extracted between 1814 and 1826.

The Brora coal pit, in operation when Sir R. Murchison visited it, in 1826, was sunk to the depth of 230 feet, the roof of the coal bed consisting of a compressed assemblage of leaves and stems of plants, passing into shaly coal. It is particularly characterized by a large species of equisetum, which also occurs abundantly in the Yorkshire oolite coal field. This plant is described by Mr. König, and is thought by that naturalist, as well as by Sir R. Murchison, to have largely contributed towards the formation of the coal.

The coal itself, which varies from 3 feet 3 inches to 3 feet 8 inches thick, is a pure bituminous seam, subdivided in the middle by a thin layer of pyritiferous shale, which has at times occasioned the combustion of the whole mass. But for the evidence of the fossil shells and plants, which testify to the geological age of this formation, it might readily have been supposed that the coal seam belonged to the true coal era.

Two sections of the borings for coal at the Brora colliery are published. The first is 251 and the other 338 feet deep.

The coal field is limited in extent. It rests upon granite, and the strata belonging to the coal formation are in immediate contact with the primitive rock throughout the greater part of their extent. The coal itself may be traced within a few feet or inches of the granite, the intervening matter consisting of shale.

Three coal seams have been worked here. The first is impure, and abandoned; the second is three feet thick; and the third is from three to four feet, and of better quality than the others. An engine pit has been sunk 45 feet below this level, passing through two other and thinner coal seams, and a bed of fine fire clay.

Sir R. I. Murchison states, that the Sutherland coal differs in no respect chemically from true coal, but that when powdered it assumes, with all lignites, a red ferruginous tinge, instead of preserving the blackness characteristic of the true coal. It may be considered one of the last links between brown coal and true coal, approaching very nearly in character to jet.

For some further speculation upon the Brora coal field, the reader is referred to a paper communicated to the Geological Society, by Mr. Robertson (Quarterly Journal of Geological Society, vol. 3).

The oolite formation in the Isle of Mull contains a lignite bed, which has been partially worked for fuel, apparently corresponding with the Yorkshire and Sutherland coal fields above named.—(Murchison.)

We have in a somewhat rapid manner passed through the upper formations; we have reviewed the alluvial strata, the chalk group, the wealden, and last, the oolite aud lias; we have endeavoured to detect those minerals with which we, in this district, are most immediately acquainted, alluding more particularly to beds of coal; we must not, however, omit to notice another mineral, the working of which gives employment to a number of people, and from which, after being subjected to certain processes, a beautiful and useful salt is obtained, viz., the aluminous shale, a member of the lias, which is abundant in the neighbourhood of Whitby, and which has given rise to the extensive alum works at Boulby, Lofthouse, Lythe, &c.

This shale abounds in beautiful fossils (Nautili, Ammonites, Gryphææ, Icththyosauri, &c.), specimens of which may be easily obtained at any of the above localities.

The process of making alum is shortly as follows:—The shale is calcined by means of a slow smothered fire. It is then lixiviated; the water concentrated by evaporation; then mixed with muriate of potash; when crystals of alum and sulphate of iron form together.—(Thompson's Chemistry, volume 2, page 757.)

In the lias beds, too, are enormous deposits of ironstone, up to this period little attended to, but now becoming of vast importance. This ironstone is very extensively worked near to Middlesborough, and thence along the coast towards Whitby, where the stratum of ironstone, which is from 12 to 14 feet in thickness, is found cropping out on the face of the first range of hills south of the former place. (For a short account of some of the localities of this mineral, see Messrs. Young & Bird's Geology of the Yorkshire Coast, page 130.)

5 *a. New Red Sandstone:—*

We are now approaching those formations with which we have to deal in our subterraneous researches in the generality of mining districts. In those which have already been treated of, we study classes of rocks with which we are not likely, at least for many years to come, to be brought into contact in this country, except as before stated in working alum shale, oolitic coal, or ironstone, which are, however, as compared with the extensive operations which will hereafter be brought before us, of trifling importance. Although the new red sandstone is the highest formation which has been sunk through in the search for coal in this country, yet it does not by any means follow that as the present coal beds become exhausted, bolder attempts may not be made, and with success, too, to reach the coal strata beneath the lias, or even the very chalk itself. This I adduce as a reason why the formations which are higher in the order of superposition should not be passed over without examination.

The lias is succeeded in England by strata of red and green marl or clay, which are conformable with the lias, and pass into it as in Gloucestershire.

It is in this upper new red system that rock salt and salt springs occur in Cheshire and other parts of England; and to this, therefore, the term "salliferous marl and sandstone formation" is properly applicable (Murchison Silurian System, page 32). It consists in Cheshire of alternating beds of red and green clay or marl, gypsum, and rock salt, upwards of 600 feet in thickness.—(Lyell's Elements of Geology, page 408.)

Salt often forms beds of great thickness, and is also frequently met with in large solitary blocks.

The Polish salt mines at Wieliczka, about 8 miles to the south-east of Cracow, have been long celebrated. They have been worked for more than 600 years; and before the partition of Poland, in the year 1772, it is said that they furnished so considerable a share of the revenue of the king, as to yield an annual profit which usually exceeded £90,000 sterling.

The following is an account of the strata which cover the salt in the Polish mines :—

Vegetable soil	2	fathoms.
Sandy clay	5	"
Fine sand, like Tripoli, effervescing with acids	$3\frac{1}{2}$	"
Marl with sand, and containing fragments of sandstone ...	9	"
Sandstone	1	"
Marl mixed with salt, in small particles and cubes ...	20	"

At the depth of 20 fathoms in the above marl are found the masses of salt which are disposed in the form of short beds, or rather detached blocks, which are imbedded in the marl. These blocks are of such a size, that in passing through the galleries formed in them, sometimes the upper and sometimes the lower end only of a block may be seen ; and often, though the galleries are 3 or 4 yards high, the breadth can only be observed, and even in some places the blocks of salt form the sides of the gallery for 15 or 20 yards. These blocks compose the upper bed of salt, and from them the whole of what is called the green salt is obtained. This salt, which is of a greenish or blackish hue, owes its colour to numerous fine particles of a substance which seems to be of the nature of argillaceous shale scattered through it. This variety of salt, on account of its impurity, is retained in the country for home consumption. In this marl also, blocks of sandstone are sometimes found imbedded, and the marl itself is strongly impregnated with salt. Lower down there is another bed of salt, called Szybicker salt, which is in some places 2 or 3 yards thick : it is of a purer quality than the former, and is exported to foreign countries. This variety of rock salt is disposed in very extensive beds. The mine has been driven in one place 600 fathoms from east to west, and 200 fathoms from north to south, and salt being still found, the utmost extent is yet unknown. The nature of the stratum beneath the Szybicker salt has not been ascertained, for the miners being apprehensive of increasing the quantity of water have never proceeded to a greater depth. The greatest depth of the mines is 120 fathoms.

It does not appear (says Mr. Williams, from whom we are now quoting) that the remains of organized bodies have been found in great abundance in the strata connected with the salt rocks now described. None have been observed, according to Mr. Townson's information, in the Szybicker salt in the lower strata ; but some have been seen in the marl which envelopes the blocks of green salt, such as bivalve shells, at the depth of 36 fathoms ; crab's claws at the depth of 40 fathoms, and charred coal mixed with salt and gypsum at the great depth of 100 fathoms.—(Mineral Kingdom, volume 2, page 190.)

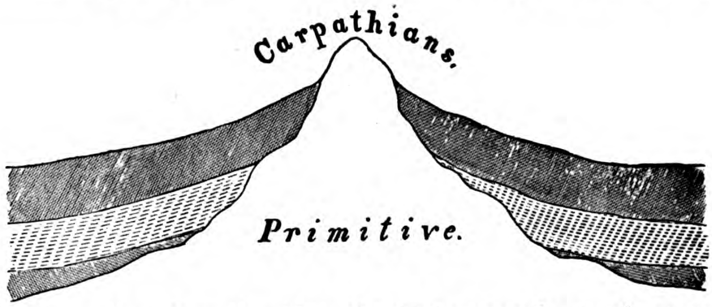
On referring to Sir C. Lyell's Elements of Geology, pp. 408 et seq., we cannot fail to observe how closely modern observation coincides with the statements above made ; the only difference of moment being, that what one philosopher calls " crabs," another dignifies with the appellation of "decapod crustacea."

A great deal has been said of the immense excavations in these mines: some of them it is said, are so extensive, that a house of many stories high might be built within them. A chapel, which is still shown to strangers, is formed in one of the blocks of green salt. Every part of it, its altar, columns, pillars, arches, statues, and other ornaments, are constructed of the same material. In this chapel, mass was formerly celebrated two or three times a week, and probably from the circumstance, it has been said that the workmen employed in the mines, to the amount of 500, live constantly below ground. Springs both of salt and fresh water are found in the mines. To keep the mines dry, the salt water is drawn up in leather sacks; the small quantity of fresh water which they afford is reserved for the use of the horses, which are employed in the subterraneous operations. At the time Mr. Townson visited them, twenty-four horses were constantly kept below ground. The mines of Wieliczka yield annually about 6 or 7,000 cwt. of salt (Townson's Travels, page 386); but, according to Peschier, the yearly product is not less than 170,000 cwt.—(Patrin, page 359.)

Rock salt is found on both sides of the chain of the Carpathian mountains. On the north side of this chain it is met with in great abundance, first at Wieliczka, and then at Bocknia, which is five leagues to the south-east of Cracow. At this latter place the salt rock reaches the same depth as at the former; but the salt is inferior in purity. The salt appears on the same side of the chain at Sambor, in Moldavia, and as far as Okna; and, altogether, fifty-eight places where salt is found, have been enumerated. On the south side of the chain the salt rock begins at Eperiés, and stretches eastward through the county of Marmoruss and Transylvania as far as Cronstadt. This whole extent of country, which includes the places now mentioned, is very rich in salt. One hundred and fifty-nine different places are enumerated which afford rock salt or salt springs.

The extent of salt rock now mentioned, on both sides of the Carpathian mountains, is supposed by some naturalists to be a continuation of the same strata from Wieliczka on the north, as far as it stretches through to Upper Hungary and Transylvania on the south side. But this supposition, according to the observation of Patrin, is very improbable, from the circumstance of beds of rock salt never having been found in primitive rocks, and the strata to the north and south being divided by the chain of the Carpathian mountains, which are primitive, being interposed.—(Williams' Mineral Kingdom, volume 2, page 201.)

This is not a very scientific conclusion: there is no doubt of the fact of the beds having at one period been continuous, but by subterraneous convulsion separated as in the diagram.



Many cases such as this, are continually brought before our notice; and in fact, there is scarcely a single section of country of any length which does not present an instance of the disturbance in question.

The salt mines of the Tyrol are situated on the ridge of a high mountain, two leagues from Halle on the banks of the Inn, and to the north east of Innsprück. The salt found in these mines is in masses, which are composed of a mixture of salt with a rock of an argillaceous nature, and containing portions of salt in all its beds. In one part of the mountain there is a very large mass of salt, which is free from any mixture of stony matter. A gallery of 260 fathoms in length, leads to this mass of salt. The passage to this gallery is kept constantly locked, that no part of it may be removed, and the workmen are even prohibited from carrying off the smallest quantity. This apparently singular circumstance is thus accounted for. As the salt in this mine is in general very impure, and should be rather considered as a simple rock impregnated with salt; to extract the pure salt the whole is dissolved in water. To effect this, the entrance to the subterraneons excavations is shut up: they are filled with water, which is allowed to remain for several months; and being then completely saturated with salt from the surrounding rock, or from the masses of pure salt that have been left, this water is let off, and the salt obtained from it by evaporation. But the pillars or masses of rock which are left to support the roof of the excavations are thus partially dissolved: and being no longer able to resist the superincumbent pressure, they are crushed, and the whole extent of the strata, to the surface of the soil, sinks: but at the end of some years, when the rubbish has acquired a proper degree of solidity, and a new deposition of salt, which is often equally abundant as the first, has taken place, the operations are renewed with equal success.

Spain affords rock salt in considerable abundance. Bowles, in his natural history of that country, has described three of the most important of the Spanish salt mines. The first is situated in an elevated and mountainous region, lying between the kingdoms of Valentia and Castile, in a gypseous territory of half a league in circumference. Immediately under the bed of gypsum there is a solid stratum of rock salt, which runs parallel to the stratum which covers it.

The next mine is in Navarre, between Caparosa and the Ebro, and is situated in a chain of hills, stretching more than two leagues from east to west: these hills are composed of limestone mixed with gypsum. The mine is in the highest part of the chain, and occupies a space of about 400 paces long and 80 broad. In this mine the beds of salt alternate with gypsum, and other earthy matters, and it is observed that they are sometimes disposed in an undulating form; in some places the gypsum is wanting, so that the strata are composed only of earth and salt.

The third mine is that of Cardona or Cordona, in Valentia, which is a mountain situated about sixteen leagues to the north west of Barcelona, and some leagues distant from the Pyrenees. This mountain is entirely composed of rock salt; it is about three miles in circumference, and about 500 feet high. No cracks, or fissures, or beds, are observed in it; and what is very singular, no gypsum, which is one of the most common minerals accompanying rock salt, is found near it.

This huge mass of salt has nearly the same elevation as the neighbouring mountains. As the depth has not been ascertained, the nature of the rocks upon which it reposes is unknown. The salt rock obtained from this mountain is in general white, some of it is reddish, and some of a bluish colour: and we are informed that it is employed in Spain to make snuff-boxes, vases, and various trinkets, like Derbyshire spar.

The salt mines of Cheshire, in England, have been long celebrated. The Salt springs of this county, as well as those of Droitwich, in ~~Staffordshire~~ Worcestershire, were known to the Romans, who gave them the name of Salinæ; and, indeed, according to the tradition of the inhabitants, it is said that not only the brine pits, but also the rock itself, were wrought by that people. If this were the case, the knowledge of the existence of rock salt in this country must have been long lost, for it was only in the year 1670 that the discovery of that mineral was again made in the neighbourhood of Northwich. Rock salt has been discovered and dug out in other places in the same neighbourhood, but in no other part of the Kingdom.

The rock salt of Cheshire is found at the depth of from 100 to 140 feet below the surface of the earth.

The first stratum of salt is from 40 to 60 feet thick, is quite solid, and can only be broken by means of iron picks and wedges. Sometimes the rock is blasted with gunpowder, by which means masses of many tons weight are detached. It has somewhat the appearance of brown sugar candy. Beneath the first stratum of rock salt there is a stratum of hard stone composed of large veins of flag, mixed with some rock salt. The thickness of this stone is from 100 to 130 feet. The next stratum going downwards is salt, some parts of which are perfectly white and transparent; others are of a brownish colour, but the whole is purer than the upper stratum. The thickness is from 15 to 20 feet. Above the rock salt is a stratum of a whitish clay. Gypsum is also found in some places covering the strata of salt.—(Williams' Mineral Kingdom, volume 2, page 205.)

There is some discrepancy between the above account and one published in a recent work. It is there stated that there are two beds of rock salt, extending a mile and a half north-east and south-west, and upwards of three-quarters of a mile in width. The surface of the lower bed is about 220 feet from that of the ground, and this bed has been penetrated to the depth of 132 feet, without any appearance of its base.—(Chambers' Information for the People, page 752.)

Of the Cheshire mines, many yield 16,000 tons of salt per annum for home consumption, and 140,000 tons are exported annually from Liverpool.—*(Ibid.)*

This red sandstone formation is very abundant in Yorkshire, and beds of gypsum have been proved by boring in the north-east part of that county; and it is by no means improbable that beds of rock salt may also be found in the same locality, although no brine springs have as yet been discovered in the district.

At Seaton, near Hartlepool, is a remarkable specimen of these strata. To the south and north of Seaton the cliffs are alluvial, but directly opposite to that village the strata rise up in the form of a ridge or arch, the highest part of which stretches out from Seaton towards the sea nearly at right angles with the shore, but rather inclining towards Hartlepool; while the strata bend down on both sides of the ridge, dipping towards Hartlepool on the north and Coatham on the south. On the shore at Seaton the waves have worn away the higher part of the rocks, and displayed in the cliff a beautiful section of the variegated strata. In the middle of the arch the upper strata are gone, and are replaced by alluvium, but we see what they have been by tracing them on both sides of the ridge. The whole series may be stated as under:—

1. A bed of sandstone, half of which is red and the other half yellow or yellowish grey...	6	feet thick.
2. Yellowish grey sandstone	6	„
3. Another bed of the same	5	„
These three beds are parted in some places by seams of blue clay.		
4. Indurated marley clay, of a greenish blue colour, containing a slight mixture of sand and mica	7	„
In this stratum are a few bands of sandstone, particularly one red band, which in some places is about 2 feet thick.		
5. Grey sandstone, harder than Nos. 2 and 3	2	„
6. Greenish blue marley clay, rather paler than No. 4, and containing a few beautiful crystals of pyrites	1	„
Here Messrs. Young and Bird remark, "that if these green stripes be coloured with oxide of copper, these crystals may be presumed to be copper pyrites." If we should ever be doubtful of the nature of any yellow sulphuret, as to whether it is composed of copper or iron, we can very easily test the difference, by simply trying if we can scratch it with the point of a penknife; if the mineral will allow of being scratched, we may be tolerably sure that it is copper pyrites, a point which the blow pipe will set satisfactorily at rest.		
7. Red sandstone, forming the lowest part of the series, here displayed—visible to the depth of about 10 feet	10	„
The red strata are of a pale brick colour, very soft and marley in many places, but in other places hard and sandy. Some of the most sandy specimens are highly schistose and micaceous. Thin masses of greenish or bluish clay are found here and there imbedded in the red rock.		

Through this new red sandstone, sinkings have been made to the coal strata in many districts, as in Shropshire, Staffordshire, and elsewhere: and also borings have been made for the purpose of finding coal, as at Entercommon, near Smeaton, about three miles to the south of Dinsdale, and on the south bank of the Tees. Here the borers penetrated to the depth of 223¼ yards. The first ten yards consisted of alluvial beds; the next 100 yards, of red sandstone in various beds, with a few bands of hard stone, etc.; and the remaining 113 yards consisted of red, grey, and white sandstone, including several very hard bands, the lowest beds being entirely grey or white as at Dinsdale, where by boring the red sandstone and gypsum were met with.

There is no doubt, I think, but that the upper measures passed through by this boring, are the saliferous marls which correspond with the keuper of the Germans, and the marnes irisées of the French; and that the remaining 113 yards are the red sandstone and the quartzose conglomerate, (the bunter sandstein of the Germans, and gres bigarré of the French,) at the bottom of which must be found the calcareous conglomerate of Staffordshire, or, more probably, its representative, the magnesian limestone of Durham (German zechstein).

The following is an account of the strata bored through at Oughton, near Hartlepool. (Plate 2).

	FAS.	FT.	IN.
Clay, gravel, and sand	12	3	2
Red sand and sandy clay	2	4	10
Clay and sand	7	2	0
Brown, red, and white freestone, with occasional beds of red and dark shale, and a bed of "white stone resembling spar," probably gypsum, 4 inches, at 43fas. 5ft. 2in. below the clay	56	0	5
Coal	"	"	4
Brown and white freestone, with a bed of white stone, as above, and hard beds of whin	8	3	8
	87	2	5

This boring is in the red sandstone and quartzose conglomerate, and probably, at no very great distance further, the magnesian limestone would have been reached, had the boring been persevered with.

There is much room for speculation as to what would be the result of exploring beneath the red sandstone in this neighbourhood. Let us examine into a few details.

We have at Monkwearmouth, Seaton, and Castle Eden, the Hutton seam lying at the respective depths, beneath the magnesian limestone, of 231, 182, and 68 fathoms respectively, the thickness of the limestone being 34, 58½, and 97 fathoms. It is clear that since these points of exploration are situated upon the same line, the direction of which is nearly north and south, and at about equal distances from each other, if the coal measures and limestone still continue, as in the instances quoted, to converge towards the South, at no very great distance further in that direction, the limestone, instead of resting upon the coal measures, will be immediately over the millstone grit, and ultimately upon the mountain limestone.

When we observe the variable distances between any given stratum of the coal measures and the magnesian limestone, we at once arrive at the nonconformability of the two formations, and as the red sandstones (above and below the limestone) are conformable with the limestone, of course the red sandstone and coal measures are unconformable. Whatever reasoning, therefore, applies to the limestone in its relation to the coal measures, applies with equal truth to the red sandstone; and as we have frequent opportunities of comparing the limestone and coal measures together, and none of instituting such comparison between the upper red sandstone and coal measures, I have made use of the limestone as a parallel rule, the use of which, I trust, will be readily seen.

If, however, notwithstanding the continued south dip of the red sandstone, the coal measures, instead of continuing unconformable to, should (as is by no means improbable, on account of the *general fact* of these being found immediately beneath the new red sandstone) as we proceed south, assume a conformability with the red sandstone formation, we shall, as has been before hinted, find the coal measures with their concomitants beneath the red sandstone. at a considerable depth from the surface most probably, but still at no greater depth than (if there) they will be reached by the indomitable perseverance of man.

5 *b. The Magnesian Limestone* is next in the order of superposition. Plate 5.

This we have abundant means of examining in the neighbourhood: as at Whitley near to Shields, or Fulwell near to Sunderland, or at various quarries, and in the cliffs between Tynemouth and Hartlepool. In fact, the whole of the eastern and southern division of the county of Durham has the magnesian limestone lying beneath the alluvial covering.

The greatest explored thickness of the magnesian limestone within my knowledge is about 600 feet. Near to the upper part it consists of a soft marl containing hollow cavities, lined with crystals of carbonate of lime. It then on descending becomes harder, and abounds in nodules, which vary in colour from white to a brick red, of sulphate of barytes or heavy spar; compact and uncrystallized. The colour of the limestone varies from a pale yellowish brown to brown, and in the lower beds assumes a bluish grey colour. Some of the beds are very hard and difficult to sink through, and in general much water is met with in putting a shaft through this rock.

The escarpment of the magnesian limestone may be seen at Boldon, Houghton-le-Spring, Coxhoe, &c., where it resembles a series of capes or headlands, the flat country into which they project, especially when covered by the thin mist of early morning, having the appearance of a sea. In this respect the escarpments of the chalk and magnesian limestone strongly correspond.

The structure of this rock varies considerably. In some places, as at Marsden, near South Shields, it is found soft and lameller, and slightly flexible; when in this form it can be obtained in plates a quarter of an inch thick, and two or three square feet in area. It is most flexible when newly quarried, becoming more brittle as it dries.

Another form of magnesian limestone is nodular, consisting of an aggregation of balls, hard, radiated, and concentric, dark brown, crystalline, and capable of receiving a fine polish, bearing a considerable resemblance to the limestone of the Rock of Gibraltar. These nodules vary in size from that of a pistol bullet to that of a man's head.

Another form of the limestone is tabular, dividing with a very smooth cleavage into small flags, of the thickness of a quarter or half an inch. Of this form it is frequently dendritic, and also hard.

The bottom bed of the formation consists of a calcareous shale bed of a foot or two in thickness, which abounds in remains of fish.

Plate 6, figure 1, is a representation of a fish (Palæoniscus Comtus), obtained in sinking the Shotton colliery, in the east part of the Durham coal-field; and figure 2 (Palæoniscus ?) was found in the Thickley quarry, near the south-west boundary of the coal-field, as at present supposed.

It will be observed how variable are the proportions of the component parts of magnesian limestone by the subjoined analysis:—

	ELDON.	AYCLIFFE.	FERRYHILL.	HARTLEPOOL.
Carbonate of lime	46	44	54·1	54·5
Ditto magnesia ...	40	42	44·7	44·9
Oxide of iron...............	1	2	0·6	0·3
Earthy matter	...	...	0·6	0·3
Residuum	13	12	...	...
	100·	100·	100·	100·

About thirty years ago, much the same doubt existed as to the probability of finding the seams of coal beneath the magnesian limestone as we, in our day, feel concerning their continuance still further to the south, under the red sandstone. My own views on the matter are, I must admit, in favour of the coal measures being found beneath the red sandstone, although it is not improbable that before a pit could pierce the coal measures beneath them it would have to be sunk at least 200 fathoms, through red sandstone and limestone.

It is true that, generally speaking, up to this present time, the greater part of the driftings and exploratings towards the supposed south limit indicate not only a deterioration of the seams of coal, but also an inclination upwards to the south, which, if continued, would of course lead to the final extinction of the coal formation. This may be local, for by all analogy the coal measures will be found beneath the red sandstone; but whether containing good workable seams of coal, must be decided some day or other by trial.

5 *c. The Lower New Red Sandstone* (Plate 5) is the next formation through which we have to pass in reaching the carboniferous series.

It consists of sandstones and shales of various sorts, some of them being red, and others white, yellow, or grey, of the aggregate thickness of 150 feet.

The uppermost bed is most frequently a soft sandstone—so soft, in fact, as scarcely to deserve the name of sandstone, but rather sand.

It is occasionally of great thickness, being at Eppleton, near Houghton-le-Spring, 110 feet thick, and so variable that at Haswell it increases, within a distance of 700 yards, from a mere scare or parting to a bed of upwards of 120 feet.

The beds of shale abound in remains of Stigmariæ, which indeed appear so interlaced together as to convey the idea that these fossils are almost the sole constituents of the shale beds.

I am not very sure whether or not coal is found in this formation. At the depth of 70 feet below the magnesian limestone, there is at Shotton a seam of coal of very peculiar quality, of the thickness of 2 feet 8 inches, having several beds of red shale, apparently part of the lower red sandstone, beneath it. This coal has not the deep blue black of the true coal, but a brownish tinge; is exceedingly brittle and soft, and can even with a strongly urged heat scarcely be made to ignite, when it burns with a poor pale blue flame. When put into an ordinary fire it falls to pieces, and drops unaltered through the bars. When heated it has the usual asphaltic smell.

We have a very good section illustrative of the positions of the magnesian limestone and lower new red sandstone in the cliff beneath the Priory at Tynemouth. We may there observe the peculiar construction of the rocks, and obtain a few fossil plants in the shale of the lower red sandstone, on the north side of the promontory. A little further to the north the coal measures rise up from beneath the lower red sandstone, and form Sharpness Point.

6 *a*. ***The Coal Measures***, in the next place, demand our attention. They consist of an immense mass of sandstones and shales, having interstratified with them beds of true coal of various thickness.

It is and has been the custom to consider all coal districts to consist of basin-shaped formations, their construction being supposed peculiar to themselves. It is not difficult to account for the cause of this supposition. Until within a very few years, the known coal fields were limited in number, and the general shape of these few favoured the idea of each being of independent formation.

Now, however, I think wider views must open before us. As we explore the known fields towards each other, we become less certain of their being distinct, and I doubt not would be much puzzled to give any definite reason why we were not of opinion that these neighbouring fields had, in days of the far past, been continuous.

And I do not see any good reason why, since we would never for a moment draw a line between, for instance, the red sandstone of this coal-field and that of Staffordshire, but agree at once in their contemporaneousness, we should maintain that the Newcastle coal-field is one basin, and the Staffordshire coal-field another.

My own idea is, that the coal measures are as much an independent formation as the chalk or the lias; and that wherever those formations, superimposed in ordinary acceptation above the coal measures, are found, there also will be found the coal measures or their type, unless of course denuded prior to the deposition of the superior formations. I do not mean to say that particular seams of coal, or even workable seams at all, are certain of being met with, because even in the veritable coal measures this is not invariably the case, but I do mean to say that there is all reasonable probability of finding coal in such situations.

Plates 7, 9, 10, 11, and 12, are representations of various coal-fields, shewing clearly the relative position of the coal measures with regard to the other formations, to be universal.

Plate 7, figure 1, is a section of the coal-field of Belgium.

According to Mr. Dunn's account of this coal-field, published in his "View of the Coal Trade," it is computed that a sinking of 900 fathoms would be required to command the lowest beds of coal in the Mons district.

The western part of the coal-field is overlaid by a formation of chalk and flint, varying according to the sinkings from 20 to 140 yards in thickness, and giving out water; but the coal stratification is remarkably free from water, and generally composed of argillaceous strata.

In the vicinity of Mons, we learn from the same authority, are known to exist 114 seams of coal, but further to the west there are no fewer than 131 workable seams of coal.

The quality varies from inferior to superior, the latter (flenu) being very rich, pure, and free from sulphur.

The area of the Belgian coal-fields is 485 square miles, or 331,392 English acres.

Plate 7, figure 2, is a section of the coal-field of Ronchamp, in the Haute Saône, France, which is the richest coal-field in the Vosges. It contains two seams, whose united thickness is from 6 to 10 feet. The highest of these is of middling quality—the lowest is a fat coal of good quality, but is now almost exhausted. The coal is of coking quality—the coke tumid and friable, and used for forges and salt works. The working commenced in 1750. We here observe the same order of superposition that, so far as observation extends, always exists; in fact, in whatever part of the world we may be situated (and now, in these times of rapid transit from place to place, when the whole world is a man's home, and there is no certainty where a few years, or even months, may scatter us), we may by the observation of a very small portion of the surface rocks make such a diagnosis of the country, as, if proper discrimination be used, would lead to an accurate knowledge of the whole stratification of the locality.

The most important coal-field of France is that in the basin of the Loire, which contains 103,040 acres of coal. It is divided into two groups—that of St. Etienne, comprising 51,642 acres, containing 18 beds of the best known fat coal, producing excellent coke; and the Rive de Gier coal-field, which contains 10 or 11 beds, resembling those of St. Etienne. The strata are shewn in detail in plate 8.

Plate 9, figure 1, represents a section of the Sarrebrück coal-field, in the lower Rhine.

M. von Dechen observes, that the lowest coal strata known in the county of Duttweiler, near Bettingen, north-eastward from Saar Louis, dip 19,406 feet and 20,656 feet under the level of the sea. These coal measures, therefore, lie as far below the level of the sea as Chimborazo rises above it, at a depth where the temperature of the earth must be 435° Fahrenheit.—(Humboldt's Cosmos.)

Plate 9, figure 2, is a section of the coal-field of Calvados, in Normandy, which contains two beds—the first or lowest furnishes coking coal, the other yields only a dry, earthy coal: it supplies fuel to Bayeux, Oire, and Caen, and is used on the spot for lime burning. The first steam engine employed in the extraction of coal in France was set to work here in 1749.

Plate 10, figure 1, is a section of the Nesquehoning, and figure 2, a section of the Illinois and Indiana, coal-fields, taken from Mr. R. C. Taylor's most excellent " Statistics of Coal.

At the centre of the Nesquehoning section it will be observed that there is an anticlinal axis or ridge, on both sides of which the strata dip in contrary directions. There are about 12 seams on either side of the axis: 8 of these were at work in 1847, and had an aggregate thickness of 163 feet of anthracite, of which a fair proportion consisted of merchantable coal. These were all south-dipping seams: those on the opposite side of the axis apparently contained at least an equal amount of good coal, probably a repetition of the same seams.

The Indiana and Illinois coal-field is about 330 miles long by 200 miles in breadth; the actual area, containing coal, which comprehends portions of Indiana, Kentucky, and Illinois, is 56,200 square miles, or about two-thirds of the area of Great Britain.

The abundance of coal which is found in Great Britain, coupled with the facilities afforded, both by nature and art, for its transportation to places where its application was most desirable, have mainly contributed to the present state of this country. Plate 11 shews its distribution, and gives also a general idea of the extent of the individual coal-fields.

Plate 12, figure 1, is a section across the Dudley coal-fields in South Staffordshire, which is described in the first Parliamentary report of the Midland Mining Commission in 1843.

This coal-field contains about 64,000 acres, and has for convenient reference been sometimes divided into two mineral districts. The southern area comprehends the larger portion, and also by far the thickest masses of coal, including the celebrated ten-yard coal seam, one of the most important in Great Britain.

Towards the centre of this district, the ten-yard coal lies at the depth of 140 yards from the surface, decreasing in depth towards the north, and shewing that the whole mass of the coal measures incline from the north to the south.

The northern portion of the Staffordshire coal-field extends from Walsall several miles northward, but for the reason just stated, the outcropping of the strata in that direction, the beds are less numerous, and of more limited extent, so that in the neighbourhood of Bilston the thick coal itself comes to the surface, and is of course lost.

That the productive coal measures extend beneath the overlying new red sandstone, to an *indefinite extent*, there is recent proof in the success of the operations of the Earl of Dartmouth, who, after sinking through the new red sandstone 151 yards, and thence through the coal measures to the final depth of 308 yards, reaching three coal seams at Christchurch one mile beyond the superficial boundary of the coal-field.

Mr. Dunn, on the authority of Mr. B. Smith, shews that at West Bromwich the coal seams amount to 43 feet 8 inches, and at Wolverhampton to 67 feet 5 inches.

Near Dudley, the strata ascertained by the operations there carried on, and described by Dr. Thompson, amounted to 940 feet. Of these, 81 feet consisted of coal comprised in 11 seams of various sizes, from 9 inches to 31½ feet thick. This latter seam, the well-known Main coal, is here 120 yards beneath the surface. It is divided into 13 different layers, separated by very thin partings of slate clay. Every one of these 13 divisions has its name, designation, and peculiarity, so as to be selected for the uses to which it is particularly applicable. The middle series consists of the best quality employed in private houses. The remaining part, amounting to about one-half, is inferior, and is used only in the iron works: this coal does not cake. It makes an agreeable fire, burning to a white ash, and does not require to be stirred.

Plate 12, figure 5, is a section of part of the Bristol coal-field, which has been described by Messrs. Buckland and Conybeare. The extent is probably not less than 200 square miles, or 128,000 acres.

The seams of coal are very thin in comparison with those which are worked in the principal English coal-fields, the aggregate thickness of the seams, in any single coal-pit, scarcely exceeding that of one of the ordinary seams in the principal districts.

It was in this region that the celebrated William Smith, the Father of English Geology, first practically proved the correctness of his geological views as to the uniform order of superposition of the rock formations, and demonstrated the soundness of that magnificent system which has been since adopted by men of science over the entire globe.

I might still further adduce examples of coal-fields corroborative of the principle laid down, but I do not consider any more necessary. I shall now proceed to an account of the Newcastle coal-field, which I propose giving more in detail, because a full account of it will, in fact, give a clear idea of all others, and because on account of its ample development, little is left to theory or speculation.

The boundary of the Newcastle coal-field, as at present known, is an irregular line, extending from Warkworth, by Morpeth, Ponteland, and Shotley, to Staindrop, and thence east to Aycliffe, and about midway between Castle Eden and Hartlepool; the total area being about 800 square miles, or 512,000 acres.

The general section of this district (plate 13) consists of the coal measures, cropping out to the north, with the inferior formations rising beneath, and dipping to the south into at present unknown regions beneath the magnesian limestone. There is also a western rise and outcrop of the coal measures; thus indicating what would be, more correctly speaking, a south-east dip and south-west direction, or water-level bearing of the strata.

The following is a section of the strata in this district, commencing at the highest and terminating with the lowest yet proved.

We do not know that in any one situation the whole of the strata will correspond to those given below—in fact, the probabilities are otherwise; but in order to approximate to a correct section, as nearly as may be, the following series are placed in the order in which they occur—the lower strata, as they are proved towards the rise, being placed beneath those upper strata which are proved to the dip of the coal-field.

MONKWEARMOUTH PIT (about a quarter of a mile north of the river Wear), before piercing the coal measures, passed through the following :—

			ALLUVIUM, MAGNESIAN LIMESTONE, LOWER NEW RED SANDSTONE.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
			1. *Clay*, with partings near bottom, and sand	...	...	...	19	3	0
			2. *Magnesian Limestone.*						
			Marl and sand, mixed with limestone	4	3	0			
			Yellow limestone	16	3	0			
			Blue limestone, in plates	10	3	0			
			Clay parting	0	0	1½			
			Strong grey limestone	1	4	6			
							33	1	7½
			3. *Lower New Red Sandstone.*						
			Grey and blue metal	1	2	10			
			Freestone sand	0	5	0			
			Blue and red metal	2	0	0			
			Coal	0	0	1½			
			Black, blue, and red metal	4	0	0			
			Strong red and grey freestone	6	0	0			
							14	1	11½
							67	0	7
NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.						
	Ft.	In.							
			Blue metal stone	1	0	0			
1	1	0	Coal, with a 2-inch band near top	0	1	2			
							1	1	2
			Blue metal and post girdles	4	3	0			
2	0	2	Coal, foul and brassy	0	0	2			
							4	3	2
			Strong blue metal and girdles	6	3	7			
3	0	1½	Coal, brassy and not regular	0	0	1½			
							6	3	8½
			Strong blue and grey stone	8	0	0			
			Grey and white post	6	0	0			
4	0	10	Coal, good in quality	0	0	10			
							14	0	10
			Blue stone and post girdles	3	0	0			
5	0	2	Coal	0	0	2			
							3	0	2
			Blue stone and grey ironstone girdles	4	5	0			
6	1	2	Coal	0	1	2			
							5	0	2
			Thill and blue metal	0	5	0			
7	0	2	Coal, foul	0	0	2			
							0	5	2
			Blue metal stone	1	1	6			
8	0	10	Coal	0	0	10			
							1	2	4
	4	5½	Carried forward	...	...	...	36	4	8½

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	4	5½	Brought forward	...	...	...	36	4	8½
			Thill and blue metal	0	3	0			
			White post	1	3	0			
			Blue stone and ironstone girdles	0	4	0			
9	0	10	Coal, foul and mixed with black stone	0	0	10	2	4	10
			Black and blue stone and post girdles	8	2	0			
			{ Coal ... ... 1ft. 0in.						
10	2	10	{ Foul Coal 0 1½						
			{ Coal 1 8½	0	2	10	8	4	10
			Thill and black stone, mixed with post	2	3	0			
11	0	6	Coal ... ... 0ft. 6in.						
			Black stone 0 6						
12	0	9	Coal 0 9	0	1	9	2	4	9
			Black stone	0	0	4			
			Strong white post and post girdles	3	4	0			
			Blue stone	10	0	0			
			White post	11	0	0			
13	1	3	Coal	0	1	3	24	5	7
			Thill and white post parting	2	1	9			
14	1	0	Coal	0	1	0	2	2	9
			Post and post girdles	9	2	0			
			Coal in north-east part of pit, but not extending above one-eighth round the shaft	0	0	11			
			Post and post girdles	4	5	1			
15	2	1	Coal	0	2	1	14	4	1
			Shivery post, and blue metal below	8	3	11			
16	1	6	Splint coal ... ... 1ft. 6in.						
			Band of stone 1 9						
17	1	4	Coal, good 1 4	0	4	7	9	2	6
			White post and metal partings	9	3	1			
18	1	6	Coal, coarse at top ... ... 1ft. 6in.						
			Soft grey metal band 0 2						
19	2	10	{ Coal, strong and good 2 1						
			{ Coal, coarse 0 9	0	4	6	10	1	7
			Strong white post, coarse, and mixed with pebbles ...	8	3	7			
20	2	3	{ Cannel coal ... ... 0ft. 10in.						
			{ Coal, good 1 5	0	2	3	8	5	10
			Grey post and girdles, and grey metal and ironstone girdles	3	3	9			
21	0	5½	Coal, coarse, mixed with black stone	0	0	5½	3	4	2½
			Black and blue metal, and post girdles	3	4	1			
22	0	2	Coal, coarse	0	0	2	3	4	3
			Thill	0	0	10			
			Coal mixed with black stone	0	0	2			
			Thill	0	2	10			
			Strong grey and white post	7	4	11			
	23	9	Carried forward	8	2	9	129	1	11

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	23	9	Brought forward	8	2	9	129	1	11
23	0	5	Coal	0	0	5	8	3	2
			Thill and post	0	0	3			
			Dark grey post, with blue metal, and post girdles ...	10	4	8			
24	0	7	Coal	0	0	7	10	5	6
			Grey metal and post girdles	2	1	2½			
			Grey and blue metal	2	0	9			
			Grey post and whin girdle	0	2	2			
			Grey metal stone	0	3	9			
			Grey and white post	2	0	5½			
			Metal parting	0	0	1			
			Shivery white post	4	0	8			
			A substance like coal, soft at one side and hard at the other	0	0	11			
			Coal pipe	0	0	2			
			White and grey scamy post	5	4	6			
25	2	0½	Coal	0	2	0½	17	4	8½
			Dark post girdles	1	3	8½			
			Grey metal	1	1	6½			
			Black metal	1	2	7			
			White post girdle	0	0	7			
			Grey metal with post and ironstone girdles	6	0	7			
26	1	10	Coal, with a 3-inch band near the bottom	0	2	1	10	5	1
			Thill and grey metal	0	4	3			
			Scamy post	1	2	1			
			Strong white post and partings	2	1	9			
27	2	10¾	Coal (Tyne yard seam)	0	2	10¾	4	4	11¾
			Thill and grey metal	0	3	10			
			White post and whin	1	4	10			
			Grey metal and post girdles	1	4	3½			
			Grey and black metal	1	1	10½			
			Strong white post	5	3	3½			
			White post and strong partings near the bottom ...	3	3	3½			
			Dark grey metal	0	1	1			
28	5	3	Coal ... ... 5ft. 3in. } Bensham or Maudlin Seam.						
			Band 0 1½						
29	1	2	Coal 1 2						
			Band and Coal ... 1 9½						
30	1	2½	Coal 1 2½						
			... ...	1	3	6½	16	2	0½
	39	1¾	Thickness of coal measures to thill of Bensham Seam ...	...	...	...	198	3	4¾

From this section we observe that the quantity of coal contained in the upper 198¾ fathoms is equal, in the aggregate, to 39 feet 1¾ inches, being 3·28 per cent. of the whole.

HEBBURN COLLIERY is situated near the south bank of the river Tyne, and is about three miles west of South Shields. It is sunk to the Bensham seam at the " C" pit, and the following is the section of the strata beneath it, as proved by boring :—

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
			Dark metal	0	0	6			
			Grey metal, with hard girdles	1	2	0			
31	1	5	Foul coal	0	1	5	1	3	11
			Dark slaty metal	1	0	0			
			Blue metal, with post girdles	0	5	3			
			Strong white post, mixed with whin	0	1	0			
			Blue metal, with post girdles	0	5	10			
			Strong white post	2	1	8			
			Grey metal and hard girdles	0	3	0			
32	1	9	Coal, with slaty bands	0	1	9	6	0	6
			Blue metal and metal stone, with post girdles	3	2	0			
			Black slaty stone, with foul coal and sulphur (fire-damp)	0	2	6			
			Blue metal	0	1	6			
			Blue metal, with thin girdles	2	2	6			
			Strong white post	4	1	8			
			Grey metal	0	3	4			
			Strong white post	0	2	10			
			Blue metal, inclining to post near top	1	4	10			
			Coal ... ... 2ft. 6in. } Low Main Seam						
			Slaty coal ... ... 0 3 }						
33	5	5	Coarse coal ... 0 10 } or						
			Slaty coal . . ... 0 8 } Hutton Seam.						
			Coarse coal ... 1 2 }						
			... ...	0	5	5	14	2	7
	8	7					22	1	0

From the Bensham seam to the thill of the Low Main coal seam is 22 fathoms 1 foot, containing 8 feet 7 inches of coal, or 6·45 per cent.

WALLSEND COLLIERY is situated on the north side of the Tyne, near the river, and nearly opposite to Hebburn. In this colliery the Low Main has been sunk to, and the strata further proved by boring, as follows :—

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
			White thill	0	5	8			
			White post	0	5	7			
			Grey scamy post	0	5	0			
			White post	0	2	0			
			Carried forward	3	0	3			

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Brought forward	3	0	3			
			Grey metal	0	3	2			
			White post	0	5	0			
			Grey post	1	3	0			
			White post...	2	2	8			
			Blue metal, mixed with post girdles	0	5	0			
			White post	0	4	11			
			Blue metal	0	0	7			
34	0	10	Coal	0	0	10	10	1	5
			Grey thill	0	1	6			
			Grey metal...	0	1	6			
			Blue metal	0	3	2			
			Grey whin	0	0	6			
			Blue metal	0	2	0			
			White post	0	1	4			
			Blue metal	0	1	0			
			White post	0	0	6			
			Whin	0	0	8			
			White post	0	1	7			
			Blue metal...	0	1	1			
			White post	0	2	8			
			Grey whin	0	1	0			
			White post	0	1	0			
			Blue metal, mixed with ironstone girdles	6	0	3			
35	0	5	Coal	0	0	5	9	2	2
			Blue metal	0	0	4			
			White post	0	0	7			
			Grey post	1	2	8½			
			Blue metal	0	1	3½			
			Black metal	0	0	10½			
			Grey metal	0	0	4½			
			Blue metal	0	4	7			
36	2	11	Coal ... ... 2ft. 11in.						
			Grey stone 0 4						
37	0	7	Coal ... ... 0 7 } Beaumont Seam.						
			Grey stone 1 3						
38	1	5	Coal 1 5						
			... ...	1	0	6	3	5	3
	6	2					23	2	10

From the Low Main to the thill of the Beaumont seam is 23 fathoms 2 feet 10 inches, containing 6ft. 2in., or 4·35 per cent., of coal.

The Towneley Main Colliery is situated on the south side of the river Tyne, six miles west of Newcastle. The following is the section of strata below the Beaumont seam, as presented in the Stargate Pit, which is 300 yards north of the 90-fathom dyke:—

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Thill stone	1	5	9			
			Blue stone and hard girdles	0	3	5			
39	2	4	Coal	0	2	4	2	5	6
			Thill	0	0	7			
			Cashy parting	0	0	1			
			White post	2	4	7			
40	2	4	Coal	0	2	4	3	1	7
			Thill	0	4	5			
			Blue stone	0	2	0			
			Whin	0	0	7			
			Grey post	0	0	8			
			Blue stone	0	1	10			
			Whin	0	0	4			
			Grey post	0	2	0			
			Blue stone	0	0	8			
41	0	4	Coal	0	0	4	2	0	10
			Thill	0	1	3			
			Blue stone and hard girdles	0	2	7			
			Thill	0	1	6			
			Blue stone	0	0	7			
			White post...	0	0	6			
			Blue stone	0	0	4			
			Whin	0	0	5			
			Grey post	0	1	0			
			White post...	0	1	9			
			Blue stone and hard girdles	0	2	0			
			Cashy parting	0	0	2			
			Whin	0	0	9			
			Blue stone	0	4	8			
42	2	8	Coal ... ... 2ft. 8in. } Stone Coal Seam.						
			Band ... ... 0 3 }						
43	0	5	Coal ... ... 0 5 }						
			... ...	0	3	4	3	2	10
			Thill	0	2	11			
			Blue stone	1	0	3			
			Whin	0	0	7			
			Blue stone and whin girdles	0	5	8			
			White post, with whin	0	1	8			
			Blue stone	0	4	6			
44	0	5	Coal ... ... 0ft. 5in. } Five-Quarter Coal Seam.						
			Band ... ... 0 4 }						
45	2	10	Coal ... ... 2 10 }						
			... ...	0	3	7	4	1	2
			Thill	0	2	4			
			Blue stone and whin girdles	0	2	6			
46	0	10	Coal	0	0	10	0	5	8
			Thill	0	0	10			
			Blue metal stone	0	0	8			
	12	2	Carried forward	0	1	6	16	5	7

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Brought forward	3	0	3			
			Grey metal	0	3	2			
			White post	0	5	0			
			Grey post	1	3	0			
			White post...	2	2	8			
			Blue metal, mixed with post girdles	0	5	0			
			White post	0	4	11			
			Blue metal	0	0	7			
34	0	10	Coal	0	0	10	10	1	5
			Grey thill	0	1	6			
			Grey metal...	0	1	6			
			Blue metal	0	3	2			
			Grey whin	0	0	6			
			Blue metal	0	2	0			
			White post	0	1	4			
			Blue metal	0	1	0			
			White post	0	0	6			
			Whin	0	0	8			
			White post	0	1	7			
			Blue metal...	0	1	1			
			White post	0	2	8			
			Grey whin	0	1	0			
			White post	0	1	0			
			Blue metal, mixed with ironstone girdles	6	0	3			
35	0	5	Coal	0	0	5	9	2	2
			Blue metal	0	0	4			
			White post	0	0	7			
			Grey post	1	2	8½			
			Blue metal	0	1	3½			
			Black metal	0	0	10½			
			Grey metal	0	0	4½			
			Blue metal	0	4	7			
36	2	11	Coal ... ... 2ft. 11in. } Beaumont Seam.						
			Grey stone ... ... 0 4 }						
37	0	7	Coal ... ... 0 7 }						
			Grey stone ... ... 1 3 }						
38	1	5	Coal ... ... 1 5 }						
			... ...	1	0	6	3	5	3
	6	2					23	2	10

From the Low Main to the thill of the Beaumont seam is 23 fathoms 2 feet 10 inches, containing 6ft. 2in., or 4·35 per cent., of coal.

The Towneley Main Colliery is situated on the south side of the river Tyne, six miles west of Newcastle. The following is the section of strata below the Beaumont seam, as presented in the Stargate Pit, which is 300 yards north of the 90-fathom dyke:—

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	Coal Measures.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
			Thill stone	1	5	9			
			Blue stone and hard girdles	0	3	5			
39	2	4	Coal	0	2	4	2	5	6
			Thill	0	0	7			
			Cashy parting	0	0	1			
			White post	2	4	7			
40	2	4	Coal	0	2	4	3	1	7
			Thill	0	4	5			
			Blue stone	0	2	0			
			Whin	0	0	7			
			Grey post	0	0	8			
			Blue stone	0	1	10			
			Whin	0	0	4			
			Grey post	0	2	0			
			Blue stone	0	0	8			
41	0	4	Coal	0	0	4	2	0	10
			Thill	0	1	3			
			Blue stone and hard girdles	0	2	7			
			Thill	0	1	6			
			Blue stone	0	0	7			
			White post...	0	0	6			
			Blue stone	0	0	4			
			Whin	0	0	5			
			Grey post	0	1	0			
			White post...	0	1	9			
			Blue stone and hard girdles	0	2	0			
			Cashy parting	0	0	2			
			Whin	0	0	9			
			Blue stone	0	4	8			
42	2	8	Coal ... ... 2ft. 8in. } Stone Coal Seam.						
			Band ... ... 0 3 }						
43	0	5	Coal ... ... 0 5 }						
			... ...	0	3	4	3	2	10
			Thill	0	2	11			
			Blue stone	1	0	3			
			Whin	0	0	7			
			Blue stone and whin girdles	0	5	8			
			White post, with whin	0	1	8			
			Blue stone	0	4	6			
44	0	5	Coal ... ... 0ft. 5in. } Five-Quarter Coal Seam.						
			Band ... ... 0 4 }						
45	2	10	Coal ... ... 2 10 }						
			... ...	0	3	7	4	1	2
			Thill	0	2	4			
			Blue stone and whin girdles	0	2	6			
46	0	10	Coal	0	0	10	0	5	8
			Thill	0	0	10			
			Blue metal stone	0	0	8			
	12	2	Carried forward	0	1	6	16	5	7

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*							
	12	2	Brought forward	0	1	6	16	5	7
			Black stone	0	2	10			
			Grey post	0	0	8			
			Blue stone and girdles	0	4	0			
47	2	6	Coal, Three-quarter seam	0	2	6			
							1	5	6
			Thill	0	1	1			
			Blue stone and post girdles	1	4	10			
			Grey post	0	1	1			
			Blue stone	0	1	1			
			Grey post	0	0	6			
			Blue stone	0	1	0			
			Whin	0	0	5			
			White post...	0	2	1			
48	0	3	Coal	0	0	3			
							3	0	4
			Thill	0	0	3			
			Strong white post, with whin	6	1	9			
			Cashy parting	0	0	1			
			Strong white post, with whin	2	3	5			
49	3	3	Coal, Brockwell seam	0	3	3			
							9	2	9
	18	2					31	2	2

From the Beaumont seam to the thill of the Brockwell seam is 31 fathoms 2 feet 2 inches, containing 18 feet 2 inches of coal, equal to 9·65 per cent.

The strata beneath the Brockwell seam were explored by a boring made at Chopwell colliery (situated near Towneley) in the year 1795. The following is the section :—

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL.		COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	Ft.	*In.*							
			Thill stone	3	1	3			
			Brown post	2	0	0			
			Black metal stone	0	2	0			
			Grey post	1	5	0			
			Black metal stone	0	0	5			
50	1	1	Coal	0	1	1			
							7	3	9
			Brown metal stone	0	1	0			
			Blue post	0	5	9			
			Dun whin	0	1	6			
			Cashy parting	0	0	1			
			Strong white post...	1	0	9			
			Blue metal stone	0	0	9			
			Strong post girdles	0	0	5			
			Black metal stone...	1	1	7			
	1	1	Carried forward	3	5	10	7	3	9

No. of Seams of Coal.	Thickness of Seams of Coal. Ft.	In.	COAL MEASURES.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	1	1	Brought forward	3	5	10	7	3	9
			Strong post girdles	0	0	5			
			Blue metal stone	1	4	4			
51	0	1	Coal	0	0	1			
							5	4	8
			Thill	0	0	10			
			Blue metal stone	0	2	10			
			Strong white post	0	2	6			
			Black metal stone	0	3	0			
			Strong white post	0	1	0			
			Black metal stone	0	1	8			
			Strong white post	0	1	0			
			Black metal stone	0	1	0			
52	0	1	Coal	0	0	1			
							2	1	11
			Black metal stone	0	1	4			
			Strong white post	1	3	4			
			Cashy parting	0	0	1			
			White post	0	1	11			
			Blue metal stone	0	0	7			
53	0	9	Coal	0	0	9			
							2	2	0
			Black metal stone, mixed with coal	0	0	6			
			Thill	0	0	9			
			Grey metal stone	0	2	2			
			White post	0	2	7			
			Cashy parting	0	0	1			
			White post girdle	0	0	8			
			Dun whin	0	2	0			
			Strong white post girdles	0	0	8			
			Black metal stone	0	1	9			
			Post girdle	0	0	5			
			Black metal stone	0	1	11			
			Post girdle	0	0	6			
			Blue metal stone	0	4	4			
			Strong white post	0	1	0			
			Grey metal stone	0	3	6			
			White post girdle	0	0	5			
			Grey metal stone	0	0	8			
			White post	0	2	7			
			Parting	0	0	1			
			Strong grey post	0	2	11			
			Parting	0	0	1			
			Strong white post	0	0	10			
			Grey post	0	2	4			
			Strong white post	1	0	6			
			Grey post	0	0	10			
54	0	2	Coal	0	0	2			
							6	4	3
			Dun post	0	5	0			
			Blue metal stone	0	0	8			
			Whin girdle	0	0	2			
			Grey post	0	1	2			
			Dun post	0	2	0			
			White post	0	2	2			
	2	2	Carried forward	1	5	2	24	4	7

NO. OF SEAMS OF COAL.	THICKNESS OF SEAMS OF COAL. Ft.	In.	COAL MEASURES.	FATHOMS.	FEET.	INCHES.	FATHOMS.	FEET.	INCHES.
	2	2	Brought forward	1	5	2	24	4	7
			Grey post	0	2	9			
			White post	0	2	2			
			Dun whin	0	2	4			
			Parting	0	0	2			
			White post	0	1	8			
			Blue metal stone	0	0	8			
			White post girdles	0	3	10			
			Blue metal stone	1	2	10			
			Grey post girdle	0	0	8			
			Blue metal stone	0	3	3			
			White post	0	2	11			
			Blue metal stone	0	3	0			
			Grey post	0	3	9			
55	0	9	Coal	0	0	9	7	5	11
			Grey post	0	1	9			
			White post	0	2	10			
			Brown post	0	0	11			
			Parting	0	0	2			
			Brown post	0	1	6			
			Parting	0	0	1			
			White post	0	3	1			
			Grey post	0	3	6			
			Blue metal stone	0	0	6			
			Grey post	0	1	8			
			Cashy parting	0	0	3			
			White post girdle	0	0	4			
			Blue metal stone	0	3	6			
			Grey metal stone	0	1	9			
			Whin girdle	0	0	7			
			Blue metal stone	0	4	4			
56	0	3	Coal	0	0	3	4	3	0
			Thill	0	1	0			
			Brown post	0	0	11			
			Grey metal stone	0	0	11			
			Dun whin	0	1	0			
			Parting	0	0	1			
			White post	0	4	2			
			Grey metal stone	0	1	4			
			White post	0	1	8			
			Grey metal stone	0	1	4			
			White post and grey metal	0	5	8			
			Black metal stone	0	2	10			
			Strong grey post	0	3	1			
			Post girdle	0	0	8			
			Strong grey post	0	1	8			
			Strong white post	0	5	3			
			Black metal stone	0	3	2			
			Grey metal stone	0	2	3			
			Strong white post	0	1	2			
			Strong brown post	0	3	1			
			Cashy parting	0	0	9			
			White post girdle	0	0	7			
	3	2	Carried forward	7	0	7	37	1	6

No. of Seams of Coal.	Thickness of Seams of Coal.		Coal Measures.	Fathoms.	Feet.	Inches.	Fathoms.	Feet.	Inches.
	Ft.	*In.*							
	3	2	Brought forward	7	0	7	37	1	6
			Grey metal stone	0	2	7			
			White post...	0	1	0			
			Blue metal stone	0	0	8			
57	0	5	Coal	0	0	5	7	5	3
			White post, with coal pipes	1	1	3			
			Blue metal stone	1	1	7			
			Dun whin	0	1	6			
							2	4	4
	3	7					47	5	1

This bore-hole proves the coal measures to exist at least 47 fathoms 5 feet 1 inch further than recorded in the sections given above. This latter section contains 3 feet 7 inches of coal, equal to 1·24 per cent.

Toward the lower part of the coal measures, then, it appears from this boring that the seams of coal become very thin and of no value, unless worked in connexion with beds of ironstone or fire-clay, by which, in some situations, they may be accompanied.

The following is a summary of the above:—

	Fas.	Ft.	In.
1. Coal strata, above the thill of the Bensham seam, as proved by sinking at Monkwearmouth colliery	198	3	4¾
2. Ditto, between Bensham and Low Main thill, as proved by boring at Hebburn	22	1	0
3. Ditto, between the Low Main and Beaumont seam thill, as proved by boring at Wallsend colliery	23	2	10
4. Ditto, between the Beaumont and Brockwell seam thill, as proved by sinking at Towneley colliery	31	2	2
5. Ditto, so far as at present explored, being proved by boring below the Brockwell seam at Chopwell colliery	47	5	1
	323	2	5¾

This is equal to 1,940½ feet.

Forster, in his Section of the Strata from Newcastle-upon-Tyne to Crossfell, describes the coal measures as being but 259 fathoms 5 feet 7 inches, or 1,559½ feet, from the bottom of the clay to the top of the first limestone of the mountain limestone formation; and as this thickness includes the whole of the millstone grit, it must evidently be short of the truth. We may safely state the thickness of the coal measures as being at least 2,000 feet: their thickness is supposed by Mr. Phillips (Encyclopædia Britannica) to be 3,000 feet in the North of England.

From the above sections, it appears that there are 57 seams of coal, varying in thickness from 1 inch to 5 feet 5 inches, their aggregate being 75 feet 7¾ inches, equal to 3·89 per cent. of the whole thickness of strata explored.

Of the above seams, only nine exceed 2 feet 6 inches in thickness; but since, in some cases, from the circumstance of thin beds of stone only intervening, two or more seams of coal, inferior in point of thickness, are worked as one seam; and supposing that a seam of 2 feet 6 inches in thickness may be worked to profit in this district, there may be said to be included in the above, ten workable seams of coal, of which the combined thickness is 37 feet 5¾ inches (say 37 feet 6 inches), being equal to 1·932 per cent. of whole explored thickness of coal strata.

The strata associated with coal are either siliceous, or argillaceous, or carbonaceous, or intermediate between these.

Siliceous strata include all those locally known as sandstone, post, and whin, according to their different degrees of hardness. The strata designated by the latter term do not, as is sometimes erroneously stated, consist of basalt, but are merely a very hard, compact siliceous stone, sometimes resembling coarse flint.

Argillaceous strata comprise all those designated as "metal," and vary also in hardness and colour. Some of these strata, more particularly those which form the seat or thill of coal seams, when ground and mixed with water, form a clay which is moulded and burnt into bricks of a very refractory nature, and well adapted for the lining of blast and other furnaces exposed to intense heat.

Beds of this shale—or, as it is termed, sagre clay, or fire clay—are frequently also interstratified with seams of coal, in some instances making them workable to profit, when otherwise they would be valueless.

Black stone and black metal stone are sometimes so highly carbonaceous as to burn with flame: they lose little in bulk, and leave behind a mixture of silica and alumina; in fact, this latter substance is occasionally in sufficiently large quantity to render the substance which contains it available for the manufacture of alum—the process being similar to that formerly described.

The celebrated black band ironstone of the neighbourood of Glasgow is a description of black metal stone, its great value consisting in the facility which its bituminous nature affords to the roasting of the ore.

The whole of the above strata contain organic remains, the argillaceous the most abundantly, and in especial profuseness in the roofs of some of the seams of coal.

Plate 14, figures 1 and 2, were found at the distance of about 200 yards from each other in the roof of the Five-quarter seam at Blackboy colliery, near Bishop Auckland. I found two specimens of figure 1, which is a spine of the Gyracanthus, a sort of fish, probably of the same kind as that described in Sir C. Lyell's Elements of Geology, page 389. Considering its vicinity to the Stigmaria (figure 2), and the general abundance of plants associated with the seam of coal, the probability is, that the fish of which this spine is a portion, inhabited a river or fresh-water lake.

The nuts or fruit (Trigonocarpum Nöggerathi), plate 15, figure 2, were obtained from the sandstone overlying the High Main coal seam at Holywell colliery, about six miles north-east of Newcastle.

Plate 15, figures 3, 4, and 5, are drawings of shells and plants from the strata sunk through at Shotton colliery.

Plate 15, figure 1, is a shell from the roof of the Bitchburn seam at West Auckland colliery, near Bishop Auckland; and as a similar bed of shells is found to form the roof of the Brockwell or Horsley Wood seam of Wylam, I was at one time inclined to suppose that these seams were identical. I have, however, some grounds for thinking that this identity is by no means certain.

Plate 16 represents specimens of Pecopteris found in the strata passed through in sinking Shotton pits.

The subject of organic remains, particularly as regards the flora of the coal measures, is most voluminous, and one upon which much has been ably written, and of course impossible to enter into at length within the bounds at present prescribed to us. The reader is referred to the elaborate work of Messrs. Lindley and Hutton as an excellent aid in the prosecution of studies in this most interesting branch of natural history.

The whole of the seams of coal worked in the Newcastle coal-field are not found in a workable state in the section given above: it may, in fact, be remarked, that in no locality are the whole of the generally workable seams found in perfection. The seams not only vary in thickness, but also, in every respect, in sections taken at comparatively short distances from each other. In some situations they are richly bituminous and caking—in others, carbonaceous and free burning; in some they discharge carbonic acid gas, and in others fire-damp; in some they are soft and brittle, and in others hard and compact.

The same seams of coal also exist in different localities under different names: their identity will be discovered on reference to plate 17, which is collated with that published by Mr. Buddle in the Transactions of the Natural History Society of Newcastle-upon-Tyne.

The workable seams, in the order of their stratification, are as follows :—

1. The *High Main*	... No.	in section.
2. The *Five-quarter*	... No. 25 and 26	„
3. The *Main Coal*	... No. 27	„
4. The *Bensham*	... No. 28 and 29	„
5. The *Hutton Seam*	... No. 33	„
6. The *Beaumont*	... No. 36 and 37	„
7. The *Stone Coal*	... No. 42 and 43	„
8. The *Lower Five-quarter*	... No. 44 and 45	„
9. The *Three-quarter*	... No. 47	„
10. The *Brockwell*	... No. 49	„

1. The HIGH MAIN COAL SEAM of the Tyne collieries is found at the following depths from the surface :—

COLLIERY.	FATHS.
Percy Main	133½
Hebburn	131
Killingworth	115
Wallsend	111
Burradon	80
Tyne Main	53
Backworth	52½
Seaton Delaval	32
St. Lawrence	34½
Hartley	24
Earsdon	12

At these collieries, with the exception of Hartley and Seaton Delaval, the High Main seam is of a rich and caking quality: it burns rather quickly, makes a hot fire, and leaves but little ash, of a darkish colour. At Hartley and Seaton Delaval it loses richness, burns to white ashes, and is a pretty good steam coal. The prime districts of the High Main are now much exhausted, but still afford the best coals shipped from the Tyne collieries.

Mr. Buddle (Parliamentary Evidence, 1835) gave the following as being the section of the High Main at the celebrated Wallsend colliery :—

ROOF, BLUE METAL.

	FT.	IN.
Good coal	6	7½
Ground coal, not good	2	2
	8	9½

The upper part only was worked: it is now entirely exhausted.

The High Main seam at Backworth colliery presents the following section :—

	FT.	IN.
Coal, strong	5	11
Soft band	0	1
Coal, very coarse	1	6
Stone band	0	8
Coal, coarse and mixed with pyrites	2	6
	10	8

But here, as at Wallsend, a great portion is left in the mine: the upper, 5 feet 11 inches, only is worked, the rest being unsaleable.

At Killingworth the height of the coal varies much, being in some places 8 feet, and in others only 4½ feet, in thickness, of workable coal.

At Seaton Delaval colliery the following is the section:—

	FT.	IN.
Coal	0	6
Coarse coal	0	8
Coal	4	8
Coarse coal	0	10
	6	8

The general thickness of the High Main is from 5 to 6 feet of good coal. A little to the south of the Tyne it is interstratified with a bed of stone, called the Heworth band, which in the Tyne Main colliery is in some places scarcely discernible, but thickens towards the south, and renders the seam unworkable a short distance from the river.

The average specific gravity of the High Main coal may be deduced from the following statement, contained in the Appendix to the Report of the Select Committee on the State of the Coal Trade in 1830.

The specific gravity of the different specimens was ascertained by a hydrostatic balance, which weighed to the one-thousandth part of a grain.

Distilled water was used, the air of the room being at a mean temperature of 61° Fahrenheit.

Russell's Wallsend (Wallsend colliery)	1·26660
Riddell's ditto (Coxlodge ditto)	1·25000
Northumberland ditto (Backworth ditto)	1·26365
Newmarch's ditto (Fawdon ditto)	1·26469
Heaton ditto (Heaton ditto)	1·26310
Hotspur ditto (Earsdon ditto)	1·26621
Bewicke's ditto (Percy Main ditto)	1·25802
Killingworth ditto (Killingworth ditto)	1·26262
Mean	1·26184

A cubic foot of coal from the High Main seam, therefore, weighs 78·64 pounds avoirdupois.

I have been favoured with the results of several experiments, which have been made in order to ascertain the time of burning portions of coal from different seams in an open fire, together with the quantity of residuum left in each case. The quantity of coal used was in each experiment 48lbs., and with the High Main the results were as follows:—

SPECIMENS.	TIME OF BURNING.	RESIDUE.	PROPORTION OF RESIDUE PER CENT.
	H. M.	LBS. OZ.	
No. 1	8 42	1 1	2·140
No. 2	7 45	0 10	1·302
No. 3	8 5	0 6	·781
Ditto	7 30	1 0	2·983
Average ...	8 0	0 12¼	1·576

These results, of course, were merely intended to be approximations to the truth, sufficiently near to give some idea of the comparative durability and cleanness of coal from different localities.

The High Main seam corresponds to the Three-quarter seam of the south and eastern part of the coal-field, and to the Shield Row seam of the western division. It is not of much value at present, however, where it is known under any other denomination than as the "High Main." It is found of good household quality between the line of the Briardean Burn and the Heworth dykes, but exists in its most perfect state between the Main or 90-fathom dyke and the river Tyne. Its western outcrop is on the declivity of a hill near Benwell village.

In the Benwell and Fenham estates, a large tract of the High Main seam was destroyed by a conflagration in the middle of the sixteenth century.

2. The Five-quarter Coal Seam of the Wear and Tees collieries, corresponding to the Grey seam of the Cramlington district, is the next in order.

In the neighbourhood of Newcastle it consists of two seams—namely, the *Metal Coal* and the *Stone Coal*—which lie 7 and 14 fathoms respectively below the High Main, but neither of which are in the present day workable to advantage, being both deficient in thickness and quality.

The depth from the surface to the Five-quarter seam, where it exists in a workable state, is as follows:—

COLLIERY.	FATHS.	
Haswell	90	These pits pass through the magnesian limestone and lower new red sandstone.
Shotton	125	
Thornley	84½	
Wingate Grange	74	
Castle Eden	119	
Coxhoe	34	
Little Chilton	37	
Newbottle	84	
Pittington	40	
Sherburn Hill	38	
Pontop	31	
Blackboy	25	
Adelaide's	37½	

This coal is generally of rich caking quality, and is more durable than that from the High Main (No. 1).

It makes a very hot fire, leaving ash of a dark colour, but in greater quantity than is left by the High Main. It is also harder, working larger, and bears carriage better in consequence.

In some places, as at Newbottle and towards the banks of the Wear, east of Durham, it is less bituminous, burns white, and is a good steam coal.

The following is a section at Shotton colliery:—

	FT.	IN.
Splint coal	0	2
Coal	3	8½
Splint	0	1
	3	11½

SECTION AT NEWBOTTLE COLLIERY.

	FT.	IN.
Coal	1	0
Coarse coal	2	5
	3	5

It is here a very hard coal, and is chiefly sent oversea.

SECTION AT BLACKBOY COLLIERY.

	FT.	IN.
Coal	3	8
Splint	1	10
	5	6

SECTION AT PONTOP.

	FT.	IN.
Coal	0	7
Jet	0	3
Coal	3	2
Splint	0	8
Coal	1	6
	6	2

In the Pontop district this seam yields good second-rate coals, and has been extensively wrought.

A great proportion of the first-class coals from the Wear and Tees collieries is wrought out of the prime districts of the Five-quarter seam. It lies in the greatest perfection beneath the magnesian limestone, and in its immediate neighbourhood.

Its usual thickness is from 3 feet 4 inches to 3 feet 10 inches of coal, workable for household use. It is often also associated with a stratum of splint, lying beneath it, which, when thick enough to afford large coals, is frequently worked along with the best part of the seam, and sold as a steam coal, for which purpose it is found to answer exceedingly well.

It is only within the last few years that the Five-quarter seam has become in so great request for household coal. Mr. Buddle, in his Synopsis of the Newcastle Coal Field (read to the Natural History Society of Newcastle, December 20, 1830), said of the Five-quarter seam :—" This seam yields coals of inferior quality; has been extensively worked in some parts of the district, but is not workable to profit in other parts." Not more than three or four years after this, the working of the Five-quarter seam was commenced at a colliery sunk exclusively for the purpose of working the seam beneath, but which was found to exist in an unfavourable state. The hardness and excellent quality of the Five-quarter coals, however, soon stamped them as being of first-rate character; and they have been, and yet are, considered as being inferior to none.

The Hartlepool, Tees, Caradoc, Kelloe, &c., Wallsend coals are shipped from this seam.

The following are results of trials with Five-quarter coal:—

SPECIMENS.	TIME OF BURNING.	RESIDUE.	PROPORTION OF RESIDUE PER CENT.
	H. M.	LBS. OZ.	
No. 1	9 23	1 8	3·125
No. 2	10 33	0 12	1·562
No. 3	9 10	1 0	2·083
Average ...	9 42	1 1	2·256

3. The next seam is the **Yard Coal** of the Tyne, the Brass Thill seam of the Beamish and Pontop district, and the Main coal seam of the Wear and Tees collieries.

Its position is from 15 fathoms to immediately beneath the Five-quarter seam: in the Pontop district, the two seams are only separated by a band of 18 inches. On the Tyne, the Yard coal has not been much worked, but, as found in the neighbourhood of Hartley, it is 3 feet thick, and an excellent steam coal.

Its depth from the surface is as follows:—

COLLIERY.	FTHS.
Hetton	108¼
Castle Eden	126
Shotton	142
Pittington	47½
Coxhoe	43½
Blackboy	40
Pensher	88½
Oxclose	43¼
Pontop	40
Earsdon	40½
Backworth	80

This seam varies from first to second rate household coal: it is harder than the High Main of the Tyne, but resembles it in many respects. It makes a very hot, cheerful, rather open burning fire, leaves little dark ash, and burns rather quickly away.

It exists in perfection in the Auckland district, supplying the Tees and Adelaide's Wallsend coals.

Under the name of the Brass Thill seam, it is not nearly so hard, but of good quality, and in the eastern parts of Durham is a strong coal, working large, but its quality is rather inferior.

SECTION AT CASTLE EDEN COLLIERY.

	FT.	IN.
Coal	1	4
Fire clay	0	7½
Coal	3	0
Parting	–	–
Coarse coal	0	7
	5	6½

The lower, 7 inches, is not used for household coal.

SECTION AT COXHOE COLLIERY.

	FT.	IN.
Coal	1	4
Band	0	5
Coal	2	7
	4	4

SECTION AT BLACKBOY COLLIERY.

	FT.	IN.
Coal	1	4
Parting	0	0½
Coal	3	11½
Splint coal	1	10
	7	2

The splint is much used for lime burning, for which purpose it is worked when required.

SECTION OF THE BRASS THILL SEAM AT BEAMISH.

	FT.	IN.
Coal	4	8

.And at Pontop the section is similar.

The following were the results obtained by burning coals from this seam :—

SPECIMENS.	TIME OF BURNING. H. M.	RESIDUE. LBS. OZ.	PROPORTION OF RESIDUE PER CENT.
No. 1—Yard coal	6 10	1 0	2·083
No. 2.—Ditto	9 35	2 0	4·166
Average	7 52	1 8	3·124
No. 1.—Auckland Main coal	8 11	1 0	2·083
No. 2.—Ditto	9 30	1 0	2·083
Average	8 50	1 0	2·083

4. The **Bensham Seam** of the Tyne, called the Maudlin seam at the collieries on the banks of the Wear, is the next in succession.

It is from 10 to 14 fathoms below the Wear Main coal, or Tyne Yard seam.

Its depth from the surface is as follows :—

COLLIERY.	FATHS.
Monkwearmouth	264
Jarrow	175
Hebburn	167
Wallsend	145
Earsdon	54
Backworth	93
Oxclose	80
Pensher	99

This seam produces coals varying from best second class to very inferior quality. It is in general rather tender, and much interstratified with bands of splint coal and slate. It is also used for the manufacture of gas.

The following is a section at Monkwearmouth colliery :—

	FT.	IN.
Coal	3	6
Splint coal	0	2
Coal	1	7¼
Band	0	1
Coal, coarse	0	7
Coal and stone	3	6
	9	5¼

The lower part of the seam, consisting of 4 feet 2 inches, is of no value, being very inferior.

SECTION AT JARROW COLLIERY.

	FT.	IN.
Coal	3	0¼
Coarse coal	0	6
Coal	3	0
	6	6¼

SECTION AT BACKWORTH COLLIERY.

	FT.	IN.
Coal	2	5
Black stone	0	6
Coal	1	3
	4	2

This seam is here unworkable at present, on account of its inferior state.

SECTION OF THE MAUDLIN SEAM AT OXCLOSE COLLIERY.

	FT.	IN.
Coal	2	8
Splint coal	0	1¼
Coal	1	4½
Parting	0	0½
Coal	0	7½
	4	10

The Bensham seam does not extend over a very large portion of the coal-field in its best state. Between the rivers Wear and Tyne, and a little to the north of the latter, it can alone be said to be workable at the present time. Its quality seems to improve towards the east, and under the sea it may probably be a most valuable seam.

The mean specific gravity of the Hilda Wallsend coals wrought from the Bensham seam is 1·26087, a cubic foot weighing 78·578lbs.

The following results were obtained by burning coals from this seam:—

SPECIMENS.	TIME OF BURNING.	RESIDUE.	PROPORTION OF RESIDUE PER CENT.
	H. M.	LBS. OZ.	
No. 1	9 35	2 8	3·645
Ditto	10 0	1 0	
No. 2	9 0	2 0	3·645
Ditto	10 15	1 8	
No. 3	10 0	2 1	4·296
No. 4	10 52	3 4	5·468
Ditto	10 45	2 0	
Average ...	10 3	2 0⅘	4·263

The Bensham or Maudlin seam, in conjunction with the Five-quarter seam of the Tyne collieries (an unworkable seam), which corresponds to the Low Main of the collieries on the banks of the Wear, forms the Low Main of the collieries south of that river, and the Hutton seam of the Pontop and Beamish district.

Under this form, its depth from the surface is as follows:—

COLLIERY.	FATHS.
Hetton	130
Castle Eden	148
Pittington	74
Pontop	70

Its quality is variable. At Hetton and the surrounding district it is a strong coarse coal, suitable for steam purposes; nearer Durham, as at Pittington, it is of much finer quality, being almost as good as the Hutton seam; and at Pontop and Tanfield collieries, though rather tender, it yields coals of the finest quality, and, being free from any admixture of pyrites or other impurity, it is preferred in metallic manufactures. This seam has supplied the celebrated "Pitt's Tanfield Moor" collieries for upwards of a century, and is now greatly exhausted.

SECTION OF THE LOW MAIN SEAM AT CASTLE EDEN COLLIERY.

	FT.	IN.
Coal and splint	0	7
Parting	–	–
Coal	1	5
Coarse coal and splint	0	4½
Coal	1	11
Slaty band	0	2
Coal	0	3
	4	8½

There is a very great resemblance between this seam and the Bensham of the Tyne, and considerable doubts may reasonably be entertained as to whether it ought not to be referred altogether to that seam.

SECTION AT PONTOP COLLIERY.

	FT.	IN.
Coal	2	6
Band	0	3
Coal	3	0
	5	9

But the band is very variable in thickness, being in some places 2 feet.

SECTION AT PITTINGTON COLLIERY.

	FT.	IN.
Coal	3	6½
Black stone	0	2½
Splint coal	0	3½
	4	0½

5. The Low Main Coal Seam of the Tyne, the Hutton seam of the Wear, and the Low Main of the Beamish and Pontop collieries, lies from 8 to 25 fathoms below the seam last described.

Its depth is as follows:—

COLLIERY.	FATHS.
Seghill	75
Hartley	53
Earsdon	68½
Felling	100
Pensher	121
Haswell	155
Castle Eden	173

COLLIERY.	FATHS.
Pittington	89½
Shincliffe	72
Pontop	78
Towneley	8

The following is a section at Hartley colliery :—

	FT.	IN.
Coal, coarse	0	1½
Coal	3	10½
	4	0

It is here a steam coal of the first quality.

[1] SECTION AT WEST CRAMLINGTON COLLIERY.

	FT.	IN.
Jet	0	3
Coal	5	1
Slaty coal	0	7
Grey metal	0	2
Coal	0	2
	6	3

Coal 5 feet 1 inch alone is worked, and is very nearly equal to Hartley as a steam coal.

SECTION AT FELLING COLLIERY.

	FT.	IN.
Coal	2	2
Parting	0	0¼
Coal	3	2
Parting	–	–
Coarse coal	0	6
	5	10¼

[1] The West Cramlington, Seghill, and Cramlington seam is divided by a band near the boundary between Cramlington and Seaton Delaval collieries. This band thickens towards the east, and at Hartley colliery is 8 or 9 fathoms thick. I am also inclined to think it probable that the same band encircles the Cramlington district on the south and west; in fact, that a seam of coal beneath the Low Main of the Tyne (perhaps No. 30 in the section) rises up to the north, and forms with it the Seghill and Cramlington Low Main seam. The following is a section in Seaton Delaval colliery, near the Cramlington boundary :—

	FT.	IN.
Coal	3	0
Band	0	4
Coal	2	0
	5	4

The upper part of this seam thickens also to the east, and forms the Hartley seam, of which a section is given above. The Hutton seam is also divided by a band in Croxdale colliery, in the south parts of Shincliffe, Whitwell, and Haswell collieries, and also in Shotton colliery, which thickens to the south and divides it into two

The coarse coal at the bottom is left. The seam here is tender, and burns to white ashes; but, as a gas coal, it is in great request. The small coal is also much used by blacksmiths on account of its freedom from pyrites.

SECTION AT HASWELL COLLIERY.

	FT.	IN.
Coal	4	7
Parting	0	1½
Coarse Coal	1	3
	5	11½

The bottom coal is occasionally worked as a steam coal. The upper part of the seam, 4 feet 7 inches in thickness, is of excellent quality, and works large. The Hutton seam of this neighbourhood is the best seam of the present day, all the attendant circumstances of thickness, facility of being worked, and distance from port of shipment being taken into consideration. The High Main of the Tyne, in its prime districts, could perhaps have competed successfully with the Hutton seam, but, as before stated, these are exhausted.

SECTION AT SHINCLIFFE COLLIERY, NEAR DURHAM.

	FT.	IN.
Coal	4	1
Band	0	2½
Coarse Coal	1	1½
	5	5

The bottom coal is not worked: the upper part is a good second-class household coal. The section at Pontop Pike colliery is 4 feet of clean coal, good in quality, but tender.

The Low Main, or Hutton seam, is undoubtedly the most valuable seam in the coal field. It is found in a workable state over a much larger extent of country than any other seam, and in different districts it affords best coals of every description, whether they be required for household use, for steam coal, or for the manufacture of gas. It yields the

distinct seams, which at Coxhoe are 4 fathoms apart, the upper seam being 2 feet 2 inches thick, and the under seam 2 feet 11 inches, of which the bottom 4½ inches are coarse coal.

This band also thickens to the west and to the south-west from Croxdale, the Hutton seam at Byers Green presenting the following section:—

	FT.	IN.
Coal	2	1
Band	0	4½
Coal	0	4½
Band	1	7
Coal	2	4
	6	9

With some exceptions, then, it may be stated that the south boundary of the Hutton seam, in a good state, is somewhere about the Tudhoe or Hett Whinstone Dyke; at least, wherever the Hutton seam has been proved to the south of this dyke it has invariably been found either to be inferior in strength, or in thickness, or else divided by a band which soon renders the seam unworkable.

Cramlington and Hartley steam coals from the district north of the Briardean Burn Dyke, burning very open and quickly away, leaving much white ash and no slag on the engine bars: the Felling, Peareth, and Pelton gas coals, from the banks of the Tyne and the neighbourhood of Chester-le-Street, where it is tender and very bituminous: and the Haswell, Hetton, Lambton, and Stewart's, &c., Wallsend, from beneath the Magnesian Limestone, and the districts bordering thereupon, where, as a household coal, it holds the highest position, and is remarkable for its richness, cleanliness, and durability. It is not so hard, and, in consequence, does not carry to market quite so well as the Five-quarter coal, but in quality it is decidedly superior.

In fact, with the exception of the district south of the Hett Whinstone Dyke, the Low Main, or Hutton seam, is found generally in a workable state over nearly the whole of the great northern coal field of Durham and Northumberland.

The specific gravity of the Cramlington coal is 1·27011, and the weight per cubic foot 79·148lbs. avoirdupois.

Of the household coal the specific gravities are as follows:—

Russell's Hetton	1·26312
Lambton's Wallsend	1·26660
Stewart's ditto	1·25885
Hetton ditto	1·26031
Average	1·26222

and the weight per cubic foot is 78·633lbs.

From this it appears that coal adapted for steam purposes is heavier than the rich caking coal suitable for household use: and it is quite natural that this should be the case from the greater admixture of the former with earthy matter, the specific gravity of which is so much greater than that of coal.

The trials of this seam gave the following results:—

DESCRIPTION.	SPECIMENS.	TIME OF BURNING. H. M.	RESIDUE. LBS. OZ.	RESIDUE PER CENT.
Steam coal (White ash)	No. 1	8 55	1 0	2·083
	No. 2	8 45	1 3	2·474
	Average...	8 50	1 1½	2·278
Household ... (Dark ash)	No. 1	12 30	0 14	1·823
	No. 2	10 5	0 10	1·301
	No. 3	12 15	1 8	3·125
	Average...	11 36	1 0	2·083
Coking ... (White ash)	No. 1	11 20	1 8	3·124
	No. 2	11 0	1 4	2·604
	No. 3	13 26	2 6	4·948
	Average ...	11 55	1 11	3·559

6. The next seam is the BEAUMONT SEAM of the Tyne, called also the Harvey's Low Main and the Towneley and Barlowfield Seam; and in the Auckland and Etherley district the Yard Coal Seam: it lies from 20 to 35 fathoms below the Hutton seam, and at the following depths from the surface:—

COLLIERY.	FATHS.
Elswick	100
Sheriff Hill	134
Haswell	176
Towneley	51
Wylam	7
St. Helen's Auckland	35
Blackboy	108
Thornley	166

SECTION AT ELSWICK COLLIERY.

	FT.	IN.
Coal	2	4
Band	1	11
Coal	0	8
	4	11

SECTION AT TOWNELEY.

	FT.	IN.
Coal, scary	0	7
Splint coal	0	2½
Coal	2	11
	3	8½

SECTION AT ST. HELEN'S AUCKLAND.

	FT.	IN.
Coal	0	11
Splint coal	0	0½
Coal	1	10½
Band	0	1½
Coal	0	8
	3	7½

SECTION AT THORNLEY COLLIERY.

	FT.	IN.
Coal	3	8

The Beaumont seam has been bored to in some of the Tyne collieries, but not found in a good state below Newcastle Bridge. It is an irregular seam in point of thickness, but its quality is good, and, with few exceptions, uniform throughout the coal-field. It produces second-class coals for household use, and the small, screened out, is well adapted for the manufacture of coke. It is generally tender and will not bear carriage.

The seams below the Beaumont are at present only known near the west boundary of the Newcastle coal-field; they are generally of pretty good quality but tender; they produce second or third-rate household coals and make excellent coke.

7. The Stone Coal lies from 8 to 14 fathoms below the Beaumont seam; it is very variable in thickness, and rarely workable.

Its depth from the surface is as follows:—

COLLIERY.	FATHS.
Towneley	63
Blaydon Main	45
Garesfield	20

The following is a section of the Stone Coal seam at Towneley colliery:—

	FT.	IN.
Coal	2	8
Band	0	3
Coal	0	5
	3	4

SECTION AT BLAYDON MAIN COLLIERY

	FT.	IN.
Coarse Coal	0	1
Coal	2	3½
Sagre clay	0	3
Coal	0	4
	2	11½

SECTION AT GARESFIELD COLLIERY.

	FT.	IN.
Coal	2	5
Band	0	0½
Coal	0	6½
	3	0

The above, however, are favorable sections.

The seam is unworkable in the Auckland district; it makes good coke.

8. Immediately below the Stone coal at Garesfield, but from 1 to 2 fathoms below it at Blaydon Main, is the Lower Five-quarter Seam which presents the following sections:—

AT WYLAM COLLIERY.

	FT.	IN.
Splint coal	0	5½
Coal	2	11½
	3	5

SECTION AT GARESFIELD COLLIERY.

	FT.	IN.
Coal	3	9

SECTION AT BLAYDON MAIN COLLIERY.

	FT.	IN.
Coal	0	10¾
Band	0	4¼
Coal	2	5
	3	8

This seam produces coals of pretty good quality, but is tender and not well adapted for purposes of export where large coals are required. It is a good manufacturing coal, and, by reason of its freedom from pyrites, suitable for smiths' purposes. It makes excellent coke, the quality of which is still further improved by an admixture with the coal from the Stone coal seam.

The Stone coal and Lower Five-quarter form the Busty Bank seam of the Marley Hill and Pontop district: according to Mr. Buddle's synopsis the Beaumont and Busty Bank seams are identified as being the same: the present opinion is as above stated.

The section at Marley Hill colliery is as follows:—

	FT.	IN.	FT.	IN.
Coal			2	8
Band	0	4		
Coal	0	6		
Band	0	1		
			0	11
Coal			1	9
			5	4

SECTION AT MEDOMSLEY COLLIERY.

	FT.	IN.
Coal	3	2
Sagre Clay	1	9
Coal	3	11
	8	10

SECTION AT BERRY EDGE, NEAR SHOTLEY BRIDGE.

	FT.	IN.
Coal	1	10
Band	0	2
Coal	2	2
	4	2

9. The THREE-QUARTER COAL seam at Towneley, corresponding to the Six-quarter at Wylam, and the Main Coal at Walbottle, is the next seam, which is only proved workable in this district. It lies from 3 to 6 fathoms below the Five-quarter seam.

At Wylam the section is as follows :—

	FT.	IN.
Coal	4	0
Splint	0	2½
Coal	0	4½
	4	7

SECTION AT WALBOTTLE.

	FT.	IN.
Coal	3	1

10. The at present supposed lowest workable seam found in the coal field of Durham and Northumberland is called the BROCKWELL SEAM at Towneley; the Horsleywood seam at Wylam; the Splint seam at Walbottle; and the Brockwell, Bitchburn, or Lower Main coal of the Auckland and Etherley district. It is found at the depth of from 30 to 45 fathoms beneath the Beaumont seam, and at the following depths from the surface :—

COLLIERY.	FATHS.
Towneley	83
Wylam	41
St. Helen's Auckland	79
Blackboy	156
Cockfield Fell	23

The following is a section of the seam at St. Helen's Auckland :—

	FT.	IN.
Coal	0	11
Band	0	1½
Coal	1	4
Splint	0	2
Coal	3	1
	5	7½

The band of 1½ inches beneath the top coal thickens to the north and north-east, and to the west disappears altogether. At the adjoining colliery of Woodhouse Close, the following is the section of the seam near the St. Helen's boundary :—

	FT.	IN.
Coal	1	3
Sagre clay	0	8
Jet	0	0½
Carried forward	1	11½

	FT.	IN.
Brought forward	1	11½
Coal	1	0¾
Splint	0	3¼
Coal	3	4¾
	6	8¼

Further to the north-east, at the Woodhouse Close shaft, which is about half a mile from St. Helen's boundary, the band has increased to 35½ feet, and the seam under the band, which is 4 feet 8 inches in thickness, is the working seam of the colliery. The top coal, however, is worked, being taken down after the ground coal has been excavated, when the thickness of the sagre clay band does not exceed one foot.

At [1] Woodifield colliery, near the village of Crook, the seam presents the following section :—

	FT.	IN.
Top coal	3	0
Band	1	0
Coal	4	2
	8	2

And at the collieries north and east, the ground coal only is worked, being generally of the thickness of 4 feet, or 4 feet 2 inches

SECTION AT TOWNELEY COLLIERY.

	FT.	IN
Coal	0	1
Jet	0	3
Coal	2	11
	3	3

SECTION AT WYLAM COLLIERY.

	FT.	IN.
Jet	0	2
Coal	2	3
Splint coal	0	7½
	3	0½

The Brockwell seam is generally rather tender, but of good quality, and an excellent coking coal.

[1] I am not quite sure whether the Woodifield seam is really the Brockwell or the Busty Bank (Stone Coal and Lower Five-quarter). I am rather inclined to believe the latter. If this be the case, it then becomes a matter for speculation whether the Bitchburn seam and the Busty Bank, or the Bitchburn and Brockwell, are identical.

It produces a [1] second-rate household coal when in its best state, but more generally occupies an inferior position in the market. Its great redeeming properties are the cheapness with which it can be worked, and the excellence of the coke manufactured from it. Until very lately, much doubt prevailed as to the proper position in the coal series of the Bitchburn seam. Not more than eight years ago, it was by some styled the "Bitchburn or Hutton seam;" and very recently, and indeed still, many are of opinion that it is the Beaumont or Harvey seam. In the year 1846, however, a boring at Blackboy colliery, from the thill of the Main coal, has almost set the matter at rest. Here we have at one view all the seams of coal, from the Five-quarter seam downwards, corresponding very nearly in relative distances from each other to their distances in situations where their identity is undoubted. A reference to the section (plate 17) will make the whole perfectly plain.

The only question remaining is, whether the Bitchburn seam is the Busty Bank or the Brockwell, or a seam yet unproved excepting in the Auckland district; but as these first-mentioned seams are only a few fathoms apart, it will be difficult to decide the point until further explorings are made between the Pontop and Auckland districts.

I have intentionally forborn to make any remarks on the Byers Green and Whitworth seam, as its connexion is not yet completely traced. So far as present observation extends, this seam appears to be the Beaumont or Harvey seam, the Brockwell or Bitchburn lying probably 40 to 45 fathoms beneath it; but whether workable or not, is of course conjectural.

Plate 18 is a section of the strata sunk through at Norwood colliery, near Gateshead, from the surface to the bottom of the sump, 4 fathoms beneath the Beaumont seam. The sinking through the clay and sand was attended with considerable difficulty, and forms a pretty good illustration of the manner of passing through such deposits. I will, therefore, at a future period, revert to it.

In this section there are seven seams of coal, of the aggregate thickness of 5 feet 10 inches, or 3·91 per cent. of the coal strata.

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[1] The following is an extract from a letter written in the year 1818 by the late Mr. George Dixon, of Bishop Auckland, to the Chairman of the Committee of Subscribers to the projected Canal from the river Tees to West Auckland.

"A fire was made of an unheaped peck of these coals (the produce of the best colliery on the river Tyne, which for obvious reasons I do not name—suffice it, they stand at 34s. on the price list), weighing 19½ lbs., and continued to burn from half past six to eleven o'clock, or 4½ hours. In 2¾ hours all were burnt to a cinder. Next morning there remained only 5 oz. of ashes, and 2¾ lbs. of cinders, being too small a quantity to make another fire.

"A fire was next made of an unheaped peck of the Auckland Greenfield coals, weighing nearly 20lbs., and broken to the same size as the last. They continued to burn in the same fire-place, and *conducted in the same manner*, five hours and a half, being an hour longer than the other. Did not all burn to a cinder till 3¾ hours after the fire had been lighted, also an hour longer than before. Next morning there remained 5 oz. of ashes and an unheaped peck of cinders, weighing 7½lbs., (being thrice the quantity which remained in the former experiment). Of these cinders a fire was made and continued to burn an hour and forty minutes, which, added to the hour in the first fire, proves them to be *more durable in consumption by two hours and forty minutes than the same quantity of the best coals from the Tyne.*

"In *both* cases the fires burnt clear and pleasantly, and were only stirred or put together twice during the periods mentioned.

"The Tyne coal burnt more briskly than the other but did not form its cinders or coke large: what remained of the former were very small.

"A similar experiment has been made with the Ramshaw coal, which gave nearly as favorable a result as the one above cited."

The deposit of clay, &c., has already been alluded to, and the three sections (plate 19, figures 1, 2, and 3) shew the position of the strata previous to and posterior to this deposit being made.

We must (having the Hutton seam of coal in the positions "a" and "b") conclude that it was formerly continuous, as shewn in figure 1. The fact of there being an alluvial deposit in the position shewn in figure 3, implies an intermediate state, when a ravine existed, as in figure 2.

The variety of changes which must have occurred to account for such results, it will be fruitless for us now to discuss. When we slowly review these great events, we find ourselves lost in the antiquity of their occurrence; and still such as these are termed recent! and are they not, when compared with the formation of the coal, with its adjacent strata, and with those still more remote formations, upon and from the debris of which the coal and its adjuncts have in their turn been deposited and derived.

The new pit is situated within the fresh-water deposit, or wash, as it is locally named, which is here 17 fathoms in thickness—the Hutton seam, as seen in plate 19, figure 3, being completely denuded. The Beaumont seam, of which a section is given (figure 4), is also much distorted at the shaft, probably owing to the influence of the same causes which occasioned the 15-feet upcast to the east, seen in figure 3, but rapidly acquires a good section, being within a dozen yards, of the thickness of nearly 4 feet, with 3 or 4 inches of band.

The following are analyses of the various descriptions of coal, according to Dr. Richardson :—

DESCRIPTION OF COAL.	LOCALITY.	CARBON.	HYDROGEN, AZOTE, AND OXYGEN.	ASHES.
Splint	Wylam............	74·823	11·265	13·912
	Glasgow	82·924	15·948	1·128
Cannel	Lancashire	83·753	13·699	2·548
	Edinburgh	67·597	17·837	14·566
Cherry	Newcastle	84·846	13 478	1·676
	Glasgow	81·204	17·375	1·421
Caking.........	Newcastle	87·982	10·655	1·393
	Durham	83·274	14·207	2·519

The variation in the quality of the seams of coal has been adverted to; but what renders the fact more remarkable is, that generally the quality of the whole of the seams in each district bears more or less the same character. Of course I do not mean to state this as an invariable occurrence; but as an example of what I state, I may adduce the Cramlington district, where the whole of the seams are very hard, free and open burning, making much white ash, and suitable for steam purposes: the Heworth district, where the same seams are friable and tender, and adapted for the manufacture of gas, but quite unsuited to the purposes first named; the Tanfield and Crook districts, where, with even a less degree of hardness than the last, a greater purity is combined, and, consequently, a better adaptation to manufacturing and coking purposes; the Hetton and Blackboy districts, where the same seams afford coal of the first household quality, and almost as hard as the produce of the Cramlington district.

The variety of quality in different seams may not appear so very surprising, but that the same seam in different localities should, notwithstanding that it must all have been deposited uniformly, vary so remarkably, is a curious subject for speculation; and it is no less so, that, although the different seams must have been deposited at different, and, in some instances, widely distant epochs, the same character should, to a certain extent, pervade the seams of an entire district, as mentioned above.

It would seem that the quality of coal is dependent less upon its original formation, than upon the processes to which it has been subjected by the various revolutions which the earth has subsequently undergone.

It would certainly appear that the agency of heat has been exerted upon coal since it was originally deposited; and I am very strongly inclined to believe, that to this cause we must attribute many of the phenomena in which the seams of coal abound. How otherwise are we to account for the peculiar crystalline form of coal—or for the state in which we find it to contain fire-damp—or for crystallized pyrites? All these last may be accounted for by the supposition of heat under pressure—air, of course, excluded.

The following is the composition of the above coals, the seam being the same, but the locality different:—

	CARBON.	HYDROGEN, OXYGEN, AND AZOTE.	ASHES.	WEIGHT OF A CUBIC FOOT.
Steam coal	80·750	15·400	3·850	77·11
Coking coal	85·580	12·280	2·140	78·86
Household coal	83·274	14·207	2·519	80·23

The coal measures of the Newcastle coal-field also contain, although in small quantities, cannel coal similar to that found so abundantly in the Lancashire and Scotch coal-fields. The following table shows the position occupied by the Newcastle cannel to be superior to any English coal of similar description, though much inferior to that of Scotch cannel coal.—(Analysis by Dr. Fyfe, Aberdeen.)

	CUBIC FEET OF GAS PER TON.	COMPARATIVE DURABILITY OF FLAME.	VALUE OF COALS ACCORDING TO VALUE AND QUANTITY OF GAS.
Best English caking coal	9,746	50·66	1·00
Lancashire cannel	10,500	44·50	1·08
Ramsay's cannel, Newcastle	9,746	62·00	2·34
Marquis of Lothian	10,000	60·00	2·41
Lismahago	10,176	70·00	3·87
Boghead	14,880	88·42	11·07

Universally throughout the coal measures, beds and nodules of clay ironstone are found and worked: they are associated with the shale beds.

As we proceed downwards towards the lower part of the coal measures, we find the beds of coal thinner and more distant from each other, and eventually we meet with a succession of coarse grits and sandstone, constituting the series termed the Millstone Grit (6. *b*), of which little mention is necessary; and we will, therefore, proceed to—

6 *c*. ***The Mountain Limestone,*** upon which it will be necessary to make a few remarks.

On referring to a geological map, we observe that the mountain limestone is widely distributed, and, in fact, for its general value, must be considered as one of the most important formations in an economical point of view.

In the upper formations we find chalk, and from it we obtain lime and building stone. Further down, coal in small quantities, and salt and alum; still further, coal and ironstone.

In the mountain limestone we have coal, alum, lime, ironstone, lead, and copper—the whole in abundance.

The mountain limestone rises beneath the millstone grit about 7 or 8 miles west of Newcastle, and near the Coquet on the north.

It is first seen on the sea coast, a little to the north of Boulmer, and crops out between Scremerston and Berwick, where the old red sandstone rises from beneath it to the day. The cliffs at the Mill-house, Scremerston, consist of the mountain limestone, but a short distance to the north there is a fine section of the upper part of the old red sandstone. The same old red sandstone is seen at Jedburgh, implying that the outcrop of the mountain limestone is not far distant.

The whole of the seams of coal of the Berwick district, and all those worked in the north and north-west parts of Northumberland, belong to the mountain limestone formation. The quality of these seams is not generally so good as that of the seams belonging to the coal measures. That of the seam at present worked at Shilbottle colliery, near Alnwick, is of a peculiar character—the coal being exceedingly durable, and the ash of a dark brown, or rather purple colour, and very heavy: this coal is very hard. Plate 20 is a section of the strata at the Shilbottle old colliery; from which it appears that there are beneath the clay 331 feet of strata to the bottom of the Shilbottle seam, containing 7 seams of coal, of the aggregate thickness of 10 feet 9 inches, equal to 3·25 per cent., and 4 beds of limestone, of the aggregate thickness of 50 feet, or 15·1 per cent.

This section is in the upper part of the series: the Scremerston coal-field is situated in the lower part, and beneath the principal limestone beds.

The following table shows the position of the Scremerston limestones, as they appear upon the sea-shore:—

BENEATH EACH OTHER.	NAME OF LIMESTONE.	THICKNESS.
FATHOMS.		FEET.
0	Dryburn	20
40	Salt-panho, south quarry	11
20	Lincoln-lee, found at Barrington ...	22
20	Salt-panho (18 feet good)	24
20	Detchen—grey mare	6
6	Dun stone, inferior	5
50	Oxford	17
60	Woodend	10
30	Dun stone, inferior	6
246		121

A seam of coal 2 feet thick is found between the Salt-panho and Lincoln-lee limestones, and the next coal of any value is found about 6 fathoms beneath the Oxford limestone.

1. This seam is called the GREENSES or ALLERTON COAL, and is 30 inches thick, and has been wrought many years on the Greenses and Allerton estates.
2. The MUCKLE HOWGATE COAL, generally about 3 feet thick, has a bandy roof, and is a leafy coal, with a blue metal thill. It is said to lie 40 fathoms above the Woodend quarry, and is seen on the road from Allerton stead, also near and on the east side of Felkington kiln, and again at Woodend. This seam has been wrought within 200 yards of the Scremerston new winning, near the turnpike-road, about 3 miles from Berwick.
3. The LITTLE HOWGATE SEAM—freestone band roof, coal 2 feet 2 inches, blue metal thill—lies about 4 fathoms above the Woodend quarry, and was also found in Hogarth's east field, near to the Salt-panho sea-houses.
4. The CALDSIDE or FAWCETT COAL—limestone band roof, coal 3 feet 4 inches (sometimes, however, with a band of 16 or 18 inches, when the coal is generally diminished in thickness), and with a freestone thill—is supposed to be on the Scremerston estate, 35 to 40 fathoms below the Little Howgate, and, consequently, about 3 fathoms below the lowest bed of limestone, or dunstone, mentioned above.

   The Caldside level has been carried, and the coal wrought, to the Unthank east boundary from the sea, a distance of nearly 2 miles. The seam has been found and wrought in the flat ground between the Longeyheugh and Berryhill cuts, on the Etal estate, where it is called the Fawcett coal. It is also wrought near the Woodend quarry, and on the east side of Etal moor and Fawcett moor (on the Barmoor estate), whence it takes its name; also on the east side of the Ford estate, and at Doddington, and Jackson's colliery, of Biteabouts: at these places it is about 22 inches thick.
5. The SREMERSTON MAIN COAL and Unthank Main coal, and at all other places named, the Blackhill seam, under which name its quality is inferior, has been wrought at Scremerston and Unthank for a century; wrought as the Blackhill coal at Felkington, near the Whin Dyke, Mattalees; near the Etal plantation-houses, and on the moor

adjoining; at Slainsfield, and at the Blackhill, in Ford moss, whence it derives its name; also on the Doddington estate. It lies about 55 fathoms below the Caldside.

The section of the Scremerston Main coal at the Scremerston new pit is:—

	FT.	IN.
Top coal	2	10
Band	0	2
Ground coal	1	3
	4	3

Immediately adjoining the coal is a limestone roof of 1 feet 2 inches thick, above which is a thin coal seam 7 inches thick.

6. The STONEY COAL, wrought on the Scremerston estate within 80 yards of the Berwick Hill boundary and on Unthank common, is a very strong coal, and works large. The section of this seam is as follows:—

	FT.	IN.	FT.	IN.
Roof, freestone	4	0		
Dant, mixed with sand	0	4		
			4	4
Top coal	0	10		
Danty black stone	0	4		
Middle coal	1	3		
Black dant	0	2		
Coarse hard stone	0	11		
Coal	0	10		
			4	4

The coal being 2 feet 11 inches, but varying from 2 feet 9 inches to 3 feet 2 inches.

This seam has been tried and found in great perfection in the Scremerston Restoration pit, but was barred up on account of its liability to spontaneous inflammation. It is 3½ fathoms below the Main coal.

7. The CANCER COAL of Berwick Hill, the Bulman coal of Murton, and the Main coal of Thornton, Shoreswood, Greenlaw Walls, Felkington, Etal, Longeyheugh, and Slainsfield, is the thickest seam of the district, but has generally a bad roof, which requires the top coal to be left as a support. The section is as follows:—

Soft metal roof, several feet thick.	FT.	IN.
Top coal	1	8
Chalkstone	0	1
Fine splint coal	1	1
Rough coarse coal	0	6
Band	0	7
Good coal	1	0
Chalkstone	0	1
Bottom coal	0	9
	5	9

The coal being 5 feet, but varying from 3 feet 5 inches to 6 feet 9 inches.

	TOTAL THICKNESS. FT. IN.		THICKNESS OF COAL. FT. IN.
Murton	5 8	......	5 0
Gatherick	4 9	......	4 3
Ford	5 0	......	4 2
Felkington	6 2	......	5 5
Shoreswood	5 10½	......	4 9½

This seam is 17 fathoms below the Stoney coal.

8. The THREE-QUARTER COAL is a good hard lumpy coal, and is wrought at Berwick Hill, Murton, Thornton, Shoreswood, Felkington, and Ford Corner. The section is as follows:—

	FT. IN.	FT. IN.
Good blue metal roof		6 0
Top coal	1 1	
Black danty coal	0 4	
Coarse grey stone	0 8	
Bottom coal	1 1	
		3 2

Thill, soft and dry.

9. The COOPER EYE SEAM, formerly called the Stoney coal at several places, and anciently at Ford called the Lady coal. The section is as follows:—

	FT. IN.
Top coal	1 0
"Macker," which will burn, but leaves a skeleton ...	0 3
Ground coal, coarse	1 4
	2 7

The coal being 2 feet 4 inches, but varying from 2 feet to 2 feet 8 inches.

At Berwick Hill, and parts of Murton and Shoreswood, a metal band takes the place of the "Macker." At Berwick Hill it varies from 2½ to 4½ feet—at Shoreswood, from 15 to 40 inches.

This seam has been proved in all the district with the exception of Scremerston, but probably exists there as well. Its position is 40 fathoms below the Cancer coal.

10. The WESTER COAL is the lowest seam that has been wrought in this district. It varies in thickness from 3 to 4½ feet. It was anciently wrought at some of the rise pits in Shoreswood, and was sunk to in the present (1839) working pit, but from its inferior quality was not wrought. It lies 13 fathoms below the Cooper Eye seam.

The distance between two adjacent seams often materially differs in different parts of the coal-field. Thus, the distance between the Bulman and Cooper Eye seams is at Ford 17 fathoms; at the adjoining colliery of Etal, 23 fathoms; at Berwick Hill, 26 fathoms; and at Gatherick, 14½ fathoms. The direction of the dip varies considerably, but always inclines more or less towards the east.

The constituent parts of the mountain limestone, as analyzed by Sir H. Davy, are as follows :—

	CARBONATE OF LIME.	RESIDUUM.	IRON.
Frosterly	96·0	3·0	1·0
Bowron	91·0	8·5	0·5
Barton	94·0	5·0	1·0

Beds of ironstone, and veins of lead and copper ore, of great value, also abound in the mountain limestone formation, but beneath it the first-mentioned are more rare, and coal ceases to exist. We, therefore, find how general the association of coal and ironstone; and as the coal strata have received a considerable portion of our attention, we will, before passing on to still lower formations, notice some of the localities and geological positions of ironstone and other metallic deposits, now of such great importance.

The gross annual production of iron in Great Britain is now upwards of 2,250,000 tons. Of this quantity, South Wales furnishes 700,000 tons; South Staffordshire, including Worcestershire, 600,000 tons; and Scotland, 600,000 tons. The remainder is divided amongst the various smaller districts.

One of the principal causes of the advantages possessed by Great Britain in the manufacture of iron, arises from the number and variety of the measures of argillaceous and black band ironstone which alternate with the beds of coal in almost all its coal-fields; and, in consequence of which, the same localities, and in many instances the same mineral workings, frequently furnish both the ore and the fuel required in smelting it.

So extensive are the ironstone beds of the coal measures, that they themselves furnish the greater part of the iron produced in Great Britain; but the iron-making resources of the kingdom are by no means confined to them. The carboniferous or mountain limestones of Lancashire, Cumberland, Durham, the Forest of Dean, Derbyshire, Somersetshire, and South Wales, all furnish important beds of ironstone and veins of hæmatite (red oxide, or per-oxide of iron). Those of Ulverstone, Whitehaven, and the Forest of Dean, are the most extensively worked, and seem to be almost exhaustless. The brown hæmatites and white carbonates of Aldstone Moor and Weardale also exist in such large masses that they must ultimately become of great importance. In the older rocks of Devon and Cornwall are found many important veins of black hæmatite, and in the granite of Dartmoor, numerous veins of magnetic oxide of iron and specular iron ore. The new red sandstone furnishes, in its lowest measures, beds of hæmatitic conglomerate. In the lias and oolites are immense beds of argillaceous ironstone, now becoming extensively worked; in fact, at Eston, near to the north-east coast of Yorkshire, is a bed of solid ironstone, 12 feet in thickness. This bed has been traced into Nottinghamshire, and no doubt will become of enormous value.

The iron ores of the green sand of Sussex, once the seat of a considerable manufacture of iron, may again, by the facilities of railway communication, become available.

The produce of the iron manufacture of Great Britain was—

In 1750	... ... about	30,000 Tons.
In 1800	... ... „	180,000 „
In 1825	... ... „	600,000 „
In 1850	... ... „	2,250,000 „

Coal was first used in the South Staffordshire district in smelting iron in the year 1619.
The principal iron works of this neighbourhood are :—

		IN BLAST.	OUT.
Walker		2	–
Bedlington		1	–
Wylam		1	–
Redesdale	engines removed	–	–
Tyne		2	–
Hareshaw		–	3
Birtley		2	–
Middlesbro'		3	–
Witton Park		4	–
Stanhope		–	2
Towlaw		2	2
Crookhall		6	1
Consett		5	2

The annual produce of iron about 100,000 tons.

The iron works of this district are gradually increasing in importance, the cost of fuel being so low as to admit of ores being brought from many different localities. The black bands of Scotland and Haydon Bridge, the brown hæmatites and white carbonates of Aldstone and Weardale, and the argillaceous ironstones of the lias of Whitby and Middlesbro', are all, in conjunction with the clay ironstone of the coal measures, used for the supply of the iron works of the North of England.

The brown hæmatites deserve especial attention. They are found associated in very large masses with the lead veins, and occasionally they occur as distinct and regular beds. They contain from 20 to 40 per cent. of iron. Sometimes they exist as riders to the vein—sometimes they form its entire mass, and, in this case, they occasionally attain a thickness of 20, 30, or even 50 yards. Their employmont for iron-making purposes is only recent, but the supply of ore which they can furnish is almost unlimited ; and when some better means of separating the lead and zinc associated with them may have been discovered, they will doubtless be found to be of great importance. Remarkable changes sometimes occur in the character of the metalliferous veins of this district—the same vein which at one point bears principally lead ore, changing to a calamine vein, and then again to brown hæmatite.

The red hæmatite ores, also imported into these works from Cumberland, are in quality perhaps the finest in the kingdom. They contain from 60 to 65 per cent. of iron. They are found both as veins traversing the beds of the mountain limestone formation, transversely to the lines of stratification, and also as beds more or less regular. The former is the general character of the Ulverstone and Furness ores, no clearly defined bed being as yet known in that district; whilst at Whitehaven there are two, if not more, beds of irregular thickness, but with clearly defined roofs and floors, and often divided, themselves, by regular partings.

These beds attain a considerable thickness, occasionally 20 or 30 feet. The area over which they extend is not yet well known, but they have been worked extensively for many years, and their workings are rapidly increasing. They lie beneath, and close to, the coal measures which both furnish the necessary fuel, and also good beds of argillaceous ironstone for admixture. The other requisite, lime, is also at hand.

In a thickness of about 2,000 feet of the alternating beds of sandstone, shale, and limestone, which form the strata of the mining districts of Allendale, Aldstone, and Weardale, there is one single stratum of limestone, called the Great Limestone, the veins in which have produced nearly, if not quite, as much lead ore as all the other strata put together. Its thickness, which is tolerably uniform over several hundred square miles of country, is about 60 feet.

Plate 21 is a section of the strata at Cronkley, in the manor of Lune, taken from a publication, entitled "Geological Sections of Hudgill Burn, &c.," by Mr. Sopwith, and illustrates the process of lead-mining very well.

The limestone called here the Whin-top limestone corresponds to that named the Tyne bottom limestone in Forster's section, and is 68½ fathoms beneath the great limestone above named.

In illustration of the rich deposits of lead ore which have been found in the great limestone, may be mentioned the Rampgill vein, sometimes 12 feet wide, nearly of solid ore; and it has been known that a single length (that is, 15 fathoms of the great limestone only) at Coalcleugh, in the course of 12 years, has raised 4,000 tons of ore.

Lead ore is also found in the other strata of the mountain limestone series, and, in fact, this mass of strata is in consequence named the lead measures.

As seen in the section, there is a great bed of basalt, locally named the Whin sill, a rock of similar composition to the basaltic dykes of the coal measures, and also to the trap rocks of the neighbourhood of Edinburgh, Glasgow, the Giant's Causeway, Staffa, &c.

A bed, termed toad stone, occurs in Derbyshire, which corresponds to the great whin sill of the North of England. The actual distinction between the two has never clearly been pointed out; and since their geological position is the same, is there not reason for concluding that they are of the same origin, and, therefore, that they ought to receive the same designation? Both are considered as trap rocks.

The whin sill is well seen at High Force and Cauldron Snout, on the Tees. It is a very hard stratum, of a dark, greenish grey colour, emits fire with steel, and very rarely produces metallic ores. Several beds of shale, post, and limestone, are found beneath the whin sill, among the rest the Great Rundle Beck or Melmerby scar limestone, which is the thickest in the Cumberland section, being 22 fathoms in thickness.

The most common ore of lead is galena, or sulphuret of lead, the composition of which is as follows :—

Lead	85·13
Sulphur	13·02

(*Thompson.*)

Professor Jameson (Mineralogy) adds that a good analysis of this ore is much wanted. A cubic foot of pure galena weighs on a medium 7,000 ounces.

In Derbyshire, the lead mines are also in the mountain limestone: they are supposed to have been wrought in the time of the Romans. The Saxons and Danes were also engaged in working the mines of Derbyshire; and from this time, during the whole period of English history, the lead mines have been an object of attention.

Lead also abounds in Scotland, in the Lead Hills and Wanlockhead.

In France, in the department of the Sambre and Meuse, lead ore is found in veins traversing limestone; and the limestone of Tarnowitz, in Silesia, also contains remarkable deposits of lead ore.

The only appearance of lead in Siberia is the red chromate of lead, which was first discovered in that country, and of which the gold mine of Beresof is the principal repository. It is found in a small vein of ferruginous quartz, which traverses a gneiss rock, which is of a reddish colour, and resembles a sandstone.—(Williams' Mineral Kingdom.)

The mountain limestone also contains copper veins. In Cumberland, Westmorland, Yorkshire, and Derby, the principal mines worked are for lead. But in Cumberland and other places there are many remains of old workings for copper; in some of which ore of a richer quality than in Cornwall is found, and many, from their great size and facility of operation, might be worked to great advantage. A rich vein of copper has lately been found at Hay-gill, on Caldbeck Fells, where, in driving for the main vein, a string of ore, from seven to eight inches in depth, was found. There is also a copper mine near Hesket Newmarket, 14 miles south of Carlisle, called Currock End, which, 40 years ago, produced some thousand pounds' worth of copper ore. The sett is very extensive, and has several lodes in it, but never has been worked to a profit. " A mineral discovery has been made in Cum-" berland, on the property of the Earl of Lonsdale, for the working of which his lordship has " granted a mining sett for 21 years. The sett is extensive, extending over all the Manor " and Forest of Ennerdale. There has been already discovered a very large and fine looking " copper lode, 12 feet wide, a leader of which produces green, black, and yellow copper ore, " 5 tons to the fathom, and another 1½ ton to the fathom. There is also a lead lode of great " promise, which is rich in silver; and about three or four miles from the copper lode there " is a very large iron lode of good quality."—(*Newcastle Chronicle*, May 27, 1853.)

Edward IV., in the eighth year of his reign, granted all his copper mines, containing gold and silver, in Cumberland, Westmorland, and Northumberland, to Dodrick Waverswick.

And Dr. Fuller, in his " Worthies of Cumberland," observes, " that in taking the rich copper mines from the Duke of Northumberland at Keswick, it came to pass that this

Queen (Elizabeth) left more brass than she found iron ordnance in the kingdom;" and in the tenth year of her reign, Plowden says, "she took from the Earl of Northumberland his rich copper mine of Keswick, because of its holding so much silver and gold in the ore."

The Ecton copper mine, on the borders of Derbyshire, is also in the limestone. This is one of the most remarkable copper mines in the kingdom. It is situated in a dark brown stratified limestone, the beds of which are greatly deranged. The ore is deposited in a large accumulated mass, which is called by the Germans stock-werk. It is supposed that this mine was worked at a very early period. At one time, about 1,000 persons were employed in the works, and then it afforded an immense produce of rich ore.

At Currie, about five miles west of Edinburgh, copper ore is also found. It is said to be deposited in limestone.

Ores of zinc are common in the limestone, especially the sulphuret, or, as it is commonly called, blende, or black jack.

The characteristic fossils of the mountain limestone are corals. There are also many univalve and bivalve shells, as spirifera, ~~turretella~~ turritella, producta, buccinum, patella, isocardia, nucula, and pecten.

We now pass on to the *Old Red Sandstone* (7 *a*):—

This formation is of enormous thickness in Herefordshire, Worcestershire, Shropshire, and South Wales, where it is seen (as well as in the northern part of Northumberland, as before mentioned) to crop out beneath the mountain limestone, and to repose upon the Silurian rocks. In that region its thickness has been estimated by Sir R. Murchison at no less than 10,000 feet. It consists there of—

1st. A quartzose conglomerate, passing downwards into chocolate, red, and green sandstone and marl.

2nd. Cornstone and marl (red and green argillaceous spotted marls, with irregular courses of impure concretionary limestone, mottled red and green: remains of fishes).

3rd. Tilestone (finely laminated hard reddish or green micaceous, or quartzose sandstones, which split into tiles: remains of mollusca and fishes).

By consulting geological maps, it will be perceived that from Wales to the North of Scotland the old red sandstone appears in patches, and often in large tracts. Many fishes have been found in it at Caithness, and various organic remains in the northern part of Fifeshire, where it crops out from beneath the coal formation, and spreads into the adjoining southern half of Forfarshire, forming together with the Trap, the Sidlaw Hills, and valley of Strathmore.

The group of rocks beneath the old red sandstone (7 *b*) consists of a series of slates, limestones, and shales, to which the general name of primary fossiliferous rocks has been attached. Many geologists have also applied to these older strata the name of "Grauwacké," by which the German miners designate a variety of quartzose sandstone, which is usually an aggregate of small fragments of quartz, flinty slate (or Lydian stone), and clay slate, cemented together by argillaceous matter.

Professor Sedgwick and Sir R. Murchison have proposed to subdivide all the English sedimentary strata below the old red sandstone into two leading groups, the upper of which may be termed the Silurian, and the inferior the Cambrian system. The following table explains the succession of the deposits of the Silurian system :—

1.	Ludlow formation	Micaceous grey sandstone ... ... Argillaceous limestone ... ... Shale, with concretions of limestone ...	2,000 feet
2.	Wenlock formation ...	Concretionary limestone ... ... Argillaceous shale	1,800 „
3.	Caradoc formation	Flags of shelly limestone and sandstone, thick-bedded white freestone	2,500 „
4.	Llandeilo formation ...	Dark-coloured calcareous flags	1,200 „

The characteristic fossils are marine mollusca of almost every order, with corals, trilobites, &c.

The well-known rock of Dudley, so rich in organic remains, belongs to the Wenlock formation, which consists in its higher division of limestone, more or less crystalline, and highly charged with corals and encrinites, of species distinct from those of the mountain limestone.

No land plants seem yet to have been discovered in strata which can be unequivocally demonstrated to belong to the Silurian period.—(Lyell's Elements, p. 461.)

It is important to remember this, as there is otherwise a considerable resemblance between some of the Silurian shales and those belonging to the coal measures—a resemblance which has already led to a grave error.

In the limestones of Lake Michigan, in North America, and other regions bordering the great Canadian lakes, chain corals and trilobites are also found, and, from their fossils generally, they seem to belong to the Silurian period. It is necessary to bear this in mind, because there is little doubt that the rapid progress continually being made in America will in all probability induce great research into the mineral resources of that country; and as we have seen above how error has been fallen into, by ignorance of the true nature of the Silurian rocks, the subject is certainly well worth a portion of our attention.

Below the Silurian strata in the region of the Cumberland lakes, in Cornwall, in North Wales, and in other parts of Great Britain, there is a vast thickness of stratified rocks, for the most part slaty and devoid of fossils. In some few places a few organic remains are detected, specifically, and some of them generically, distinct from those of the Silurian period. These rocks have been called Cambrian by Professor Sedgwick, because they are largely developed in North Wales, where they attain a thickness of several thousand yards. They are chiefly formed of slaty sandstone and conglomerate, in the midst of which is a limestone containing shells and corals, as at Bala, in Merionethshire. A slaty sandstone, forming the bottom of the Cambrian system in Snowdon, contains shells of the family brachiopoda, and a few zoophytes.

We now pass on through the slates, among which we find roofing slate, of which there are extensive quarries not far from Bangor, in North Wales, to the lower strata of mica and clay slate, gneiss, &c., to *Granite* (7).

These rocks are the repositories of tin and copper in the great mining districts of Cornwall.

These ores, as in the case of lead, are found in veins, associated with different varieties of spar. The veins in Cornwall have no determinate size, being sometimes very narrow, or exceeding several fathoms in width—extending sometimes to a great length and depth, or terminating after a short course in either direction. As regards their form, they are occasionally, though rarely, contained within parallel and regularly-inclined sides or walls. but are continually varying in width, both on the line of their course and of their inclination, partaking often of the same undulating and even-curved form of the rocks which they traverse.

On the kindly appearance of lodes, Mr. Henwood says:—" All the harder rocks in the mining districts are quartzose; and whether they are granite, elvan (porphyry), or slate, this character is unfavourable. A distinctly crystalline structure of the granite, and their slaty texture, and high inclination in killas (clay slate), is also discouraging; but a soft nature, both in granite and slate, and in the latter the moderate thickness of the beds, and the slight inclination of the laminæ, are encouraging features. In granite, the lodes which are chiefly productive of tin ore, are for the most part composed of a pale greenish feldspar, of a confusedly crystalline structure, but seldom containing distinct crystals."

The component parts of granite are feldspar, quartz, and mica, of which the two first frequently exhibit a crystalline form.

The proportions of the crystalline parts of granite are extremely variable, but in general the feldspar is most abundant: sometimes the proportion of quartz is very small, and often the mica is scarcely perceptible. Sometimes, too, the ingredients of granite are very unequally distributed, and in particular the feldspar, which is disposed in large masses, as is sometimes observed in the granite of the island of Arran, as well as that of the island of Mull. In the latter, the crystals of feldspar are from one to several inches in diameter.

In some specimens of granite from Arran, the mica assumes a crystallized form, the breadth of the crystals not exceeding the thirtieth part of an inch.

The quartz of granite is generally of a greyish colour; the feldspar, whitish grey, or reddish; and the mica is sometimes black and sometimes white. Beside the three principal ingredients now mentioned, some varieties of granite contain also schorl, horn-blende, and garnets.

In the granite found at Aberdeen and its vicinity, which, from its appearance, comes under the denomination of grey granite, and is the description best known here, and which, from the grains of the ingredients of which it is composed being of small size, is called small grained granite, the feldspar and quartz are in the greatest proportion; the quantity of mica is small, and its place is sometimes occupied by small specks of hornblende, or schorl.

The arches of the Victoria bridge over the Wear are composed of this stone.

The above formations, besides metals, salt, coal, &c., generally produce stone and lime, or cement, suitable for building purposes.

The admirable report of Sir Henry de la Beche, and Messrs. Barry, Warington W. Smyth, and C. H. Smith, as to the result of an inquiry undertaken under the authority of the Lords' Commissioners of Her Majesty's Treasury, with reference to the selection of stone for building the New Houses of Parliament, affords most ample information and invaluable remarks upon the subject; and much of what I shall communicate upon this head is derived from their report.

If we look around us, we cannot fail to lament the decay which we everywhere behold in many of those beautiful monuments of the past, the fine old cathedrals, churches, and castles, bequeathed to us by those whose bones have long since mouldered in the dust.

In exemplification of this, I may adduce Tynemouth priory, Durham cathedral, the castle and church of St. Nicholas at Newcastle-upon-Tyne, &c. More recent buildings also show the little care that has been bestowed upon the selection of a proper material; for instance, the Newcastle gaol, which is already beginning to feel the hand of time, and also several other comparatively modern buildings in that town.

We observe from the report above-named, that in the greater part of the limestone employed at Oxford, the magnesian limestone of York minster, and in the sandstones of which the public buildings of Derby are constructed, we find, among numerous other examples, incontestible and striking evidence of the necessity and importance of making ourselves acquainted with the durability of the material of which we construct buildings, which are intended to resist the ravages of time.

The unequal state of preservation of many buildings, often produced by the varied quality of the stone employed in them, although it may have been taken from the same quarry, shows the propriety of a minute examination of the quarries themselves, in order to acquire a proper knowledge of the particular beds from whence the different varieties have been obtained. An inspection of quarries is also desirable, for the purpose of ascertaining their power of supply, the probable extent of any given bed, and many other matters of practical importance.

It frequently happens that the best stone in quarries is neglected, or only in part worked, from the cost of baring and removing those beds with which it may be associated, and, in consequence, the inferior material is in such cases supplied, especially when a large supply is required in a short space of time, and at an insufficient price, which is often the case with respect to works undertaken by contract.

As an economical supply of stone in particular localities would often appear to depend on accidental circumstances, such as the cost of quarrying, the degree of facility in transport, and the prejudice that generally exists in favour of a material that has been long in use, and as the means of transport have of late years been greatly increased, it becomes essential to ascertain whether better materials than those which have been employed in any given place may not be obtained from other, although more distant, localities, upon equally advantageous terms.

With respect to the decomposition of stones employed for building purposes, the Commission observes that it is effected according to the chemical and mechanical conditions to which such stones are exposed. As regards the sandstones that are usually employed for such purposes, and which are generally composed of either quartz or siliceous grains, cemented by siliceous, argillaceous, calcareous, or other matter, their decomposition is affected according to the nature of the cementing substance, the grains being comparatively indestructible. With respect to limestones composed of carbonate of lime, or the carbonates of lime and magnesia, either nearly pure or mixed with variable proportions of foreign matter, their decomposition depends, other things being equal, upon the mode in which their component parts are aggregated, those which are most crystalline being found to be the most durable, while those which partake least of that character suffer most from exposure to atmospheric influences.

The varieties of limestones called oolites, being composed of egg-shaped bodies cemented by calcareous matter of a varied character, will of necessity suffer unequal decomposition, unless such oviform bodies and the cement be equally coherent, and of the same chemical composition. The limestones which are usually termed shelly, from being chiefly formed of either broken or perfect fossil shells, cemented by calcareous matter, suffer decomposition in an unequal manner, in consequence of the shells (for the most part crystalline) offering the greatest amount of resistance to the decomposing effects of the atmosphere.

Sandstones, from the mode of their formation, are very frequently laminated, more especially when micaceous, the plates of mica being generally deposited in planes parallel to their beds. Hence, if such stone be placed in buildings, with the planes of lamination in a vertical position, it will decompose in flakes according to the thickness of the laminæ; whereas, if it be placed so that the planes of lamination be horizontal—that is, most commonly upon its natural bed—the amount of decomposition will be comparatively immaterial.

Limestones, such, at least, as are usually employed for building purposes, are not generally liable to the kind of lamination observed in sandstones; nevertheless, varieties exist, especially those commonly termed shelly, which have a coarse laminated structure, generally parallel to the planes of their beds, and, therefore, the same precaution in placing such stone in buildings, so that the planes of lamination be horizontal, is as necessary as with sandstones above noticed. In the magnesian limestone of the county of Durham, it may, however, be remarked, that there is a bed of tolerably crystalline limestone, which is much laminated, and when exposed to the weather very soon splits into thin plates, and rapidly decays away. Instance several bridges, engine-houses, &c., upon some of the public and colliery railways in that county.

The effects of the chemical and mechanical causes of the decomposition of stone in buildings are found to be greatly modified, according as such buildings are situated in town or country. The state of the atmosphere in populous and smoky towns produces a greater amount of decomposition in buildings so situated, all other conditions being equal, than in those placed in the open country, where many of the äeriform products which arise from such towns, and are injurious to buildings, are not to be found.

The chemical action of the atmosphere produces a change in the entire matter of the limestones, and in the cementing substances of the sandstones, according to the amount of surface exposed to it. The mechanical action due to atmospheric causes occasions either a removal or disruption of the exposed particles—the former by means of powerful winds and driving rains, the latter by the congelation of water forced into or absorbed by the external portions of the stone. These effects are reciprocal, chemical action rendering the stone liable to be more easily effected by mechanical action, which latter, by constantly presenting new surfaces, accelerates the disintegrating effects of the former.

Buildings in this climate are generally found to suffer the greatest amount of decomposition on their southern, south-western, and western points, arising, doubtless, from the prevalence of winds and rains from those quarters; hence it is desirable that stones of great durability should at least be employed in fronts with such aspects.

Buildings situated in the country appear to possess a great advantage over those in populous and smoky towns, owing to lichens, with which they almost invariably become covered in such situations, and which, when firmly established over their entire surface, seem to exercise a protective influence against the ordinary causes of the decomposition of the stone upon which they grow.

As an instance of the difference in degree of durability in the same material subjected to the effects of the atmosphere in town and country, we may notice the several frustra of columns and other blocks of stone that were quarried at the time of the erection of St. Paul's cathedral, in London, and which are now lying in the island of Portland, near the quarries from whence they were obtained. These blocks are invariably found to be covered with lichens, and although they have been exposed to all the vicissitudes of a marine atmosphere for more than 150 years, they still exhibit beneath the lichens their original form, even to the marks of the chisel employed upon them; whilst the stone which was taken from the same quarries (selected, no doubt, with equal, if not greater, care than the blocks alluded to), and placed in the cathedral itself, is, in those parts which are exposed to the south and south-west winds, found in some instances to be fast mouldering away.

One great cause of the rapid decay of buildings in large and smoky towns, especially when, as in the case of St. Paul's, they are built of limestone, is very apparent: I allude to the quantity of sulphurous acid which is every minute produced by burning coal. We may, perhaps, be disposed to smile at this; but, before doing so, let us calculate (roughly, indeed) the quantity of sulphurous acid annually dissipated into the London atmosphere by the simple process above alluded to. The annual quantity of coal consumed in London is, in round numbers, 3½ millions of tons; and taking the average quantity of sulphur contained in coal (exclusive of that contained in the pyrites) at the low estimate of 1 per cent., this will give the enormous quantity of 35,000 tons of sulphur annually converted into sulphurous acid in London and its environs.

As water absorbs 33 times its volume of this gas, it is no wonder that those aspects most exposed to rain should suffer decay in the manner above alluded to.

As examples of the degree of durability of various building stones in particular localities, the following may be enumerated :—Of the sandstone buildings examined by the Commission, they notice the remains of Eggleston abbey, of the thirteenth century, near Barnard Castle, constructed of a stone closely resembling that of Stenton quarry, in the vicinity, as exhibiting the mouldings and other decorations, even to the dog's tooth ornament, in excellent condition. The circular keep of Barnard Castle, apparently also built of the same material, is in fine preservation. Tintern abbey may also be noticed as a sandstone edifice that has, to a considerable extent, resisted decomposition; for although it is decayed in some parts, it is nearly perfect in others. Some portions of Whitby abbey are likewise in a perfect state, whilst others are fast yielding to the effects of the atmosphere. The older portions of Ripon cathedral, constructed of sandstone, are in a fair state of preservation. Rivaulx abbey is another good example of an ancient sandstone building in a fair condition. The Norman keep of Richmond castle, in Yorkshire, affords an instance of a moderately hard sandstone which has well resisted decomposition.

As examples of sandstone buildings of more recent date in a good state of preservation, we may mention Hardwicke hall, Haddon hall, and all the buildings of Craigleith stone in Edinburgh and its vicinity. Of sandstone edifices in an advanced state of decomposition, we may notice Durham cathedral, the churches at Newcastle-upon-Tyne, Carlisle cathedral, Kirkstall abbey, and Fountain's abbey. The sandstone churches of Derby are also extremely decomposed; and the church of St. Peter's, at Shaftesbury, is in such a state of decay, that some portions of the building are only prevented from falling by means of iron ties.

As an example of an edifice constructed of a calciferous variety of sandstone, we may notice Tisbury church, which is in unequal condition, the mouldings and other enrichments being in a perfect state, whilst the ashlar, apparently selected with less care, is fast mouldering away.

The choir of Southwell church, of the twelfth century, may be mentioned as affording an instance of the durability of a magnesio-calciferous sandstone, resembling that of Mansfield, after long exposure to the influences of the atmosphere.

Of buildings constructed of magnesian limestone, we may mention the Norman portion of Southwell church, built of stone similar to that of Bolsover Moor, and which are throughout in a perfect state, the mouldings and carved enrichments being as sharp as when first executed. The keep of Koningsburgh castle, built of a magnesian limestone from the vicinity, is also in a perfect state, although the joints of the masonry are open, in consequence of the decomposition and disappearance of the mortar formerly within them. The church at Hemmingborough, of the fifteenth century, constructed of a stone resembling that from Huddlestone, does not exhibit any appearance of decay. Tickhill church, of the fifteenth century, built of a similar material, is in a fair state of preservation. Huddlestone hall, of the sixteenth century, constructed of the stone of the immediate vicinity, is also in good condition. Roche abbey, of the thirteenth century, in which stone from the immediate neighbourhood has been employed, exhibits generally a fair state of preservation, although some portions have yielded to the effects of the atmosphere.

As examples of magnesian limestone buildings in a more advanced state of decay, we may mention the churches at York, and a large portion of the minster, Howden church, Doncaster old church, and others in that part of the country, many of which are so much decomposed that the mouldings, carvings, and other architectural adornments are often entirely effaced.

We may here remark, that, as far as our observations extend, in proportion as the stone employed in magnesian limestone buildings is crystalline, so does it appear to have resisted the decomposing effects of the atmosphere—a conclusion in accordance with the opinion of Professor Daniell, who has stated that, from the results of experiments, he is of opinion, that "the nearer the magnesian limestones approach to equivalent proportions of carbonate of lime and carbonate of magnesia, the more crystalline and better they are in every respect."

Of buildings constructed of oolite and other limestones, we may notice the church of Byland abbey, of the twelfth century, especially the west front, built of stone from the immediate vicinity, as being in an almost perfect state of preservation. Sandysfoot castle, near Weymouth, constructed of Portland stone in the time of Henry VIII., is an example of that material in excellent condition, a few decomposed stones used in the interior (and which are exceptions to this fact) being from another oolite in the immediate vicinity of the castle. Bow-and-Arrow castle, and the neighbouring ruins of a castle of the fourteenth century, in the island of Portland, also afford instances of the Portland oolite in perfect condition. The new church in the island, built in 1766 of a variety of the Portland stone termed roach, is in an exceilent state throughont, even to the preservation of the marks of the chisel.

Many buildings constructed of a material similar to the oolite of Ancaster, such as Newark and Grantham churches, and other edifices in various parts of Lincolnshire, have scarcely yielded to the effects of atmospheric influences. Windrush church, built of an oolite from the neighbouring quarry, is in excellent condition; whilst the abbey church of Bath, constructed of an oolite in the vicinity of that city, has suffered much from decomposition, as is also the case with the cathedral and the churches of St. Nicholas and St. Michael, in Gloucester, erected of a stone from the oolite rocks of the neighbourhood.

The churches of Stamford, Colley Weston, Kettering, and other places in that part of the country, attest the durability of the shelly oolite termed Barnack rag, with the exception of those portions of some of them for which the stone has been ill selected. The excellent condition of those parts which remain of Glastonbury abbey show the value of a shelly limestone similar to that of Doulting; whilst the stone employed in Wells cathedral, apparently of the same kind, and not selected with equal care, is in parts decomposed. The mansion, the church, and the remains of the abbey of Montacute, as also many other buildings in that vicinity, constructed of the limestone of Ham Hill, are in excellent condition. In Salisbury cathedral, built of stone from Chilmark, we have evidence of the general durability of a siliciferous limestone; for although the west front has somewhat yielded to the effects of the atmosphere, the excellent condition of the building generally is most striking.

In the public buildings of Oxford, we have a marked instance of both decomposition and durability in the materials employed; for whilst a shelly oolite similar to that of Taynton, which is employed in the more ancient parts of the cathedral, in Merton college chapel, &c., and commonly for the plinths, string courses, and exposed portions of the other edifices of that city, is generally in a good state of preservation, a calcareous stone from Heddington, employed in nearly the whole of the colleges, churches, and other public buildings, is in such a deplorable state of decay, as in some instances to have caused all traces of architectural decoration to disappear, and the ashlar itself to be in many places deeply disintegrated.

In Spofforth castle, we have a striking example of the unequal decomposition of two materials, a magnesian limestone and a sandstone—the former employed in the decorated parts, and the latter for the ashlar or plain facing of the walls. Although the magnesian limestone has been equally exposed with the sandstone to the decomposing effects of the atmosphere, it has remained as perfect in form as when first employed, whilst the sandstone has suffered considerably from the effects of decomposition.

In Chepstow castle, a magnesian limestone in fine preservation, and a red sandstone in an advanced state of decomposition, may be observed, both having been exposed to the same conditions as parts of the same archways; and in Bristol cathedral there is a curious instance of the effects arising from the intermixture of very different materials, a yellow limestone and a red sandstone, which have been indiscriminately employed, both for the plain and decorated parts of the building. Not only is the appearance in this case unsightly, but the architectural effect of the edifice is also much impaired by the unequal decomposition of the two materials, the limestone having suffered much less from decay than the sandstone.

Judging, therefore, from the evidence afforded by buildings of various dates, there would appear to be many varieties of sandstone and limestone employed for building purposes which successfully resist the destructive effects of atmospheric influences. Amongst these the sandstones of Stenton, Whitby, Tintern, Rivaulx, and Craigleith; the magnesio-calciferous sandstones of Mansfield; the calciferous sandstone of Tisbury; the crystalline magnesian limestones or dolomites of Bolsover, Huddlestone, and Roche abbey; the oolites of Byland, Portland, and Ancaster; the shelly oolites and limestones of Barnack and Ham

Hill; and the siliciferous limestone of Chilmark, appear to be among the most durable. To these, which may be all considered as desirable building materials, may be added the sandstones of Darley Dale, Humbie, Longannet, and Crowbank; the magnesian limestone of Robin Hood's Well; and the oolite of Ketton; although some of them may not have the evidence of ancient buildings in their favour.

The Commission state in conclusion, that if they were called upon to select a class of stone for the more immediate object of their enquiry, they should give their preference to the limestones, on account of their more general uniformity of tint, their comparatively homogeneous structure, and the facility and economy of their conversion to building purposes; and of this class they should prefer those which are most crystalline; and that, after having weighed to the best of their judgment the evidence in favour of the various building stones which have been brought under their consideration, and freely admitting that many sandstones as well as limestones possess very great advantages as building materials, they feel bound to state, that for durability, as instanced in Southwell church, &c., and the results of their experiments—for crystalline character, combined with a close approach to the equivalent proportions of carbonate of lime and carbonate of magnesia—for uniformity in structure, facility and economy in conversion, and for advantage of colour, the magnesian limestone or dolomite of Bolsover Moor and its neighbourhood is, in their opinion, the most fit and proper material to be employed in the proposed New Houses of Parliament.

From the report, it appears that the average price per cubic foot of stone at the quarries for ordinary ashlar stone is 10·83 pence; the magnesian limestones averaging 11·2 pence, the sandstones 9·85 pence, and the oolites 10·75 pence. 10·83 pence is the average price at seventy-three quarries.

The following analyses shew the composition of these varieties of building stone:—

1.—SANDSTONE.

	CRAIGLEITH.	HEDDON.	KENTON.	MANSFIELD. (RED.)
Silica	98·3	95·1	93·1	49·4
Carbonate of lime	1·1	0·8	2·0	26·5
Carbonate of magnesia ...	0·0	0·0	0·0	16·1
Iron, alumina	0·6	2·3	4·4	3·2
Water and loss	0·0	1·8	0·5	4·8

2.—MAGNESIAN LIMESTONE.

	BOLSOVER.	HUDDLESTONE.	ROCHE ABBEY.
Silica	3·6	2·53	0·8
Carbonate of lime	51·1	54·19	57·5
Carbonate of magnesia	40·2	41·37	39·4
Iron, alumina	1·8	0·30	0·7
Water and loss	3·3	1·61	1·6

3.—OOLITE.

	ANCASTER.	BATH BOX.	PORTLAND.
Silica	0·0	0·0	1 20
Carbonate of lime	93·59	94·52	95·16
Carbonate of magnesia	2·90	2·50	1·20
Iron, alumina	0·80	1·20	0·50
Water and loss	2·71	1·78	1·94
Bitumen	Trace.	Trace.	Trace.

4.—LIMESTONE.

	BARNACK.	CHILMARK.	HAM HILL.
Silica	0·0	10·4	4·7
Carbonate of lime	93·4	79·0	79·3
Carbonate of magnesia	3·8	3·7	5·2
Iron, alumina	1·3	2·0	8·3
Water and loss	1·5	4·2	2·5
Bitumen	Trace.	Trace.	Trace.

		SPECIFIC GRAVITY.	WEIGHT PER CUBIC FOOT. LBS.	OZ.	COMPARATIVE COHESIVE POWER.
Sandstones ...	Craigleith ...	2·232	145	14	111
	Heddon	2·229	130	11	56
	Kenton	2·247	145	1	70
	Mansfield ...	2·338	148	10	72
Magnesian Limestone.	Bolsover ...	2·316	151	11	117
	Huddlestone ...	2·147	137	13	61
	Roche Abbey...	2·134	139	2	55
Oolite	Ancaster ...	2·182	139	4	33
	Bath Box ...	1·839	123	0	21
	Portland ...	2·145	135	8	30
Limestone ...	Barnack... ...	2·090	136	12	25
	Chilmark ...	2·481	153	7	101
	Ham Hill ...	2·260	141	12	57

Among the lower formations, we find granite, gneiss, and syenite to produce building materials which, for strength, hardness, and durability, occupy the first rank ; but they will not resist very high temperature, although gneiss, when the mica in it is very abundant, has in some cases been used with success as a facing for fire-places and furnaces, subjected to a strong heat. Granite and syenite are the most suitable for the purposes of cut or dressed stone, particularly in cases where great solidity is indispensable, owing to the large blocks in which they can be procured from the quarry, and the perfect accuracy with which the surfaces can be wrought. Gneiss seldom splits evenly, and is therefore more suitable for rubble or hammered stone: it is also an excellent material for a flagging stone, and all three of these stones are in common use for structures requiring great solidity and permanency, as for revetment walls of fortifications, quay walls, sea walls, lighthouses, &c.—(Mahan's Civil Engineering.)

With regard to this description of stone, the Commission above alluded to state as follows:—

We have not considered it necessary to extend our enquiry to granites, porphyries, and other stones of a similar character, on account of the enormous expense of converting them to building purposes in decorated edifices, and from a conviction that an equally durable, and in other respects more eligible, material could be obtained for the object in view among the limestones or sandstones of the kingdom.

Slate, as has been before stated, is found among the lower rocks. It may consist of the ingredients of granite, or of an extremely fine mixture of mica and quartz, or talc and quartz. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish grey to a lead colour.

Whilst upon this part of the subject, we should be leaving the description of building material incomplete did we not examine a little into the question of artificial stones and cement, as without a certain knowledge of the properties of these useful materials our information would be very imperfect.

The best brick earth is composed of a mixture of pure clay and sand, deprived of pebbles of every kind, but particularly of those which contain lime or other metallic substances, as these, when in large quantities and in the form of pebbles, act as fluxes, destroy the shape of the brick, and weaken it by causing cavities or cracks. Good brick earth or clay is frequently found in a natural state, and requires no other preparation for the purposes of the brickmaker. When he is obliged to prepare the earth by mixing the pure clay and sand, direct experiments should in all cases be made to ascertain the proper proportions of the two. If the clay is in excess, the temperature required to semi-vitrify it will cause it to warp, shrink, and crack; and if there is an excess of sand, complete vitrification will ensue under similar circumstances, unless, however, the sand itself should be of a refractory nature, as in the case of powdered firestone.

The quality of the brick depends as much upon the care bestowed upon its manufacture as upon the quality of the clay. The first stage of the process is to free the clay from pebbles, which is most effectually done by digging it out early in the autumn, and exposing it in small heaps to the weather during the winter. In the spring, the heaps are carefully riddled, if necessary, and the earth is in a proper state to be tempered. The quantity of water required will depend upon the quality of the clay: no more should be used than will be sufficient to make the earth so plastic as to admit of its being easily moulded by the workmen. If too much water be used, the brick will not only be very slow in drying, but it will in most cases crack, owing to the surface becoming completely dry before the moisture of the interior has had time to escape; the consequence of which will be, that the brick, when burnt, will be either entirely unfit for use, or very weak.

Great attention is requisite in drying the brick before it is burned. It should be placed for this purpose in a dry exposure, and be sheltered from the direct action of the wind and sun, in order that the moisture may be carried off slowly and uniformly from the entire surface. When this precaution is not taken, the brick will generally crack from the unequal shrinking arising from one part drying more rapidly than the rest. The burning and cooling should be done with equal care. A very moderate fire should be applied, for about twenty-four hours, to expel any remaining moisture from the raw brick. The fire is then increased until the burning is complete, and then the cooling slowly effected, otherwise the bricks will not bear the effects of the weather.

Brick, when of good quality, exhibits a fine, compact, uniform texture when broken across, and gives a clear ringing sound when struck. It is found by experiment that good brick, having the specific gravity of 2·168, requires 1,200lbs. on the square inch to crush it. The ordinary dimensions of common bricks are 9 inches in length, 4½ inches in breadth, and 2¾ inches in thickness, 400 of which are equal to one cubic yard.

Lime is made by burning limestone or carbonate of lime in kilns, until the water and carbonic acid are driven off. After having been subjected to this process, the lime has a strong avidity for water, and when perfectly pure it will absorb about three-and-a-half times its bulk in the process of slaking, and the bulk of the hydrate of lime thus formed will be found to have increased in the same proportion. The descriptions of lime with which, in Northumberland and Durham, we are best acquainted, are those made from the magnesian limestone and mountain limestone: that from the magnesian limestone of Houghton-le-Spring or Fulwell affords a good example of the former, and that from Stanhope of the latter. The lime made from the blue lias limestone possesses the property of setting under water

The magnesian lime, when of its best quality, is generally considered more economical, by allowing a greater proportion of sand to be mixed with it, than the lime from the mountain limestone; but as regards their comparative applicability to agricultural purposes, the latter is far superior.

Lime is also made from chalk. This description is suitable for interior work, plastering, ceilings, &c. Good building lime should allow of an admixture of sand in the proportion of 3 of sharp sand to 1 of lime, its quality as a cement being improved by the addition.

When a greater proportion of sand than this exists, the product is a weak mortar, which adheres but slightly to the stone, and is apt to become pulverulent. It is the received opinion that the union of the lime and sand is merely of a mechanical nature, the lime entering the pores of the sand, and thus connecting the particles much in the same way as the particles of granular stones are connected by a natural cement. The sand itself serves the important purposes of causing the mass to shrink uniformly, whilst the hardening or setting of the mortar is still in progress, and thus prevents any cracking, which must always be the result of irregularity in the shrinking: it promotes the rapid desiccation of the mass, and is conducive both to solidity and economy, from its superior strength, hardness, and cheapness to lime.

CHAPTER II.

Dykes: Slips: Mineral Veins: Internal Heat.

THE whole of the stratified rocks above-named are seldom found to preserve their continuity over any very large extent, but have it broken at uncertain intervals by what are commonly called dykes or slips.

It is generally the custom to apply these terms indiscriminately to fissures filled with basalt or whinstone, and to throws of the strata or faults; but I consider it better to give distinct names to each of these, and will therefore by the term "dyke" mean a fissure filled with basalt, and by "slip" a throw of the strata or fault.

Dykes, as may be seen by referring to plate 1, are understood to be connected with volcanic rocks beneath, from which they have been ejected in a molten state into fissures probably formed by the eruptions causing the dykes. The substance of which dykes are composed is basalt or trap, of different degrees of fineness in the grain, some of it being coarse and granular, and some of finer texture, like some of the scoriæ of iron furnaces. Their direction is usually straight, or nearly so, and their magnetic bearing in the North of England is more or less north-west; the course of the principal dykes being as follows:—

1. *Hitchcroft Dyke,* near Alnwick	No. 72° W.
2. *Acklington Whin Dyke*	No. 80° W.
3. *Mausoleum Dyke,* Hartley colliery	No. 61° W.
4. *Swallow Dyke,* Hartley colliery	No. 65° W.
5. *Coaley Hill Dyke*	No. 45° W.
6. *Tynemouth Dyke*	No. 63° W.
7. *Willington* or *Tudhoe Dyke*	No. 82° W.
8. *Cockfield Dyke*	No. 45° W.

1. The HITCHCROFT DYKE is seen in a quarry a little to the west of the turnpike road from Alnwick to Newcastle, about four miles south of Alnwick. The dyke is here in the form of a ridge running across the country, the width of the whin being about 69 feet. The ridge is remarkably intersected by a small rivulet, to the depth of 40 or 50 feet. The whin is a strong, hard, coarse basalt, and is used for the roads. In the centre of the dyke the whin is most compact, which may either have arisen from the crater having been in this position, the ejected lava flowing as it were over itself, and, gradually cooling, forming the sides; or it may have resulted from the greater pressure laid upon it by the external mass. The outer portions are slightly stratified and columnar.—(Plate 22, figure 1.)

2. The ACKLINGTON DYKE passes about half-a-mile south of Radcliffe colliery, and thence a short distance north of Acklington colliery, through the village of Acklington, crossing the Coquet near Brainshaugh, where it has been partially worked.

3. The MAUSOLEUM DYKE was seen and passed through in the Hartley colliery workings, its position being nearly underneath the Mausoleum in the Seaton Delaval grounds. By it the strata are thrown down to the north-east to the extent of 8½ fathoms. This dyke consists of two walls of basalt of the thickness of 9 feet and 4 feet 4 inches, separated from each other by a mass of the debris of other strata of the thickness of 8 feet 10 inches.—(Plate 22, figure 2.)

4. The SWALLOW DYKE is at Hartley, between 300 and 400 yards south of the Mausoleum dyke, and is a downcast to the north of 12 fathoms. Its course is nearly parallel to the Mausoleum dyke, though they diverge a little to the west. This dyke passes 20 chains north of the pits at Seaton Delaval colliery, the thickness of the basalt being here 12 feet, accompanied by 55 yards of detritus on its south side. The dyke is here an upcast to the north of 10 feet, and 17 yards further north is a small slip, a riser to the north of 3 feet.

5. The COALEY HILL DYKE has been noticed at length in a paper read by Mr. Buddle to the Natural History Society of Newcastle-upon-Tyne, January, 1830. It was discovered in the workings of the Beaumont seam in Montague Main colliery, in 1795.

Plate 22, figure 3, is a section of the strata passed through in a stone drift cut through the dyke at Benwell colliery.

	FT.	IN.
No. 1.—The seam changed into shattered glance coal, which is diminished in thickness from its full height, 3 feet 4 inches, into a mere leader, by the descent of the blue grey metal roof: from the roof, a tongue of the blue grey metal is protruded into the coal	—	—
No. 2.—The bluish grey metal roof passing downwards	3	0
No. 3.—Grey post, mixed with crystallized carbonate of lime	7	0
No. 4.—Black metal, much mixed with coal, and semi-vitrified	6	0
No. 5.—A singular rock, apparently composed of fragments of shale or metal stone, the interstices being filled up with a fine white powder, which is nearly pure alumina, and calcareous spar. The shale composing the substance of this rock is entirely changed in its nature, differing very materially from the general character of the rock as met with in the district	16	0
No. 6.—Basalt	13	0
No. 7.—Compact indurated black metal stone	20	0
No. 8.—Black metal, with scares of coal	15	0
No. 9.—Same as No. 3	2	0
No. 10.—Same as No. 2	0	6
No. 11.—Coal, same as No. 1	—	—
	82	6

The section shews that the whin dyke does not pass through the Beaumont seam at this place, but that it merely depresses the seam a few feet below its natural level, thinning it as if by pressure into a mere leader, and deteriorating the quality of the coal. It is a matter of doubt whether the whin extends upwards from the Beaumont seam to the Low Main seam, or not; or whether or not its vertical extent is limited to the space between those two seams, which is about 30 fathoms. A cinder dyke is described in the plan of the Low Main workings, but whether any whin was observed at this dyke is now uncertain. This dyke is passed through at Spital Tongues colliery in the workings of the Low Main seam, 42 yards west of the shaft. It hades considerably to the south-west, overlying at an angle of about 30° or 35°.—(Plate 22, figure 4.)

The section of the dyke here is as follows:—

	FT.	IN.
Cinder coal	6	0
Basalt	12	0
Loose blocks of sandstone and shale	18	0
Cinder coal	4	0
Total	40	0

The strata are not dislocated by this dyke.

We have a traditionary account that a cinder dyke runs across the Town Moor, at Newcastle, which spoils the coal in the High Main seam for upwards of 100 yards in breadth, through the whole extent of the Moor from the Cowgate to the Bullpark, where the coal is supposed to be not more than 20 fathoms from the surface. The High Main is here 60 fathoms above the Low Main, and from 85 to 90 fathoms above the Beaumont.

From Coaley Hill we do not discover any traces of the dyke at the surface until we come to the Ouseburn. Here in the freestone quarry on the east side of the burn, the stone as well as the clay and earth above it, and also the debris which covers the face of the bank from top to bottom, shew that the whole has been subjected to a high degree of heat, and several scattered fragments of basalt, of various shapes and sizes, occur on the south side of the quarry.

This whin dyke passes through old Byker colliery, the Jane pit being sunk about the middle of it, also through Walker and Hebburn collieries, at the latter of which it is cut through in the workings of the High Main seam, at the depth of 120 fathoms from the surface. In the immediate vicinity of the dyke the coal is charred for about 9 feet on either side, and the thickness of the coal reduced.

The section of the seam, 10 yards from the dyke, is as follows:—

	FT.	IN.
Coal	2	2½
Heworth band	1	10
Coal	0	8½
Band, shale	0	2
Coal	2	7¼
Total	7	6¼

Adjoining the dyke the section is as follows :—

	FT.	IN.
Coal, charred	1	10¼
Heworth, band	2	1
Coal, charred	0	7
Band, shale	0	1¾
Coal, charred	2	3¼
Total	6	11½

The following is a section of the dyke at this point :—

	FT.	IN.
Basalt, mixed with spar	1	6
Basalt	5	0
Ditto, mixed with freestone and shale detritus ...	17	6
Basalt	5	6
Ditto, mixed with spar	0	9
Total	30	3

This whin dyke, which appears at the surface at Simonside, a mile and a half south of Jarrow church, was quarried here for road material. The quarry has been for some time filled up, but the men who worked it stated that it cropped out in Hedworth Burn, at which point they commenced working. They followed it to some distance, probably 50 yards, in which distance it thickened from 6 to 11 feet. It dipped considerably to the north-west, which, on account of the influx of water, stopped their operations.

6. The Tynemouth Dyke. This dyke is exposed in the cliff beneath the lighthouse, and is about 5 yards from the south point of the promontory, about 35 feet in height of the cliff being above high-water mark.—(Plate 23, figure 1.)

The section of the dyke is as follows :—

	FT.	IN.
No. 1.—Hard coarse basalt, of a dark grey colour, with abundance of reddish crystals of irregular form, and much shaken and crushed	5	9
No. 2.—A soft decayed "core," containing crystals of feldspar. A portion of this (about 12 inches in depth) has been washed out by the spray and weather	0	7
No. 3.—Hard basalt, resembling No. 1	5	10
Total	12	2

The sandstone adjoining the dyke has a slightly bluish tinge, occasioned probably by heat, but is not much altered. The dyke does not occasion any dislocation of the strata.

The strata passed through at this point by the dyke are a portion of the lower new red sandstone, immediately beneath the magnesian limestone. A few yards north of the dyke, the magnesian limestone is seen in the upper part of the cliff, but the dipping of the surface towards the south point of the cliff occasions its absence in the immediate neighbourhood of the dyke.

7. The WILLINGTON or TUDHOE DYKE passes about a mile north of Witton-le-Wear, where it has been put through in the workings of the coal seam at Marshall Green colliery, at the depth of 8 or 10 fathoms from the surface. It is again found at Willington colliery, near Bishop Auckland, its thickness at this point being 19½ feet of whin, with 5 feet of cinder coal adjoining it on either side. This dyke crosses the Durham and Auckland turnpike at the bridge, a quarter of a mile from the London road. It is quarried at Hett for road material, and also near Cassop. A branch of this dyke passes through Shincliffe colliery, near Durham: in one place, where put through, the thickness was 8 feet, the whin being exceedingly hard; but at a short distance from this point the whin does not rise into the coal, but appears in the floor of the seam. Immediately upon the whin the coal is converted into a hard cinder, into which veins of whin have been forced up.

The Willington dyke passes through Shotton colliery at about half-a-mile north of the shaft. The thickness of the whin is here 67 feet.

8. The COCKFIELD DYKE is the most considerable basaltic dyke intersecting the coal measures of this district.

At Butterknowle colliery, near the extreme south-west limit of the coal-field, the dyke is 7½ feet thick, underlying to the north about 15 inches to the fathom, and casting the strata up 2 fathoms to the south. At the distance of 10 feet from the basaltic dyke is a common slip, an upcast to the south of 6 fathoms. The dyke is again exposed on the north-west side of Cockfield Fell, near the Lead-yard, and both there and further south-east on the fell, is extensively quarried as a road material. At the latter place it is 22 yards thick: it is here traversed by a slip, a downcast to the south-east of 12 fathoms, by which the whin dyke is thrown its full breadth out of its regular course, the dyke on the south-east side of the slip being 22 yards north of its position, had its course been unchanged. An underlay of 15 inches to the fathom is insufficient to account for this, as a 12-fathom slip would only throw the dyke 15 feet out of its course, instead of 22 yards. Possibly the slip may have had a lateral as well as a vertical motion. One fact, at any rate, is established—viz., that the slip took place subsequent to the formation of the dyke. In working towards the dyke, when within 50 yards of it, the coal begins to change: it first loses the calcareous spar, which occurs in the joints and faces, and begins to look dull, grows tender and short, and also loses its quality for burning. As it comes nearer, it assumes the appearance of a half-burnt cinder; and on approaching still nearer the volcanic mass, it grows less and less in thickness, becoming a pretty hard cinder, and only 2 feet 6 inches thick. Eight yards further it is converted into real cinder, and more immediately in contact with the basalt it becomes by degrees a black substance, called by the miners dant or swad, resembling soot caked together, the seam of coal being reduced to 9 inches in height. There is a large portion of pyrites lodged in the roof of that part of the seam which has been reduced to cinder. On each side of the dyke, between it and the regular strata, there is a thin gut or core of clay, about 6 inches thick, which turns the rain water on the rise side, and forces it to the surface, forming numerous springs as it traverses the country. The coal spoiled by the action of this basaltic dyke is as follows :—25 yards of bad short coal, half reduced to cinder; 16 yards of cinder, and 10 yards of the sooty substance before described; making, together, 50 yards. Should a similar effect have taken place on the rise side, it will make upwards of 100 yards, to which must be added the thickness of the dyke itself (22 yards); or, altogether, more than 120 yards in breadth of coal, which the effect produced by this dyke has rendered either barren, or quite unfit for ordinary colliery purposes.

On Cockfield Fell, the dyke is an upcast to the south of 3 fathoms. It runs nearly in a direct line south-east to Maybecks, in Yorkshire. In several parts of its course the dyke protrudes to a considerable height above the surface, as at the ridge called Parker's Howe in Glazedale, at a place in Lownsdale, and especially at Cliff Rigg and Langbargh in Cleveland, where it forms a very prominent ridge.

At Preston and Langbargh the width of the dyke is 70 feet.—(Plate 23, figures 2, 3, and 4.

The whole of the above are examples of vertical whin dykes intersecting the strata; but, as another description, viz., the horizontal whin dyke, or tongue of basalt, is sometimes found more destructive in its results than the vertical dyke, we must not omit to mention it in this place.

The whin sill of the mountain limestone district in Cumberland, Yorkshire, &c., and the toadstone of Derbyshire have already been described, and that they ought to be referred to volcanic origin, there can at this day be no manner of doubt. In these cases the thickness of the basalt is tolerably uniform, but there are others in which we find the mass to lie in a less stratiform manner, crossing the other strata obliquely and with variable thickness.

An example of this description of dyke is found in Ayrshire, where, in the neighbourhood of Bartonholme, near the river Garnock, the basalt is found in Stephenson's colliery to be of the thickness of 8 feet; about 300 yards further to the east, the thickness is 15 feet, and further in the same direction, the basaltic stratum is found to thicken, cutting off the seams of coal both above and beneath in its progress.—(Plate 24).

The Steinsburg, near Suhl in Germany, is a mountain formed of nearly horizontal beds of variegated sandstone. A basaltic ridge appears on the summit about 66 feet thick. This ridge appears on the surface for a length of 393 feet in a direction from south-west to north-east. On the slope of the hill is a quarry in the sandstone. A society of geological amateurs united in order to have a gallery pierced from the quarry to the basaltic mass at about 66 feet from the surface, and at about 26 feet in vertical depth the basalt was met with still cutting and traversing all the sandstone beds as it descends. The basalt is separated from the sandstone by a species of vertical crust of sandstone, nearly one inch thick, afterwards by a bed of soft clay of a blackish colour, a little more than one inch thick, in which are fragments of sandstone, and which also contain tables of basalt. The basalt is afterwards found in tables, disposed parallel to the side of the mass, and, lastly, the basaltic mass full of irregularly disseminated clefts. This basalt contains much olivine, hornblende, and feldspar: it also contains fragments of sandstones, but neither variolites nor lavas have been discovered in it.—(Annales des Mines, 1817.)

This dyke is evidently similar to those of Cockfield, Hitchcroft, &c., before described.

A very interesting and detailed account of the trap dykes of Anglesea, by Mr. Henslow, occurs in the first volume of the Cambridge Philosophical Transactions, page 401, &c.; and those of the Hebrides, &c., will be found ably discussed by Dr. McCulloch, in his account of the Western Islands; and in the Geological Transactions, which also contain many other descriptions of similar facts.—(De la Beche, Translations of Geological Memoirs.)

It is very probable that dykes and slips are in some degree connected with each other, both owing their origin to subterranean convulsion. In what manner faults or slips result is not very easy to determine; but it is most likely all of these phenomena are the consequence of the *depression* of the strata now situated on the dip side of the fault, and not of the upheaval of those on its rise side. I must be understood to refer to *leading faults;* for it is impossible to conceive that great convulsions, such as will be hereafter described, could occur without causing subordinate breaks in the strata, by some of which they might be locally thrust up or down, or forced into almost any fantastic shape. The probability is, that slips have either been formed by the settling down of the surface into hollows formed subterraneously by the discharge of volcanic matter, or that the discharge of volcanic matter, instead of being the cause of the slip, is merely its consequence.

The following are a few of the principal slips which have been met with in the exploration of the coal measures of the North of England:—

The Great Tynedale Fault—also called the 90-Fathom dyke, the Main dyke, and Stublick dyke—is a slip of great magnitude, which traverses the coal measures from west to east, on the north side of which the strata are depressed to the north from 90 to 180 fathoms.

It passes along the south side of the Midgeholme, Hartley Burn, and Stublick coal-fields; and to its influence not only these, but probably a large portion of the coal measures of the Newcastle coal-field, owe their existence.

At Stublick several slips have been proved: the map (plate 25) shews their position. By the slip at this point, the coal measures on the north, and the mountain limestone on the south, are placed in juxtaposition. On the north side of the fault the coal strata rise to the north at the rate of 1 in 4, though nearer to it the inclination is much greater; consequently, they soon crop out.

This fault passes through the Grand Lease colliery about 300 yards south of the Stargate pit, crosses the Tyne above Scotswood Bridge, and then passes through Montague Main colliery about 200 yards north of the Benwell colliery boundary: its course here is east, and its downthrow is probably 100 fathoms.

From this point it stretches across the north part of Newcastle town-moor, passing a short distance north of Gosforth pit, and through Killingworth royalty, about three-quarters of a mile south of the working pit. Here its depression is greatest, being probably not less than 200 fathoms.

It passes through Backworth royalty, about 1,600 yards south of the "B" pit. In the vicinity of the fault, near to which the workings have been prosecuted, the strata rise towards the north nearly 1 in 2; but they gradually become flatter, so that at the distance of a mile from the slip their position is nearly horizontal. Such is the declivity of the strata occasioned by this great dislocation, that from the Backworth "B" pit to the face of the south workings there is a depression of 80 fathoms. At this place the extent of throw is supposed to be about 160 fathoms. The direction of the slip which has so far been nearly east is now changed to the south-east, and continued until, after passing through Earsdon, Murton, and Whitley collieries, it is traced into the sea, a little to the south of Cullercoats, being seen in the cliff at the north end of the Long Sands.

By the section (plate 26), the strata are here apparently dislocated to the extent of from 80 to 90 fathoms.

The coal measures on the north side of the slip, and immediately adjoining to it, are here covered by the lower new red sandstone and the magnesian limestone. Near Killingworth, at Closing Hill quarry, the lower new red sandstone is found on the dip side of the fault, overlying the coal measures.

The date of this slip, geologically speaking, is therefore posterior to that of both the coal measures, lower new red sandstone, and magnesian limestone.

A branch of the 90-fathom dyke passes from a point north-west of Long Benton through Willington, Percy Main, and Collingwood Main collieries, through North Shields and the Black Middens, into the sea below Tynemouth barracks. It is ascertained to be an upcast of 40 fathoms to the north in Collingwood Main, but it diminishes in size as it passes through Percy Main and Willington collieries. By this slip the High Main is thrown completely out, and is wanting to the north of the Chirton pit for about 150 yards, when it is brought in again by a downcast slip of 11 fathoms.—(Buddle's Synopsis of the Newcastle Coalfield.)

The Brierdean Burn Dyke runs in an easterly direction from its commencement in Holywell colliery, and through the south part of Hartley royalty. It increases to the east, and where it passes through East Holywell colliery, its throw is probably from 25 to 30 fathoms down to the north. By this slip the High Main seam, after rising to the surface a little north of Earsdon, is again brought in, and is found throughout a large tract of country. About this line the quality of the High Main changes from a rich house coal, as at Earsdon, to an excellent steam coal, as at East Holywell.

A downcast slip to the north of 35 fathoms passes a short distance from Burradon pit: towards the east it divides and joins the 90-fathom dyke in Killingworth.

A downcast to the north-west of from 7 to 8 fathoms passes through Seaton Burn colliery, about 600 yards north from the shaft. This slip passes in the direction of Arcot, and thence through West Cramlington colliery, a short distance west of the pit, where it is a downcast north-west of 11 fathoms.

At a short distance further west is another slip running nearly in the same direction, which is an upcast north-west of 15 fathoms. A downcast north-west of 40 fathoms passes through Callerton and Throckley collieries, crossing the Tyne midway between Crawcrook and Wylam collieries, bringing down into the latter the seams wanting on its south-east side: it passes a little to the west of Bradley Hall, and joins the 90-fathom dyke at or near the village of Hedley.

A branch of this slip passes also through Throckley towards Walbottle colliery, a downcast north of 13 fathoms.

An upcast north of 7 fathoms passes beneath the Ouseburn, near the viaduct; thence through Heaton and Long Benton royalties, at which latter place it is divided into two slips, the southern branch being a downcast north of 9½ fathoms, and the northern branch an upcast north of 8 fathoms. Near to the Craster pit they reunite, and pass on to Shire Moor, where they form an upcast north of 14 fathoms.

A slip called the Delight Pit Dyke, so named from its having been discovered in the Delight pit, Walker colliery, runs through Wallsend colliery from east to west, passing at 150 yards south of the "A" pit, where it is a downcast to the south of 5½ fathoms, and at 88 yards south of the "G" pit, where it is a downcast of 8½ fathoms.—(Buddle on Mining Records.)

A downcast north-west of 15 fathoms passes through Jarrow colliery at 150 yards south of the shaft. This slip diminishes to the east, passing under the river through the south part of Percy Main royalty, and again crossing the river under South Shields, where it is a downcast north of 6 feet. To the west it passes through Hebburn, where it is divided—one branch being an upcast north of 13½ fathoms, and the other about a quarter of a mile further south, a downcast north of 14 fathoms. It passes under the river into Walker colliery.

At 120 yards south of the Hilda pit, South Shields, is a downcast slip to the south of 58 fathoms. The course of this slip is south 87½° west. It passes through Jarrow colliery, where it is divided, its principal branch being a downcast south of 6 fathoms.

The Heworth Dyke is an upcast to the south of 25 fathoms. This is a well-known slip, having been proved in Farnacres colliery, and in Dunston haughs, by the skirt of Whickham banks, and in Blaydon Main colliery, near to Axwell Park. It is here called the Shibdon dyke. It then runs in a north-western direction, and crosses the 90-fathom dyke at Stephen's Hall, in Towneley Main colliery, but in crossing it is changed into a downcast south of 4 fathoms. It then continues its line of direction past the new pit, in Crawcrook colliery, and across the Tyne between Close House and Wylam colliery.—(Buddle's Synopsis.)

An upcast north of 13 fathoms passes through Felling colliery. This is probably a branch of the Heworth dyke.

An upcast of 9 fathoms to the north passes through the north part of Ravensworth colliery and through Gateshead Fell: its direction is about north 86° east.—(Bailey's Survey of Durham.)

An upcast west of 12 fathoms passes about one-third of a mile west of Kibblesworth colliery: its direction is by the west part of Ravensworth towards Whickham.

The TANFIELD or TANTOBY DYKE is a downcast slip south of 40 fathoms upon Tanfield Moor, but grows less as it advances east and west. It crosses Derwent a little below Derwent Cote forge, and thence runs in an easterly direction, through Hamsterley, over Tanfield Moor; from thence by Beamish hall, and through the south part of Blackburn Fell; from thence, near Urpeth colliery engine, and through the collieries of Birtley Fell, Ouston, Leefield, and Fatfield. It is here a downcast of about 30 fathoms, and known by the name of the Birtley dyke. In Leefield colliery, near the village of Birtley, a spring of salt water issues from the fissures of the slip.—(Bailey's Survey of Durham.) This slip also passes through Washington colliery, where it is a downcast south of 20 fathoms.

A downcast to the south of 12 fathoms passes about 50 yards south of Andrews' House pit and along the valley, dividing the Marley Hill and Crookbank, &c., royalties. The direction of this slip is about north 70° west.

An upcast south-west of 4½ fathoms passes through Beamish colliery, and thence, after increasing to 12 fathoms, it passes through Waldridge colliery.

An upcast to the north of 9 fathoms runs in a south-easterly direction through the north part of Fatfield, Oxclose, and the south part of Washington.—(Bailey's Survey of Durham.)

A dyke, which is supposed to make the coal tender and bad, runs in a north-easterly direction through North Biddick colliery: it passes beneath the Washington station on the York and Newcastle railway. As the coal is here converted partly into a cinder, there is probably a whin dyke which has not risen up into the seam.

Between this dyke and the river Wear, and running in the same direction, is an upcast to the north varying from 5½ to 14 fathoms.

A downcast of 12 fathoms to the south runs in an east and west direction through the collieries of Lambton, Bourn Moor, and Newbottle. In the last, about 200 yards further south, is another slip bearing north-east, which casts the strata 25 fathoms down to the south.

WOODSTONE HOUSE DYKE is an upcast slip to the south of 25 fathoms, and runs in an east and west direction through the collieries of Lumley and Murton. It passes a little to the north of Houghton and Seaton collieries, at which latter place it is probably diverted into a succession of slips, amounting to a downcast of 25 or 30 fathoms to the north.

A downcast north of 20 fathoms passes through the south part of Lumley colliery. At Rainton it is a downcast north of 6 fathoms: it is here joined by a downcast south of 15 fathoms. This fault then passes a little to the south of Eppleton colliery, where it is a downcast south of 8 fathoms.

A downcast north-east of 15 fathoms passes a short distance south of Murton colliery.

About a quarter of a mile south of Burnhope colliery is an upcast north of 8 fathoms, and a short distance further south is another slip, which throws the strata up to the south upwards of 20 fathoms. The direction of these slips, which are accompanied by some others of less importance, is towards Lanchester.

An upcast to the north of 16 fathoms passes through Waldridge colliery.

An upcast to the east of 18 fathoms passes through Haswell colliery 1,600 yards east of the shafts—its direction is a little to the east of south; and after passing through the Tudhoe or Hett whinstone dyke, it is found 120 yards west of the Shotton pits, where it is an upcast to the east of 9½ fathoms.

At 200 yards west of the Shotton pits is another slip, a downcast to the east of 7½ fathoms. Near these slips the inclination of the strata is rather rapid, being about 1 in 9, rising towards the west.

An upcast north of 10 fathoms passes north, and a downcast north of 10 fathoms passes south, of the pit at Ludworth.

Plate 27 is an illustration of a singular system of faults occurring in the Greenfield colliery, near West Auckland. The whole of this group of faults passes under the name of the AUCKLAND or BUTTERKNOWLE DYKE: it passes through Woodhouse Close colliery, near to Etherley Grange farm-house. An attempt was made to approach it at this colliery, but owing to the rapid dip of the strata (1 in 3) down to the slip, the drifts were stopped. It traverses Auckland park, and passes through Westerton colliery, and about 300 yards north of the Old Cornforth pit.

At Cornforth, the displacement of the strata cannot be under 80 or 90 fathoms. Further to the east its position has not been correctly ascertained.

The same effects that on the Tyne are produced by the 90-fathom dyke are produced in Durham by this fault. The dip of the strata to the slip is similarly rapid; for where the north drifts at Cornforth colliery were discontinued, their declination was at the angle of 23°.

The lower new red sandstone and magnesian limestone are also thrown in on the dip side of the slip. The lower new red sandstone is seen in the Westerton old quarry, near the Auckland park gates, and the magnesian limestone about half a mile further to the east. A downcast east of 7 fathoms passes about 70 yards east of the Coundon east pit.—(Plate 28.)

An upcast to the north-east of 20 fathoms passes a little to the south of the Westerton pits, and through the south-western portion of the Leasingthorn royalty. It is a branch of the Auckland or Butterknowle dyke.

From the above it appears, that whatever uniformity of direction may be possessed by whin dykes, but little attaches to slips or faults.

When faults traverse the lower formations, and especially the limestone beds of the mountain limestone series, they become metalliferous, and are then commonly called veins. Slips have generally between the cheeks of the strata a space occupied by the debris of the adjoining rocks; and when they are metalliferous, it is in this debris that the metallic ore is found. In the coal measures we often find in such situations iron pyrites, and not unfrequently galena and blende; rarely, copper pyrites; carbonate of lime is in many instances most abundant. In an economical point of view, however, the quantity of the ores is too limited, and the uncertainty of any being found at all too great, to make the mineral veins of the coal measures of any practical value.

In the lead measures, the most common and the most promising of the mineral stones as concomitants of ore, are the spars and veinstones of different species constituting the debris before alluded to. There is a compound stony concretion, found in many veins, called by the miners a rider, which is hard and heavy, sometimes compact and solid, but frequently cracked and cavernous, rising in irregular and misshapen masses: it is generally of a brown colour, and is now found to be an ore of iron containing a large proportion of metal. Strong wide veins often contain a large rib of this veinstone between the sides, several feet thick. Some veins shew this rib as a ridge above the surface of the ground, as the great vein called the backbone in Aldstone Moor, Cumberland.

The next most common stone found in mineral veins is spar, of which there are several kinds. The most common are calcareous spar, or crystallized carbonate of lime; fluor spar, or Derbyshire spar; quartz; sulphate of barytes, or heavy spar; and carbonate of barytes, or witherite.

1. Calcareous spar. Constituent parts—lime, 56·15; carbonic acid, 43·70. Specific gravity, from 2·5 to 2·8. Rhombohedral; generally brittle; not very hard. Colour, most frequently white and grey, but found also red, blue, green, yellow, brown, and rarely black.

2. Fluor spar, or pure fluate of lime. Constituent parts—lime, 67·75; fluoric acid, 32·25. Specific gravity, 3·0 to 3·3. Octahedral; brittle; rather harder than calcareous spar or heavy spar, but not nearly so hard as quartz. Colours, white, blue, red, green, grey, and purple. When found compact, it is called by the Derbyshire miners Blue John, and is made into vases and other ornaments, receiving a fine polish.

3. Quartz, or nearly pure flint. Constituent parts—silica, 97·75; alumina, 0·50; water, 1·00. Specific gravity, 2·5 to 2·7. Rhombohedral; brittle; hard; will scratch glass. Colour, most frequently white, but grey, less frequently black, blue, green, yellow, red, and brown.

4. Sulphate of barytes. Constituent parts—barytes, 66·00; sulphuric acid, 34·00. Specific gravity, 4·1 to 4·7. Prismatic; brittle; not very hard. Colour, white, grey, black, blue, green, yellow, red, and brown.

5. Carbonate of barytes. Constituent parts—barytes, 79·66; carbonic acid, 20·00; water, 0·33. Specific gravity, 4·2 to 4·5. Prismatic; brittle; not very hard. Colours—white, grey, and yellow, or greenish yellow.

The ore is sometimes found in ribs or strings between ribs of rider, or between rider and vein cheek, or in masses disseminated through the vein. In Allendale and Aldstone Moor, veins have been found from 6 to 12 feet wide of solid lead ore. About the year 1815, a very rich mining field was opened in Aldstone Moor, by John Wilson, Esq., & Co., known by the name of Hudgill Burn. The mine consisted of two principal veins, denominated the sun vein and north vein, with other collateral strings or veins between them. The north vein in the year 1821 had its east forehead or face 3 feet wide of pure galena in the tuft or water sill (a bed of post 9 feet thick, and situated 75 fathoms above the whin sill, and immediately beneath the great limestone). This vein at Hudgill Burn was also 17 feet wide in the great limestone, consisting of four ribs of galena from 2 to 4 feet each. The sun vein at the time was also about 12 feet wide, blended with galena. Including altogether, the mine has produced upwards of 9,000 bings of ore in one year. This was one of the richest mines ever discovered, and during its most profitable period the number of miners did not exceed 80.

Veins, however, rarely present this form, but are more usually composed of thin strings of galena disseminated through the vein: even these are by no means regularly met with, and sometimes little ore is found, though many yards of ground may be passed over, at much expense of time and money. Much the same remarks which have been made concerning lead veins apply to those of tin and copper, inasmuch as the depositories of these metals are in, probably, the same veins, only at a lower level.

It is generally found that as we approach a slip which throws the strata down, the strata rise towards it, and the contrary, although this is by no means always the case. We also, in almost all instances, find that when the slip we are approaching makes an acute angle with the floor of the stratum in which we are exploring, it throws the strata down, and that if it makes an obtuse angle with it, the strata are, on the other side, cast up. In approaching slips in fiery seams of coal, it is necessary to use great caution, as in the soft coal usually adjoining them much fire-damp is frequently confined, which often escapes with a violence almost explosive. Many serious accidents may be traced to this cause.

Whilst upon the subject of dykes and slips, we must not neglect to notice some other phenomena closely allied to slips, which cause much inconvenience, and often considerable expense: I allude to balks and nips.

Balks are sudden depressions of the roof into the coal, which usually occur when the roof is of sandstone or post. They are of various size: when small, say under two feet in breadth, and descending not more than a foot or eighteen inches, they are frequently called horse-backs, and are, in all likelihood, the trunks of trees lying upon the coal. In the roof of the Bustybank seam at Burnupfield colliery, where they abound, the branches are present, and in tolerably perfect condition. Sometimes, however, the balks descend so far as completely to extinguish the coal, and continue for a considerable distance. When this is the case, they become nips. Several of these occur: one, in the Pontop district, may be named, where, for at least 200 yards, there is a continual succession of balks forming an extensive nip.

Plate 29 is an example of a balk which occurs in the Bustybank seam at Burnupfield colliery.

We have now examined the strata in their usual or regular form, and also viewed both them and their dislocations as far as the lowest explored depths. How far such researches could possibly be prosecuted is, perhaps, now a fit subject for enquiry.

If the earth has a proper temperature due to itself, at the same time taking into consideration the feeble conducting power of the substances near the earth's surface, we cannot avoid the conclusion that it will be impossible, by the method hitherto pursued to fix with any certainty upon the mean rate of increase of temperature as we descend; (the usual manner of conducting such experiments being to divide the depth in feet by the difference in temperature between the point of observation underground and the mean temperature of the surface, sometimes deducting from the depth the supposed depth of surface mean temperature, say 50 feet,) because, if we take a line of equal distance from the centre of the earth, sufficiently distant from the surface to be quite unaffected by solar radiation, we must at this point have the temperatures isothermal: and since in different latitudes, if we were to select points a few feet below the surface we would find the mean temperature lower in cold than in warm latitudes, we must, of course, find that in cold latitudes we will have the rise in temperature as we descend, much more rapid than in warm ones.

The following is the result of an experiment, by Professor Phillips, at Monkwearmouth colliery, soon after sinking the shaft.

The depth of the pit to the place of observation was 264 fathoms. The depth below the level of the sea, 250 fathoms. The mean annual temperature, 47·6°. The observed temperature of the air at the surface on the day of experiment (15th Nov. 1834), 49°. Of air at the bottom of the pit, 62°. Near the end of the drift, 64°. Close to the coal, 68°. Temperature of water collected in the pit bottom, 67°. Of salt water issuing from a borehole made on the same morning, 70·1°. Of similar water as it first gushed out, 71·4°. Of gas bubbles issuing through the water, 72·6°. Temperature of the front of the coal, 68°; of the interior, 71¼°. A thermometer left in a borehole for a week indicated 71·2°. If invariable temperature be supposed to commence at 100 feet, and the mean annual temperature of the place be taken at 47·6° then 72·6° — 47·6° = 25° in 1,484 feet, or 1° Fahrenheit in 60 feet nearly. The pit has since been sunk deeper, and the temperature found to rise still higher.—(Phillips' Geology.)

According to the experiments of M. Arago upon Artesian Wells, the mean results were as follows:—

NO. OF OBSERVATIONS.	DEPTH.		INCREASE.		DEPTH FOR ONE DEG. FAHRENHEIT IN ENGLISH FEET.
	Metres.	English Feet.	Deg. Centig.	Deg. Fahr.	
1...............	66·	216·48	2·3	4·14	52·3
2...............	56·	183·68	2·2	3·96	46·4
3...............	63·	206·64	3·0	5·40	38·2
4...............	100·	328·00	3·7	6·66	49·2
5...............	110·	360·80	5·0	9·00	40·1
6...............	140·	459·20	6·0	10·80	42·5

The results from Artesian Wells, the water being pure, are probably as much to be depended upon as those from mines.

The following are the results of a few observations which I have made upon this subject: they do not differ very widely from those last quoted: they are founded upon the temperatures of small issues of water flowing from the roofs of the various seams of coal.

PLACES OF OBSERVATION.	DEPTH BELOW SURFACE, AND DISTANCE BETWEEN POINTS OF OBSERVATION.		EXCESS ABOVE MEAN TEMPERATURE OF FORTY-SEVEN DEGS., AND INCREASE OF TEMPERATURE BETWEEN POINTS OF OBSERVATION		DEPTH FOR ONE DEGREE FAHR. IN ENGLISH FT.
	Depth.	Distance.	Excess.	Increase.	
	FEET.	FEET.	DEGREES.	DEGREES.	
Marley Hill colliery—Bustybank seam...	432	...	10·5	...	41·1
Norwood colliery—Brockwell seam	468	...	12·5	...	37·4
Ditto —Beaumont seam......	252	...	7·0	...	36·0
Ditto —Between seams	...	216	...	5·5	39·3
Pontop colliery—Bustybank seam	642	...	17	...	37·7
Ditto —Main coal	382	...	10	...	38·2
Ditto —Between seams	...	265	...	7	37·8
Burnupfield colliery—Bustybank seam...	540	...	15	...	36
Ditto —Main coal seam...	288	...	8	...	36
Ditto —Between seams ...	...	252	...	7	36
Killingworth colliery—High Main seam	1200	...	23	...	52·1

It is to be regretted that in making experiments similar to the above there is not a fixed standard of comparison: some experimentalists merely taking the difference between the mean annual temperature of the surface, and the temperature underground, and dividing the depth in feet by this difference: whereas others assume that at a certain depth beneath the surface the temperature will be uniformly correspondent to the mean temperature of the surface, and divide the difference between this assumed depth and the depth where the temperature is taken, by the differences of temperature as above.

The latter method seems, in principle, the more correct of the two, although it is probable that at a point much nearer the surface than 50 feet we shall find the line of mean temperature.

The most correct method, however, must unquestionably be to base our calculations upon double observations taken at different depths in the same locality.

From the above observations it appears that although we have an increase of temperature as we descend, it is not by any means at an uniform rate; and although we have not sufficient information upon the subject to enable us to arrive at any accurate conclusions, it appears highly probable that as we descend to still greater depths than any of those above enumerated, although we may find the temperature still to increase, such increase will be at a comparatively much slower rate than we might calculate from observations made hitherto.

It would be very easy to find by experiment in each locality where pits are sunk, a certain point below the surface where the temperature is uniformly, say 50°, and if our experiments were so classified as to be given in the following shape, a great step would be made towards establishing as fact what is at present only an approximation thereto.

LOCALITY.	Depth of Temperature of 50 deg.	Depth of Temperature of 70 deg.	1,100 feet of increased depth for 20 degrees of increased Temperature = 1 deg. to
A.	Say 100 feet.	Say 1,200 feet.	55 feet.

The practical value of the above experiments will appear as the upper deposits of coal, metallic ores, &c., become exhausted, and when we shall find it necessary to prosecute our labours further down into the interior of the earth.

The probable temperature of the lower beds of coal in the lower Rhine, is estimated by Baron Humboldt to be 435° Fahrenheit, the depth being upwards of 20,000 feet, or 3442 fathoms; and such a temperature would of course secure this deposit from the reach of man. At what depth the temperature will have risen so high as to render mining no further practicable, is, as yet, difficult to say; because, in the first instance, we do not exactly know the rate of increase of the temperature, and in the next, we cannot say what temperature will stay our further progress, because, although it is perfectly clear that the same amount of labour cannot be performed in an elevated as in a moderate temperature, yet we may call machinery to our aid, and work economically long after the energy of the human frame must have become exhausted by heat, as the mere directing of a machine may be undertaken when a very slight degree of bodily exertion would be totally impossible. In the deep mine of Monkwearmouth, the temperature in some of the working places is as high as 86°.

CHAPTER III.

Iron Ores: Manufacture of Iron.—Lead Ores: Manufacture of Lead.—Copper Ores: Manufacture of Copper.—Tin Ores: Manufacture of Tin.

IRON ORES, AND MANUFACTURE OF IRON.

1. Native Iron. This description of iron ore is extremely rare: it has been found at Kamsdorf, in Saxony, disseminated through a mass of brown oxide of iron: also in a ravine formed by torrents across the lava and scoriæ of the mountain of Graveneire in Auvergne: and has also been found entering into the composition of aërolites, or meteoric stones.

The composition of native iron is about 96 or 97 per cent. of iron, with 3 or 4 per cent. of nickel.

This description of ore cannot, however, in a mining point of view, be considered as possessing any interest.

2. Iron Pyrites is a combination of iron and sulphur, in the following proportions:—

	HATCHETT.	BERZELIUS.
Iron	47·85	45·74
Sulphur	52·15	54·26

Specific gravity, 4·75 to 5·0. Colour, brass yellow, sometimes approaching to bronze yellow, and occasionally to steel grey: lustre metallic: it is brittle, but does not yield to the knife point. Iron pyrites is abundant in coal, forming what are commonly known as brasses: it occurs compact and crystallized in the cube and octahedron, and in forms common to them both as primary crystals. It is not used as an ore of iron, but is becoming much in demand for the manufacture of sulphuric acid, sulphate of iron, &c. When exposed to heat it decrepitates violently, and causes sparks to fly out of the fire when it is contained in the coal.

3. Specular Iron is the pure peroxide of iron, in the proportion, according to Beudant, of iron 69·34, oxygen 30·66. Specific gravity, 5·0 to 5·3. Form, Rhombohedral. Colour, deep steel grey, with a brilliant and often iridescent tarnish externally: internally it possesses a shining lustre. It occurs in transition and primitive rocks, both in beds and veins. The mines of this substance, in the isle of Elba, are of great extent, and are said to have been worked upwards of 3,000 years.

4. Red Hæmatite contains—peroxide of iron, 94·00; silica, 2·00; lime, 1·00; water, 3·00 (d'Aubuisson). Specific gravity, 4·8 to 5·3. The fibrous variety has externally a bluish

or iron grey colour, or presents either a metallic lustre, or is red and without lustre: internally it is red, or brownish red. It occurs in botryoidal masses, or in stalactites formed of concentric coats, and having a radiated structure. The fact is becoming daily more universally understood, that the use of the hæmatite ores imparts greater strength, greater power of resistance to sudden shocks or strains, and will produce more dense, solid, and sound metal than any other ore of iron: their purity and easy fusibility render the use of them very desirable, especially in furnaces, where more refractory and less pure mineral is used, as the rich ores assist to fuse, smelt, and separate more perfectly the iron from the poorer ores.—(B. Poole's Statistics of Iron Ore.)

Taking a retrospective view of the hæmatitic iron ore trade in Furness, it appears that half a century ago the total quantity of ore sent from Barrow, say in the year 1800, was 1,200 tons, and in 1849 it amounted to 146,000 tons, as shewn by the books of the harbour trustees.

The following is a careful analysis of the Furness ore:—Iron, 64·40; oxygen, 30·60; silica, 2·00; lime, 1·00; water, 2·00; which corresponds closely with that of d'Aubuisson, given above.

5. Brown Hæmatite is of a clove or blackish brown colour: externally it is often steel grey, and resplendent. In Scotland, it forms veins in sandstone at Cumberhead in Lanarkshire, at Sandloge in the Shetland Isles, and in Hoy, one of the Orkneys. In Cornwall, it occurs at Botallack near the Land's End, and in Tincroft mine near Redruth, and in Aldstone Moor and Weardale. It affords a very malleable and much harder iron than the red hæmatite, and excellent steel.

6. Carbonate of Iron—Clay Ironstone—Blackband, &c. The following are analyses of several descriptions of this, hitherto the most important, ore of iron found in the Clydesdale district:—

CONSTITUENT PARTS.	*a.*	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*
Water	0·00	0·99	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Carbonic acid	32·53	33·63	31·86	30·76	26·35	33·10	32·24	35·17	34·27
Protoxide of iron	35·22	45·84	42·15	38·80	36·47	47·33	43·73	53·03	42·35
Protoxide of manganese	0·00	0·20	0·00	0·07	0·17	0·13	0·00	0·00	0·00
Lime	8·62	1·90	4·93	5·30	1·97	2·00	2·10	3·33	3·78
Magnesia	5·19	5·90	4·80	6·70	2·70	2·20	2·77	1·77	4·95
Silica	9·56	7·83	9·73	10·87	19·90	6·63	9·70	1·40	12·70
Alumina	5·34	2·53	3·77	6·20	8·03	4·30	5·13	0·63	
Peroxide of iron	1·16	0·00	0·80	0·33	0·40	0·33	0·67	0·23	
Calcareous or bituminous matter	2·13	1·86	2·33	1·87	2·10	1·70	1·50	3·03	
Sulphur	0·62	0·00	0·00	0·16	0·00	0·22	0·02	0·00	
Moisture and loss	0·00	0·00	0·00	0·00	1·91	2·26	2·34	1·41	1·95
Total	100·37	100·68	100·37	101·06	100·00	100·00	100·00	100·00	100·00

a. From Crossbasket, about 7 miles south-east from Glasgow. Specific gravity, 3·1993. This is the highest and least valuable of the Crossbasket strata of ironstone used in the blast furnace. Thickness, from 3 to 3½ inches.

b. From Crossbasket. Specific gravity, 3·3801. Found 4 feet beneath the preceding one. Thickness, 9 inches. The purest of the Crossbasket ores.

c. From Crossbasket. Specific gravity, 3·2699 ; thickness, 6 to 8 inches.

d. From Crossbasket. Specific gravity, 3 1175 ; is from 10 to 14 inches in thickness ; of good average quality.

e. From the neighbourhood of the Clyde iron-works about 4 miles south-east of Glasgow. Specific gravity, 3·1482 ; thickness, about 2½ inches ; of inferior quality, and seldom smelted.

f. An ore lying under the last-named, and immediately in contact with it. Specific gravity, 3·2109 ; thickness, 1½ to 2 inches. This stratum is situated 4 inches above the splint coal, and both coal and ironstone are worked together to great advantage. This bed of ironstone is the most valuable ore in all the fields around Glasgow, with the exception of the black band, which is smelted at the Clyde iron-works.

g. This specimen was procured from Easterhouse, near the line of the Monkland canal, and about 6 miles east from Glasgow. Specific gravity, 3·3109. As this stratum exists in precisely the same relative situation with regard to all the other accompanying minerals as the two last described, it is considered to have been produced by the coalescence of these two strata. Its average thickness is from 2½ to 3 inches. It is used pretty extensively in the blast furnace, and is esteemed of good average quality.

h. From the neighbourhood of Airdrie, about 10 miles east of Glasgow. Colour, clove brown, the intensity of the shade varying considerably in streaks, which are parallel to the direction of the stratum ; when reduced to powder, the colour is brown. Fracture, fine-grained, earthy, rather uneven; tough, and with difficulty pounded, communicating a feeling of elasticity under the pestle ; rather hard ; scratched by the knife ; adheres to the tongue, a property which does not appear to be possessed in a sensible degree by any of the ores already described. Specific gravity, 3·0053.

Numerous bivalve shells, of a pale wood brown colour, occur scattered through the mass of this ore, and form a strong contrast with its darker shade.

This is one of the most valuable iron ores of Scotland, where it is familiarly known under the name of black ironstone, or Mushet's blackband. The latter appellation has been given from its having been first smelted by Mr. Mushet. It lies about 14 fathoms below the fifth Glasgow coal-bed or splint coal, and constitutes a layer about 14 inches in thickness. It is remarkable that it has been found nowhere hitherto except in the neighbourhood of Airdrie, although several attempts have been made to reach it in other localities by boring. At the Clyde iron-works, it is justly regarded as the richest and most valuable ore which they possess.

As has been before mentioned, the blackband ironstone resembles most strongly many of the beds of blackstone or shale in which the Newcastle coal-field abounds.

i. From a stratum situated in the vicinity of Crossbasket.

The following is an analysis by Messrs. Richardson and Browell, of Newcastle-upon-Tyne, of an ore of iron found in the Pontop district of the Newcastle coal-field :—Protoxide of iron, 47·99 ; bisulphuret of iron, 1·32 ; lime, trace ; clay, 16·55 ; loss by heat, principally carbonic acid, 31·95. When pure, carbonate of iron is composed of—protoxide of iron, 61·37 ; carbonic acid, 38·63.

An ore of iron, which may also be termed a clay ironstone, has been recently discovered to exist in enormous quantities in the lias formation. Where it is worked near to and at its outcrop on the declivity of the range of hills south of Middlesbrough, its thickness is from 12 to 14 feet : it dips to the south, and will no doubt be found over a large tract of country.

Its contents are as follows:—Silica, 12½ per cent.; alumina. 7½; carbonate of lime, 3½; carbonate of iron, 44; peroxide of iron, 30; carbonate of magnesia, a trace; moisture and loss, 2½. It contains about 41 per cent. of metallic iron. Its colour is greenish, and there is little in its external appearance to indicate its value. The great advantage which it possesses consists in the cheapness, as compared with other ores, with which it can be worked. It has been discovered in Northamptonshire, and will no doubt be found wherever the lias is the prevailing formation. The discovery of this stone has given a powerful impetus to the iron manufacture of the county of Durham, and great exertions are in consequence being made by several powerful companies to extend their works.

The smelting of iron in this country to the prodigious extent to which it is now carried is comparatively recent, and can scarcely be dated further back than 70 years. The quantity now annually smelted exceeds 2½ millions of tons. The two great foci of the iron manufacture in Great Britain are the neighbourhood of Swansea and the country between Wolverhampton and Dudley. A good deal, however, is made in Shropshire, Yorkshire, Derbyshire, Durham, and Northumberland, and also in Scotland.

The following is a short sketch of the method of smelting iron ore practised in this country.

1st Process—Roasting. The ore broken into small pieces is mixed with small coal, and laid to a height of 6 or 7 feet on large pieces of coal, forming a heap which is narrow, but as long as the ground will permit. The combustion is begun at one end, and allowed to proceed until it reaches the farthest extremity. The quantity of coal used in this process varies in different places according to the goodness of the coal, and also according to the nature of the ore itself—some being so bituminous as to require little coal, the most being 1 ton of coal to 5 tons of ore. By this process the carbonic acid of the ore is driven off. The loss of weight varies from one-fourth to one-third, according to the goodness of the ore: in general, 3½ tons of the ore are reduced to 2½ tons; from this quantity of ore about 1 ton of cast-iron is obtained.

The following is from the analysis of M. Berthier:—

	RICH WELCH ORE.	POOR WELCH ORE.	RICH ORE OF DUDLEY.
Loss by ignition or wasting	30·00	27·00	31·00
Insoluble residuum	8·40	22·03	7·66
Lime...	0·00	6·00	2·66
Peroxide of iron	60·00	42·66	58·33
The peroxide is equal to carbonate of iron ...	88·77	65·09	85·20
Or metallic iron	42·15	31·38	40·45

2nd Process—Smelting. This process consists in mixing the roasted ore with limestone and coal or coke, and exposing it to a strong heat in a blast furnace.

The blast furnace is a kind of cone from 36 to 60 feet high, according to the extent of the work. Its most common height is from 45 to 50 feet, of which the chimney constitutes one-fifth part. The diameter of the chimney varies from 4 to 6 feet. The undermost part of the furnace may consist of a square or round building, then it swells out, and is, at its widest, about one-third from the bottom, after which its dimensions gradually contract to the chimney. It is built of good fire brick, and is double to keep in the heat. The following measurements represent the interior structure of two well-going furnaces:—

	No. 1.	No. 2.
	FEET.	FEET.
Height from hearth throat to mouth ...	45	49
Do. of the crucible or hearth	6½	6
Do. of the boshes	8	7
Do. of the cone	30½	36
Do. of the chimney or mouth	8	12¾
Width of the bottom of the hearth ...	2½	2
Do. of its upper end	3	2⅔
Do. of the boshes	12⅔	13½
Do. at one-third of the belly	12	11½
Do. at two-thirds of the belly	8⅔	9½
Do. at the mouth	4½	3⅔
Inclination of the boshes	59°	52°

Limestone is used as a flux to separate the clay (alumina and silica) with which the ore is always contaminated, for lime has the property of uniting with clay and melting with it into a liquid glass. The proportion of limestone varies according to the goodness of the ore, in general 2½ tons of roasted ore require 19 cwt. of limestone, with hæmatite about 6½ tons of ore require 1 ton of limestone. Ordinary bituminous coal, before it can be employed for smelting iron ore, requires to be coked. The method followed is to place from 6 to 8 tons of coal in a dome of fire-brick, 10 or 12 feet in diameter (plate 30), and to consume all the gaseous matter, sufficient air only being admitted for the purpose. It is seldom necessary to ignite the coal, as the dome usually retains sufficient heat from its previous charge to produce this effect. The process is completed when no more flame is seen to rise from the mass; it is then allowed to remain for a few hours in the oven to cool, after which, with the aid of water to cool it still further, it is drawn out by means of rakes. The coal is now found to have changed its appearance into that of a dense silvery looking mass, which is carbon in a tolerable state of purity. Various plans have been contrived, and patents effected for the purpose of facilitating the manufacture of coke, and although, as regards the reduction of the amount of manual labour employed under the old system, fully answering the desired end, they, as yet, when the quality of the coke produced is taken into consideration, cannot be said to have realized any improvement.

By the process of coking bituminous coal loses from one-half to one-third of its weight. The following statement shows the progress in the management, and results of the employment of the hot blast at the Clyde Iron Works, as indicative of its economy, and is given by M. Dufrenoy.

In 1829, when the combustion was effected by the cold air blast, there were consumed for smelting one ton of metal:—

	T.	C.	LB.
3 tons of coke, equal in coals to	6	13	0
For the blowing engine	1	0	7
	7	13	7
And limestone	0	10	56

In 1831, with the blast at 612° Fahrenheit:—

	T.	C.	LB.
1 ton 18 cwt. of coke, equal in coals to	4	6	0
For heating the air, 5 cwt.: blowing engine, 7 cwt. 4 lb.	0	12	4
	4	18	4
Limestone	0	9	0

In July, 1833, with the hot blast at 612°, raw coal alone being used, there were used for smelting one ton of cast iron:—

	T.	C.	LB.
Coal	2	0	0
For heating the air	0	8	0
For the blowing engine	0	11	2
	2	19	2
Limestone	0	7	0

The ore, the coke or coal, and the limestone, are introduced into the furnace after it has been kindled. The furnace is always kept full, and after being lighted, it is never extinguished until it requires to be repaired. The blast of air is driven into the furnace either direct from large cylinders by means of a steam engine, as in the case of the cold blast, or through metal tubes, which are powerfully heated by external firing, as in the case of the hot blast. Formerly, in the case of the cold blast, the cylinders were plunged into water, and by this means rendered air tight; but it was soon found beneficial to remove the water, and keep the air dry. By the joint action of the lime and fuel, the ore is freed from its impurities, which melt into a liquid glass; while the iron, deprived of its oxygen, tumbles by its weight to the bottom of the furnace below the blast, where it accumulates in a melted state, and over which the scoriæ float in a state of fusion.

The furnace is tapped every twelve hours, and the melted iron allowed to run into sand moulds, forming large ingots called pigs. The scoriæ flow out after the iron, and are thrown away. By this process the iron is obtained in the state of cast iron, of which there are three qualities, distinguished by the names of No. 1, No. 2, and No. 3. Of these, No. 1 is most valuable in the state of cast iron, and No. 3 is the least valuable. The appearance of the scoriæ enables us to distinguish which of these three qualities the furnace has yielded.

The scoriæ of No. 1 are uniform in colour and appearance, glassy, and feebly translucent.

The scoriæ of No. 2 are opaque, heavy, of a yellowish green colour, exhibiting bands of bluish enamel.

The scoriæ of No. 3 are black, vitreous, blebby, and give out the smell of sulphuretted hydrogen.

The quantity of cast iron made by one furnace in a given time has of late years very much increased. A furnace of the best construction will yield, when hard driven, 160, or even, in extreme cases, 180 tons of cast iron in the week. When the Clyde iron-works were first erected, the produce from two furnaces was only 15 tons per week.

For the following analyses of cast irons we are indebted to MM. Gay Lussac and Wilson :—

	IRON.	CARBON.	SILICA.	PHOSPHORUS	MANGANESE.	REMARKS.
White cast iron, from Siegen	94·338	2·690	0·230	0·162	2·590	By wood and charcoal.
Ditto Coblentz ...	94·654	2·441	0·230	0·185	2·490	Ditto.
Grey cast iron, from Nivernais...	95·673	2·254	1·030	1·043	Trace.	Ditto.
Ditto Berry	95·573	2·319	1·920	0·188	Ditto.	Coke and charcoal.
Ditto Creusot ...	93·385	2·021	3·490	0·604	Ditto.	Coke.
Ditto Wales	94·842	1·666	3·000	0·492	Ditto.	Ditto.
Ditto Ditto	95·310	2·550	1·200	0·440	Ditto.	Ditto.
Ditto Ditto	95·150	2·450	1·620	0·780	Ditto.	Ditto.

3. The next process is called REFINING. When cast iron is intended to be used in the same state in which it is first obtained, the object of the smelter is, so far as is in his power, to form No. 1 pig. But when all the iron smelted is to be converted into bar iron, the cast iron is used in the state of No. 2. The composition of the scoriæ in this case is most commonly—

2 atoms silicate of lime ;
1 atom silicate of alumina ;

but there is also usually present some silicate of iron and silicate of magnesia.—(Thompson's Chemistry of Inorganic Bodies, vol. 1.) By this process it is converted into No. 3, or white cast iron. 6 pigs of cast iron, in weight from 1 ton to 30 cwts., are put at once into the refining furnace, and covered with coke above and below: the whole is fused, and kept in that state for about two hours. During this process a good deal of carbonic oxide gas is given off, as is obvious from the blue flame. It is then drawn from the furnace, and cast into a cake 10 feet long, 3 feet wide, and 2½ inches thick. It is then cooled with water. In this state it is white and very hard. Its fracture is fibrous or radiated, and it is often filled with spherical cavities. The scoriæ from this process are obviously derived from impurities in the cast iron, and from the ashes of the coke: they are black, metallic, often fibrous, and crystallized. A specimen, analyzed by Berthier, was found to be composed of—

1 atom phosphate of alumina ;
8½ atoms silicate of iron.

The loss sustained by this process is from 12 to 17 per cent., and from 4 to 5 cwts, of coke are consumed for each ton of metal refined. When phosphoric acid is present, it appears from the analysis of the scoriæ that it is got rid of by this process.

In some of the iron-works of Staffordshire the refining process has been successfully abandoned. The presence of phosphoric acid renders iron *cold* short, a property which the Staffordshire iron rarely exhibits, being generally *hot* short. The ore of that county, therefore, would appear to contain little of the phosphates of lime or iron ; and hence, probably, the reason why the process has been discontinued without detriment.—(Johnson's Economy of a Coal-Field.)

In the Chillington works, instead of being subjected to the refining process as described above, the iron is run direct from the furnace into a long trough, perhaps 15 feet by 10, dug in the floor, and paved with iron or stone blocks: in this it forms a cake 3 or 4 inches thick, on which a stream of cold water is allowed to flow until it is perfectly cooled: it is then broken up easily, being white and brittle, and presenting the ordinary fracture and hardness of refined iron.

In regard to the quality of the iron manufactured by this process, Mr. Mushet stated (March 6, 1838), in a paper read before the Institution of Civil Engineers, that he considered it "peculiarly adapted for railway purposes; that by omitting the refining process, a greater mass of fibre can be produced than in any other manner; and that this fibre, in consequence of the iron not being exposed to so severe a degree of decarbonization, is stiffer and harder than that acquired by repeated heatings and rollings."—(Mining Review, April 30, 1838.)

4. The fourth process is called Puddling, which was contrived by Mr. Cort, of Gosport, about the year 1785. It lasts about two hours and a half. The white cast iron or fine metal of the last process is put into a reverberatory furnace, in which it is arranged around the edges, where flame is made to play upon it. The metal softens: it is stirred, and gradually falls to pieces. The fire is then lowered, and the stirring continued until the metal is reduced to the consistence of sand. In this state much carbonic oxide is given out, and when the evolution of this gas is perceived to be at an end, the fire is raised and the stirring continued. The particles begin gradually to cohere, or work heavy, as the workmen term it. The operator now collects the iron into balls, and raises the heat to a welding temperature. It is now taken out of the furnace, and either hammered or rolled into bars or crushed, during which process the scoriæ are squeezed out, and the iron left in a state of comparative purity.

The quantity of coal used in this process varies in different places: in Wales, 10 tons of coal are consumed in puddling 9 tons of metal. The loss of weight sustained by the iron during the process varies from 8 to 10 per cent. The scoriæ formed are black, very heavy, and sometimes crystallized, and the shape of the crystals is that of pyroxene or augite.

These scoriæ are not always identical in their composition, but most commonly consist of a silicate of iron, and contain in them a greater per centage of metal than is found to exist in clay ironstone: they were formerly altogether, and are still to a considerable extent rejected, a deterioration in the quality of the iron produced being, under ordinary circumstances, the result of their introduction into the blast furnace. Since, however, the hæmatite ores have been used more extensively, it has been found practicable to employ these slags also, the enormous heaps of which in the larger localities of iron manufacture will no doubt, ere long, become of great value.

5. The fifth process is called WELDING. The iron, after being drawn out into bars after puddling, is called mill-bar-iron, or puddled bar: its quality is still so bad that it is scarcely fit for any purpose. To improve it, the bars are heated red hot, and cut in pieces by scissors. Four of these pieces are placed one above another in a re-heating furnace. In half-an-hour they begin to adhere. They are then drawn out into bars between rollers, forming common iron. Scoriæ appear during this process: they are lamellar, and steel grey. In their cavities they contain crystals of augite. Still further to improve the quality of the iron, it is again cut up and re-rolled, and the same process is repeated when it is desired to make the iron still better.

Iron has a greyish colour and metallic lustre, and when polished has a great deal of brilliancy: its hardness exceeds that of most of the metals, and it may be rendered harder than most bodies by being converted into steel: its specific gravity is 7·843.

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2. LEAD ORES AND MANUFACTURE OF LEAD

1. NATIVE LEAD. Lead is described as occurring in small quantities in the lavas of the Island of Madeira and other volcanic districts forming the native lead of some mineralogists, but it is still a very problematical mineral.

2. SULPHURET OF LEAD or GALENA consists as follows:—

Lead	79·6	83·00	85·13 *(Durham.)*
Sulphur	13·4	16·41	13·02
Silver	7·0	Traces.	0·00
	(Beudant.)	*(Westrumb.)*	*(Thompson.)*

Specific gravity from 7·4 to 7·6.

Silver is very often found mixed with galena and in extremely variable proportions; its presence, however, which can only be ascertained by analysis or cupellation, does not influence either the physical or external character of the species in any way. Externally of a lead grey colour. Primary form, the cube.

Galena is a mineral of very frequent occurrence, forming veins and beds both in primary and secondary rocks; the rich repositories of Derbyshire, Cumberland, and the Northern Districts of England, are contained in the mountain limestone. Lead appears to have been very early known and is one of the most abundant of metals. The following is a description of its extraction from galena :—

The galena is first roasted in a reverberatory furnace : a white smoke arises which is condensed in a long horizontal chimney; this smoke consists chiefly of sulphate of lead. By continuing the roasting the whole galena might be converted into sulphate of lead, but the process is never carried nearly so far. The roasted galena is now heated on a hearth with coal and a small quantity of limestone which is added every now and then. The lead is thus reduced and collected in vessels from which it is cast into large ingots called pigs. Sometimes the process is conducted in a reverberatory furnace and sometimes in a blast furnace. The slag formed is run into water which causes it to fall to powder, and this powder is again smelted to extract a little more lead.

According to the different degrees of richness of the ore, it yields lead containing from 2 to 22 ounces of silver to the ton.

Lead is of a bluish-white colour, and, when newly melted, is very bright, but it soon becomes tarnished by its exposure to the air, in consequence of the formation of oxide upon its surface. It has scarcely any taste, but emits on friction a peculiar smell. It stains paper or the fingers a bluish colour. When taken internally it acts as a poison.

It is one of the softest metals ; its specific gravity is 11·3523. From the experiments of Crichton, of Glasgow, we learn that lead melts when heated to the temperature of 612° Fahrenheit.

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3. COPPER ORES AND MANUFACTURE OF COPPER.

1. **Native Copper** consists of 99·8 per cent. of pure copper with a trace of gold and iron, its specific gravity is from 8·5 to 8·9. Its colour is reddish-yellow, frequently with a tinge of brown, often tarnished externally, blackish. Occurs crystallized in the cube and octahedron. It is abundantly met with in the copper mines of Cornwall, Brazil, and Siberia, as also in the district to the north of Lake Superior, where masses exceeding a ton weight have sometimes been extracted.

2. **Sulphuret of Copper.** A combination of copper and sulphur consisting of:—

	SIBERIA.	ROTHENBURG.	CORNWALL.
Copper	78·50	76·5	84·0
Sulphur	18·50	22 0	12·0
Iron	2 25	0 5	4 0
	(Klaproth.)		*(Chenevix.)*

Specific gravity from 5·69 to 5·8. Colour, lead or iron-grey ; often tarnished black and occasionally iridescent. Primary form, the cube ; structure, perfectly lamellar. In the blow-pipe flame it yields a bead of copper, the sulphur being driven off. The sulphuret is met with in veins and beds accompanying the other ores of copper, and is highly prized by the miner. The crystallized varieties occur abundantly and almost exclusively in the mines of Cornwall, and particularly in those near Redruth; while the more compact and massive are found also in Siberia, Hessia, Saxony, and the Bannat.

3. **Grey Copper Ore** is a combination of sulphur, copper, iron, silver, and antimony, or arsenic, the proportions of which are very variable as indicated by the following analyses :—

LOCALITY.	COPPER.	ARSENIC	ANTIMONY.	IRON.	SULPHUR.	SILVER.	ZINC.	SILICA.	AUTHORITY.
Freyberg	48·0	14·0	0·0	25·5	10·0	0·5	0·0	0·0	Klaproth.
Gwennap, Cornwall	48·4	11·5	0·0	14·2	21·8	0·0	0·0	5·0	Hemming.
Cornwall	45·32	11·84	0·00	9·26	28·74	0·00	0·00	0·00	Phillips.
St. Marie aux Mines	40·60	10·19	12·46	4·66	26·83	0·60	3·69	0·00	Rose.
Clausthal	34·48	0·00	28·24	2·27	24·73	4·97	5·55	0·00	Rose.
Wolfach	25·33	0·00	26·63	3·72	23·52	17·71	3·10	0·00	Rose.
Corbiers	34·30	1·50	25·00	1·70	25·30	0·70	6·30	0·00	Berthier.
Gersdorf	38·63	7·21	16·52	4·89	26·33	2·37	2·76	0·00	Rose.
Not named	40·25	0·75	23·00	13·50	18·50	0·30	0·00	0·00	Klaproth.

Specific gravity 4·4 to 5·2. It is of a steel-grey or iron-black colour, occurring crystallized in the tetrahedron which is considered as its primary form. It yields a bead of copper with the blow-pipe. The largest known crystals are found at some of the mines near St. Austell in Cornwall.

4. **Copper Pyrites.** This is the most abundant variety of copper ore, nearly one-third of the ore obtained by metallurgical processes being extracted from it, and in Great Britain furnishing more metallic copper than all the other ores put together. It is a combination of the sulphurets of copper and iron, its analysis is as follows :—

	RAMBERG.	FURSTEMBERG.	CORNWALL.
Copper	34·40	33·12	30·00
Iron	30·47	30·00	32·20
Sulphur	35·87	36·52	35·16
Silica	0·27	0·39	0·00
	(Rose.)	*(Rose.)*	*(Phillips.)*

Specific gravity, from 4·16 to 4·3. Colour, brass yellow, but externally subject to tarnish, and often iridescent. The crystals present the general form of the tetrahedron, having the solid angles always replaced; lustre, metallic; yields to the knife; and may hence be distinguished from iron pyrites, which it often greatly resembles. In Cornwall it occurs associated with tin, forming veins in killas (clay slate), and accompanying galena, grey copper, and blende. The great repository of copper at Fahlun, in Sweden, consists of extensive masses of this species, which are surrounded by a coating of serpentine, and imbedded in gneiss. Copper pyrites has also been found in the coal measures of the North of England, although in very small quantities—a piece having been found associated with galena near to a small slip, in the Hutton seam at Haswell colliery, and another in the Five-quarter seam at Cornforth colliery, near to where the seam is overlaid by the lower new red sandstone.

5. Blue Carbonate of Copper is a compound of carbonic acid, copper, and water, in the following proportions:—

	CHESSY.	BANNAT.	SIBERIA.
Deutoxide of copper	69·08	69·08	70·00
Carbonic acid	25·46	25·72	24·00
Water	5·46	5·20	6·00
	(Phillips.)	*(Karsten.)*	*(Klaproth.)*

Specific gravity, 3·5 to 3·77. Colour, Berlin blue, sometimes with a tinge of black. It occurs in veins of primitive and secondary mountains, chiefly with green carbonate and red oxide of copper. Chessy, near Lyons, is the principal locality of this beautiful mineral: it is there met with in great abundance, and under a great variety of crystalline forms. Wheal Buller, near Redruth, has afforded some fine crystallized varieties, and at Aldstone Moor and Wanlockhead small quantities are occasionally met with. It is also found massive and in rounded concretions, sometimes of considerable dimensions. When obtained in sufficient quantity, it is a valuable ore.

6. Green Carbonate of Copper or Malachite consists as follows:—

	CHESSY.	SIBERIA.	
Deutoxide of copper	72·2	71·7	70·10
Carbonic acid	18·5	20·5	21·25
Water	9·3	7·8	8 65
	(Phillips.)	*(Klaproth.)*	*(Vauquelin.)*

Specific gravity, 3·5. Exteriorly it forms globular, reniform, botryoidal, and stalactital shapes, and occurs in the same repositories as the last species. Splendid specimens of the fibrous kind are found in Siberia, at Chessy, and in the old mine of Sandloge, in Shetland. Compact malachite is found in the Tyrol, and in small quantities associated with the blue carbonate in Cornwall, Wales, and many other places. This is a valuable ore of copper, and from its variegated appearance, and the brilliant polish of which it is susceptible, is much prized for ornamental purposes. Such varieties as are sufficiently compact are cut into vases, snuff boxes, &c., and in St. Petersburg it is formed into tables and other magnificent articles of luxury. For this purpose, as the malachite rarely occurs in slabs exceeding a foot square, the pieces are united so as to render the concentric lines of the stone continuous, and thus massive tablets of 6 or 7 feet in length are formed of apparently one piece of this beautiful substance.

These splendid specimens of Russian manufacture formed a prominent feature in the Great Exhibition at London in 1851.

The richest copper mines of this country are situated in Cornwall where they occur in veins traversing primary rocks and consisting chiefly of copper pyrites and grey copper ore. These ores after being dug out and cleaned as much as possible are still mixed with a great quantity of quartzy matter, from which it is impossible, nor would it be desirable, to free them. The processes of smelting copper are numerous, but the theory of the whole may be reduced to the driving off of the sulphur, oxidizing the iron, and converting it into the state of silicate which separates in the state of scoriæ, while the oxide of copper is reduced to the metallic state.

The first process is to roast the ore in a reverberatory furnace for about twelve hours, taking care not to raise the heat so high as to produce fusion. By this process a great deal of the sulphur is driven off, the iron is partly oxidized and this gives the whole of the ore a black colour. The ore thus roasted is in the next place fused in a melting furnace, and when in a state of complete fusion it is well stirred, in order to induce as complete a separation as possible of the metal from the slag. By this fusion the silica is made to unite with the protoxide of iron, and forms bisilicate of iron, which constitutes the slag. This slag is then skimmed off, and then a new charge is poured in and fused as before. The copper which remains is allowed to run into water where it becomes granulated; it is still much mixed with impurity, the mass only containing about one-third of its weight of pure copper. It is again smelted, and is reduced to a mass containing 60 per cent. of copper.

The calcination or roasting is again repeated, and the roasted metal is smelted anew; the product of which third smelting is called coarse copper, and contains about 90 per cent. of pure copper.

This coarse copper is then exposed to a current of hot air in a furnace, which expels the remaining volatile matter and oxidizes any iron, &c.

Lastly, the copper is melted: its surface is covered with charcoal, and a birch pole is plunged into the melted mass; gas is evolved, which occasions a kind of boiling; and this is repeated until the copper becomes ductile, and acquires the requisite toughness and closeness of grain. Copper has a fine red colour, and a great deal of brilliancy; its taste is styptic and nauseous; its specific gravity, when pure, is 8·953 (Thompson); it melts at the temperature of 2548° Fahrenheit.

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4. TIN ORES, AND MANUFACTURE OF TIN.

1. Oxide of Tin is composed of nearly pure oxide. Its composition is as follows:—

	CORNWALL.	FINBO.
Oxide of tin	99·00	93·6
Oxide of iron	0·25	1·4
Oxide of manganese	0·00	0·8
Oxide of tantalum	0·00	2·4
Silica	0·75	0·0
	(Klaproth.)	*(Berzelius.)*

Specific gravity, 6·4 to 6·9; common form, a quadrangular prism terminated by four-sided pyramids; almost transparent, and either colourless or of a yellowish tint; reddish brown and translucent, or deep brown and opaque; reducible on charcoal by the blow-pipe to the metallic state. Tin is found in various parts of the world, but its chief repository is in Cornwall, in veins traversing granite and clay slate. Stream tin, as its name indicates, is the alluvial debris of tin veins separated from the deposit of gravel by washing: it is a valuable ore of tin.

2. Sulphuret of Tin or Tin Pyrites is a combination of sulphuret of tin with sulphuret of copper—consisting of tin 34·0, copper 36·0, iron 2·0, sulphur 25·0 (Klaproth). Specific gravity, 4·35 to 4·76. It is massive, of a steel grey colour, and is extremely rare.

The only ore from which the metal is extracted is tin stone or peroxide of tin, and the following is a short outline of the process employed:—

The ore is first ground, after which it is washed—this process removing the earthy matter and some of the metallic ores with which the tin is usually associated. The next process is roasting the ore in a reverberatory furnace: this expels the sulphur and arsenic from such of the metallic ores as the washing process did not carry away, thus diminishing their weight, and allowing them to be carried off by the next washing. The tin ore being thus freed as much as possible from foreign matter, is mixed with Welch culm and limestone, and heated strongly in a reverberatory furnace, by which means the tin is reduced to the metallic state, and falls by its weight to the bottom of the furnace. The tin thus obtained is still very impure. It is put back into the furnace, and exposed to a heat just sufficient to melt it. The pure tin flows out into a kettle, while a quantity of impurity remains behind not melted. The tin in the kettle is kept in fusion and agitated, by which a quantity of impurity accumulates on the surface. It is skimmed off, and the tin now refined is cast into blocks.

The stream tin is smelted by means of charcoal, and the fire is urged by bellows. The mass of grain tin is heated until it becomes brittle, and is then allowed to fall from a height; by this it splits into a great number of irregular prisms. This splitting is a mark of the purity of the tin, for it does not happen when the tin is impure.

Tin, when pure, has a fine white colour like silver, and when fresh its brilliancy is very great. It has a disagreeable taste, and emits a peculiar smell when rubbed. Its specific gravity, according to Herapath, is 7·285 It is very flexible, and produces a remarkable crackling noise when bended. When heated to a temperature of 442° Fahrenheit it melts.

CHAPTER IV.

Boring for Coal: Boring in Germany, &c.: Boring against Old Wastes: Frame Dams: Sinking: Timbering: Piling at Framwellgate Colliery: Sinking through "the Wash" at Norwood Colliery: Wedging Cribs: Walling: Sinkers' Tools: Metal Tubbing: Plank Tubbing: Crib Tubbing: Brattice: Pumping and Winding Engines: Pumps and Crabs.

ONCE upon a time the usual way to find, or rather to attempt to find, any required mineral was to make use of what was called the virgula divinatoria or divining rod. The article upon this subject, in Chambers' Dictionary, says that "the virgula is a forked branch in form of a Y cut off a hazel tree; the person who bears it walking very slowly over the places where he suspects mines or springs may be, the effluvia exhaling from the metals or vapour from the water impregnating the wood makes it dip or incline, which is the sign of a discovery." "Some dispute the matter of fact, and deny it to be possible: others convinced by the great number of experiments alledged in its behalf, look out for the natural causes thereof."

"The corpuscules," say these authors, "rising from the springs or minerals entering the rod determine it to bow down, in order to render it parallel to the vertical lines which the effluvia describe in their rise, &c."

The "Compleat Collier," however, who wrote his book nearly 150 years ago, either appears not to have been acquainted with the virtues of the virgula, or to have had very little faith in its powers, for in describing his views on the practicability of finding coals in a certain situation, he very sensibly says:—

"Sir, my reasons (for hoping to win a colliery in your grounds) are as follows: In the first place your ground borders on other collieries which are working collieries, which makes it plain that there is coal so near you: but more especially you may please to observe in your grounds the undoubted tokens or signs of a colliery, which are these following: first, there is an outburst or an appearance above ground of some vein of coal, which some history writers say was the first encouragement to begin coal work; or, secondly, you have an outburst or appearance of such stone as we call coal stone. But if these signs do not assure you thoroughly, we have in the last place this undeniable proof and assurance by boring the grounds with proper instruments, whereby we can discover the nature of the earth, minerals, and water that may be met with in our way of sinking; nay, we can thereby discover, to a small matter, how deep your coal lies in the earth, and what thickness the coal bed is of."

The search for coal is to be differently commenced, according to the state of our information with regard to the locality in which the search is to be made; and this information may be classed under three heads :—

Firstly. Where there is no knowledge of the presence of coal in the district to be explored.

Secondly. Where coal is supposed to exist, being found at some little distance from the locality.

Thirdly. Where coal is worked in adjoining properties.

Firstly. The search for coal in a district where we have no information respecting its existence should be commenced by a general survey of the aspect of the country—of the nature of the strata where exposed by the intersection of ravines, and in the rocky beds of rivers and streams. It will be seen by reference to the sections of coal strata before given, that, next to the appearance of coal itself, the occurrence of thin sandstones and soft and dark-coloured shales containing fossil land plants, the bark of which we find converted into coal, forming what are termed coal-pipes, is most encouraging; but that if, instead of these, strata of chalk or the newer formations are met with, we cannot expect to find any true coal unless at enormous depths below the surface; or, if we should observe limestones containing trilobites, or even abundance of apparently coal shales, but entirely free from land plants, we may conclude that all labour bestowed upon the search for coal will be entirely fruitless. We must also examine the waters of springs, an ochry deposit being a frequent indication of the neighbourhood of the carbonates of iron accompanying coal, but this is not by any means to be relied on, as a similar deposit is often thrown down from water issuing from certain clays, as well as from peat bogs.—(Williams' Mineral Kingdom.)

The outcrop of a seam of coal is not unfrequently indicated by a dark shade on the surface of the ground, especially after recent ploughing; and a similar dark shade is often seen under similar circumstances in the clayey banks of rivers or ravines. In either of these cases an examination should be made, the appearance of coal being immediately pursued by an exploring drift driven into the ground or river-bank.

If there be a seam of coal, its presence will speedily become manifest. The sooty dark earth will become intermixed with grains or small fragments of coal, which will be found more and more frequent as the drift advances. At last the coal will be found of its full height, still very friable, but of its natural quality. The drift should be continued until the roof is found firm and parallel with the floor of the seam.

It will be fortunate for the party engaged in exploring for coal if the seam found in this manner be of workable thickness and quality; but even should it not do so, it will afford sufficient proof that the country contains coal, the search for a workable seam of which may now be conducted with some probability of ultimate success.

Henceforward the means adopted for proving coal in a district, such as the one in question, apply to that of which our knowledge is imperfect, and we are therefore led to—

Secondly. That case in which the nearest positive existence of coal is at some distance.

In this case we assume it to be known that we have to do with a coal country, an examination of which, with a view to ascertain the direction and dip of the strata, will therefore be the first proceeding.

This may be effected by an inspection of any quarries or cliffs, or by a baring off of the alluvial covering where this deposit is of trifling thickness, and must be attended to with care, as a little inaccuracy in the dip, or inattention to any local circumstances affecting it, may lead to very erroneous calculations and results.

To ascertain the angle of dip the clinometer will be found a useful little instrument, and to give results with quite sufficient accuracy for general purposes. It resembles a foot-rule, but may be made of any length, with one joint in the middle: it has a bubble-tube inserted in its upper edge, and at the joint is a graduated quadrant of a circle. By placing its lower edge upon the bed of a rock in the line of its full dip, and raising the upper edge until the spirit-level denotes it to be horizontal, the angle of inclination may be observed on the quadrant.

The object in obtaining the direction of the strata, and the angle of dip, is to furnish data for the pointing out of situations proper for the exploring of the district by means of boring. It is immaterial whether we commence operations at the rise or dip extremity of the district in course of being explored; we will suppose, however, that we commence at the rise, by putting down a bore-hole to the depth of say 30 fathoms.

It is evident that no stratum cropping out on the dip side of this bore-hole will be passed through by it, and the depth of the holes being determined upon, say 30 fathoms, the situation of the next one will be just so far to the dip of the first that it may at the depth of 30 fathoms from the surface reach the uppermost stratum passed through by the first bore-hole.

Supposing the dip of the strata to have been ascertained to be 3 inches to the yard, or 1 in 12, and the surface to be level, the second hole will be required at 720 yards from the first, and the third 1,440, and so on; but the holes had better be placed nearer together than this, so that if the expected stratum be not found, a dislocation or slip may at once be suspected, and another bore-hole commenced still nearer to No. 1.

Boring is usually contracted for by a master borer, who finds all labour and materials according to a regular scale of charges, which at present is as follows :—

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

And so on in arithmetical progression, rising 7s. 6d. per fathom for every additional 5 fathoms in depth.

The following is the rule for finding the cost of a borehole at the above prices, the depth of the borehole being (say) 60 fathoms. Consider the question as a series in arithmetical progression, whose first term is $(5 \times \overset{s.}{7 \cdot 5}) = \overset{s.}{37 \cdot 5}$, and last term $\overset{s.}{37 \cdot 5}$, multiplied by the number of fathoms divided by 5.

$$\frac{60}{5} = 12, \text{ the number of terms.}$$

$$\left.\begin{aligned} 12 \times \overset{s.}{37 \cdot 5} &= 450 \\ 1 \times \overset{s.}{37 \cdot 5} &= 37 \cdot 5 \end{aligned}\right\} \text{extremes.}$$

$$\& \; \frac{450 + 37 \cdot 5}{2} \times 12 = £146 \; 5s.$$

For boring, however, through very hard rocks, the above price is insufficient, and in the case of magnesian limestone either double the above prices are charged, or the boring is done by day's work, according to arrangement; and boring through what is commonly called whin is always performed by day's work.

Boring apparatus consists of three principal parts—the head-gear, which always remains at the surface ; the tools which pierce the strata ; and the rods, with their appendages, which connect the tools with the head-gear.

The head-gear commonly used in this country consists of—

1. A set of shearlegs	Plate 31,	Fig. 1, *a*.
2. A jack-roll	„	„ *b*.
3. Blocks and rope	„	„ *c*.
4. A brake	„	Fig. 2.
5. Braceheads	„	Fig. 3, *a*, *b*, *c*, *d*.
6. A runner	„	Fig. 4.
7. A topit	„	Fig. 5.
8. Keys	„	Fig. 6.

1. The shearlegs or triangles are placed over the borehole, for the purpose of supporting the blocks by which the rods are drawn out of or lowered into the hole when it is necessary to renew the chisel. It is obvious that the more frequently it is required to break the joints in drawing the rods, the more time will be occupied in changing or examining the chisels, and the more tedious will the operation become, especially as the depth of the borehole increases. It therefore becomes of much importance that the rods should be drawn and lowered as rapidly as possible, and, to attain this end, as long lengths as practicable should be drawn at each lift.

The length of lift depending altogether upon the height of the pulley above the top of the borehole, the length of the shearlegs for a hole of any considerable depth should not be less than 40 or 50 feet ; and to add to their efficiency, the borehole may be commenced by sinking (particularly where the upper stratum consists of gravel or dry clay) a staple of 6 or 8 fathoms, at the bottom of which the man who has charge of the borehole may be stationed while working the rods.

There is also another reason for sinking the staple—which is, that in proportion to its depth is that of the borehole diminished, a consequence of more importance than appears at first sight; for, supposing the hole to be 90 fathoms, the staple saves £52 17s. 6d. for boring, at a cost of (say) £10 for sinking, the distance to bore being reduced from 90 fathoms to 82, besides diminishing risk, which increases in a much greater ratio than the depth of the boring, and also saving time, the lowest 8 fathoms at such a depth being usually of very slow accomplishment.

The shearlegs should be made of three good sound Norway spars, 8 inches in diameter at the bottom, and set upon a frame, as shewn in plate 31.

2. The jack-roll may be 12 inches in diameter, properly fit up with a paul, and brake, so as to regulate the speed with which the rods are lowered down into the borehole.

3. The blocks may be either single, double, or further multiplied, according to the depth of the borehole and consequent weight of the rods; and here we observe, that upon this system, with the increased depth of boreholes, instead of the means of drawing and lowering the rods being increased in proportion as regards speed, the reverse is the case.

This at once suggests the application of machinery, which, in an easily transportable form, would greatly facilitate the operation of boring, and to considerably greater depths than those usually attained.

4. The brake. For boreholes of moderate depth, say under 20 fathoms, the boring is effected, so far as the raising and lowering of the rods in the act of piercing the strata, by means of a bracehead, which is a piece of wood 3 feet long and 3 inches in diameter, which passes through an eye in a piece of iron which screws on the top rod: this is called a single bracehead, and by its means two men can bore, without any other aid, to the depth of 10 fathoms. A double bracehead consists of two similar pieces of wood, inserted through two eyes at right angles to each other: by it, four men may be applied, and a borehole put down to the depth of 20 fathoms.

When, however, the hole has reached this depth, the work becomes too heavy for four men, and, especially if the depth of the hole is expected to be much greater, it is advisable to set up a brake in preference to increasing the number of arms of the bracehead, and of men at the borehole.

A brake is a simple lever, made of Memel fir, of the length of 10 or 12 feet; the fulcrum being 18 inches or 2 feet from one end, and having an iron crook attached, from which the rods are suspended by a piece of rope doubled, and passed over the bracehead at the top of the rods. The fulcrum of the brake is an iron axle, working in a carriage bolted to its underside, as shewn in the figure.

The operation of boring with the brake is conducted as follows:—Supposing the rods, with a chisel attached, to have been lowered into the borehole, we have at the bracehead, the master of the shift, and at the brake, two men. The men at the brake, by pressing with the necessary weight upon the longer end of the lever, raise the rods; when raised, the master of the shift turns the bracehead partly round; the men at the brake suddenly detach their weight from the lever, which instantly causes the rods to fall and the chisel to cut into the stratum ; again the rods are lifted, turned, dropped, and so on.

After this process has been continued, in the opinion of the master-borer, for a sufficient length of time, the bracehead is unscrewed, and a runner, attached to the rope from the jack-roll, is passed over the top of the rods, and then a topit is screwed on. The two men who were at the brake, by means of the jack-roll, draw up the rods as far as the height of the shearlegs will allow, when the master-borer, by passing a key upon the top of the rod at the top of the hole beneath the joint, takes the weight of the rods at the first joint above the hole, the jack-roll men having reversed the rods for the purpose; with another key the rods are unscrewed at this joint, the rope is lowered down again, the runner put over the rod; another topit screwed on, the rods lifted, and the process continued until the chisel is drawn from the hole and replaced by another.

Schemes have been contrived, especially in France and Germany, for diminishing the labour of boring, or rather for performing nearly the whole of it by machinery, generally yet, however, worked by men. One of these, the invention of Mr. Kind, a German borer of eminence, has been described by Mr. Combes in his treatise on the working of mines.

It consists of a large wheel, called a " roue à marches," which is of the diameter of 17 feet, and of the width of 8½ feet (plate 32), and its operation is as follows :—Six men place themselves inside and as many outside of the wheel; the lever (brake) of the bore-rods is raised by four rollers adjusted between two parallel discs, disposed like the poles of a lamp: these rollers are moveable on their axes, in order to diminish the friction. The spring, formed of planks laid on each other, is placed beneath the lever. The elevation of the bore-rods can be carried as far as 20 inches. The bore-rods are suspended from the lever by the stirrup, into which they are inserted by a screw (*e*), which permits the length of the rods to be augmented in proportion to the increase in depth of the borehole. The figure renders any further explanation unnecessary. This contrivance, however ingenious, must be infinitely surpassed in economical application by a small portable steam-engine, as above suggested; for the whole of the work which, by the German process, appears to require the assistance of a dozen men, could, with an engine, be easily performed by one. A very deep boring, where this machine was applied, will be afterwards described.

Boring tools consist of—

1. Chisels	Plate 31,	Fig. 7.
2. Wimbles	„	Fig. 8.
3. Sludgers	„	Fig. 8.
4. Instruments for boring through coal	„	Fig. 9.
5. Bèches	„	Fig. 10.
6. Rounders	„	Fig. 11.

1. The chisel is 18 inches long, and usually 2¼ inches in breadth, and at the cutting edge is faced with the best steel: it weighs 4½ lbs. The borer has several of these: they are used to cut through the strata, and require constant attention, and great care that they

may be immediately replaced with fresh ones when any of the substance is worn off their sides, so as to diminish their breadth. If this circumstance is not attended to, the size of the hole of course decreases, so that when a new chisel of the proper size is put in, it will not pass down to the bottom, and much unnecessary delay is occasioned in again enlarging the hole.

Whilst using the chisel, the borer keeps the bracehead attached to the rods in both hands, one placed on each side of the rods, at the same time moving round the borehole, so that the chisel may not fall a second time exactly on the same place, the object being to keep the hole perfectly circular and true. An experienced borer can tell to a nicety the nature of any stratum pierced by the chisel, by the peculiarity of the shock, so to speak, occasioned on its striking the rock bored through: it may, however, simply be remarked, that in passing through shale or metal of any description, portions of it are always attached to the chisel when it is drawn to the surface; but that with post or sandstone this is not the case. The rods should be drawn out of the hole and the chisel examined after boring every 6 inches, supposing the nature of the stone to be such as to permit this process to be made; if, however, as it frequently happens, the stone is very hard, so that probably the chisel may be worn off before proceeding half an inch, it still requires to be frequently drawn to the surface, and examined for the reasons mentioned above.

2. The wimble is 3 feet long altogether, but has the lower 24 inches cylindrical, with a partial covering at the bottom, and an opening up one side for the admission of the bruised material, the covering at the bottom being for the purpose of retaining the core with which this instrument fills, when working in the hole. The external diameter must be such as to admit of its following the chisel: it weighs about 12lbs.

The wimble is also used in boring through clay, for which purpose it is well adapted. It is turned round in the hole, the cover at the bottom, like that of a shell auger, being a little turned down, occasioning the instrument to penetrate the clay.

3. The sludger is also 3 feet long, of nearly the same shape as the wimble, the only difference in external appearance being, that instead of having an open side, it is closed to nearly the bottom, where there is a clack fixed for the purpose of retaining borings of a soft and wet nature, or for preventing them from being washed out of it in a wet borehole.

Sometimes these two last named instruments are used for boring through coal when it is not very hard, and the sludger is often used for bringing up samples of coal bored by the chisel, but left at the bottom of the borehole. The wimble is also sometimes used for this purpose, and, in that case, it is a common practice to stuff a piece of clay into the bottom of it, to which the fragments of coal may adhere. Neither of these plans, however, are satisfactory, the samples, when clay is not used, being usually washed away and lost, especially if the hole be wet, and when clay is used, affording no correct indication of the purity of the coal, and of its freedom from bands of shale.

4. An instrument much better adapted for boring through a seam of coal than any of those yet named has been contrived by Mr. George Stott, of Ferryhill, near Durham, a

master-borer of very considerable experience and great accuracy. Its object is twofold—namely, to break off the coal in such samples as not only to afford specimens of sufficient magnitude to indicate the quality of the seam, but also its hardness and general appearance. It is formed of cylindrical iron, the body being 12 inches long, of similar diameter to the wimble, and tapering at the top to the joint attaching it to the bottom of the bore-rods. The bottom of the instrument is serrated, and has, besides, two cross-cutters at the bottom within the circle, the whole being for the purpose of cutting, and not bruising, the coal, and answering the object remarkably well. Upon the top of these cutters is also a clack, on which the fragments of coal rest after being forced into the instrument : near to its top, in the tapering part, is an oblong moveable piece of iron, or door, which is screwed into its place by a screw-key before putting the instrument into the hole, and which prevents not only any water from washing the coal out, but also any fragments of shale or upper strata from being mixed with the specimens of coal, by being rubbed down into the instrument on its passage out of the borehole. After the instrument has been brought up, the door is unscrewed, and the samples taken out.

The difference between the specimens of coal obtained by means of Mr. Stott's instrument and those obtained in the ordinary way is very remarkable :—in the one instance, they are in the form of powder : by the former process, pieces of the size of nuts may be procured.

5. The bèche is used when the bore-rods have broken in the borehole, for the purpose of drawing out that portion remaining in the hole : it is a hollow cone, 25 inches long altogether, with a cavity extending upwards, 16 inches : it is 1¾ inches in diameter internally at the lower extremity, the internal diameter diminishing upwards to five-eighths of an inch.

When the rods have broken, the part above the fracture is drawn out of the borehole, and the bèche screwed on in place of the broken piece : when this is lowered down upon the broken rod, a smart blow is sufficient to cause the hollow part of the bèche to grip the broken piece with sufficient power to allow the portion below the fracture to be drawn out of the borehole.

6. The rounder resembles a bèche externally, but is solid and well steeled at the bottom : it is used for breaking off any irregularity which may have been occasioned either by careless boring, or by small pieces of iron pyrites or iron stone, which may have been too hard to allow the chisel to cut them with the rest of the strata. The rounder, however, is an instrument which should as seldom as possible be found necessary, because in almost all cases, proper care will preclude its introduction : all that is required to be done, is to round out the hole continually with the chisel, and not merely to be satisfied with doing this at the bottom of the hole, but to have the rods raised a few inches from the bottom, and ascertain that it is round there : by doing this the hole will always be kept round, and the time lost by drawing the rods and putting in the rounder saved.

The common rods (Plate 31, fig. 12) consist of bars of the best Swedish iron, and may be made either of round, canted, or square iron, but the latter is preferable, as it permits the application of the keys for unscrewing the rods throughout the whole length of each piece.

The rods consist of lengths of 3 or 6 feet each, at one end of which is a male and the other end a female screw, for the purpose of connecting them together. They are made of different degrees of strength, according to the depth of the hole for which they are required, but on an average are 1 inch square, and weigh 22lbs. to the fathom: the screw should not have less than six turns. There are also short pieces, varying from 6 inches to 2 feet in length, which are put on at the top, for the purpose of adjustment of the rods to a convenient height. The common rods being most liable to accident, should be carefully examined every time they are drawn out of the borehole, as a neglect of this precaution may occasion much inconvenience, and even the loss of the borehole altogether. A great liability to rupture arises from the splitting of one of the sides of the female screw, and the consequent drawing out of the male screw, thus leaving the rods in the hole: the screw itself may also, by ordinary wear and tear, have its thread worn off, and, becoming in consequence liable to slip, occasion the same result.

Besides the above apparatus, there are also frequently required pipes of iron to put into boreholes, in strata of soft clay or sand. When this is the case near the surface, the wimble used in boring through the clay should be of sufficient size to admit of the introduction of the pipes as far as the bottom of the first length bored, which will be dependent on the judgment of the master borer. When it is found that the wimble, on being withdrawn from the hole, cannot from the lateral pressure be at once returned to the same depth from which it was taken, it must be concluded that the sand or clay is of a running nature. No time should then be lost in enlarging the hole from the surface, or what is better, if the depth be not great, in commencing anew from the surface with a larger wimble, say 3 inches in diameter, and putting down the hole to nearly the same depth with all speed. An iron pipe, say 10 feet long, having an internal diameter of 2½ inches, is then driven into the hole, and when this has been effected, another pipe of similar dimensions is screwed into its upper end, and the driving repeated; and so on, until a sufficient number of pipes have been put on, to reach the bottom of the borehole. If the ordinary wimble be now introduced through these pipes, it will have free access to the clay or sand, and after a few feet further have been bored, another pipe may be screwed on, and the whole driven further down. In this manner several fathoms of soft and running material may be bored through. If the thickness of the surface clay or sand, however, is very considerable, the method here mentioned will not be found sufficient, as the friction of the pipes occasioned by the pressure of the clay, &c., will in some instances be found so great, that perhaps not more than 12 or 14 fathoms of pipes can be driven in, without their being injured. When this is the case, it is necessary to put down the highest part of the hole with a still larger wimble, and to insert pipes of proportionate diameter; then to continue the hole of smaller diameter, putting in another column of pipes of less size: and thus to proceed until the stone head is reached.

If, after having passed through upper strata of rock, a stratum of quicksand should be met with at a considerable depth, the process becomes very expensive, as the whole of the borehole will be to enlarge from the surface, and pipes to insert, as above described.

The most difficult case of all, however, is when there is a running stratum near the surface, and another at some depth, and beneath the solid rock, both requiring tubing. When the borehole is finished, the tubes may partly be recovered by means of a sort of solid box-key, which is tapered slightly to the bottom, the diagonal dimensions of the bottom of the key being a little less, and of the top a little greater, than the diameter of the tubes, the instrument being, in fact, the reverse of the bèche. It is also attached to rods, having the screws turned in a different direction from the screws of the tubes. When the key is driven down into the uppermost tube, and turned round by the bracehead, it unscrews the tube, and, as in the case of the bèche, the friction is often sufficient to draw the tube to the surface. Many of the tubes are, however, usually lost.

Attempts have been made to substitute cordage for bore-rods, and for moderate depths the plan has been successful. It consists in merely a frame, with a jack-roll and pulley, over which the cordage is carried, a moveable clutch fastening the cord to a brake or lever placed alongside for the purpose of raising a heavy chisel attached to the bottom of the cord. When the depth of the hole is great, the stretching of the rope is such as to prevent any of the effect being produced at the bottom of the borehole. If the plan is capable of being made perfect, it perhaps might be made so by the application of wire ropes. There must be considerable difficulty, however, in keeping the borehole round.

Bore-rods of wood have also occasionally been used, with what advantage will be seen presently.

The deep borehole, alluded to before as having been executed by Mr. Kind, was put down at Cessingen, near Luxemburg.—(Combes' Traité de l'Exploitation des Mines, volume 1, page 191.) It was commenced on the 6th February, 1837, and stopped on the 22nd March, 1839. During this lapse of time, the hole was bored 534·85 metres, or 292 fathoms 2 feet 9 inches.

The strata passed through were as follows:—

	FM.	FT.	IN.
Lias limestone	34	2	2
Luxemburg grit	45	4	1
Sandy marl	13	5	5
Keuper, with gypsum and saliferous marl	90	4	5
Middle grit	4	5	2
Gypsum and saliferous marl	102	5	6
Fathoms	292	2	9

The hole was commenced with a diameter of 11·81 inches, and at the bottom the diameter was 3·937 inches. Kind made use of iron rods in the first instance, of the "roue à marches" already described; and of a valved cylinder, attached to a cord for the purpose of lifting the cut strata out of the borehole.

At the depth of 126 fathoms 1 foot 1 inch, the diameter of the hole being reduced to 10·236 inches, the wasting of the sides of the hole rendered it necessary to insert a column of pipes of thin iron of the length of 49 fathoms 1 foot 2 inches, which did not descend to the bottom. The boring having been continued of the diameter of 9·05 inches to the depth of 130 fathoms 2 feet 11 inches in the midst of constant wasting, it was attempted to withdraw the column of pipes, but without success. They then enlarged the hole beneath the pipes, and succeeded in driving them down about 13 feet, and stopping the wasting of the marl. They were, notwithstanding, soon obliged to put in a second column of 6 fathoms 5 feet 5 inches, and to reduce the hole to 7·874 inches in diameter. In consequence of fresh wasting (éboulements), they drew out this last column of tubes, and were able to drive down the first column about 17½ feet further: they then re-descended the second column, which had been lengthened, and was now 12 fathoms 5 feet. At the depth of 133 fathoms 5 feet 7 inches, fresh wasting compelled the extraction a second time of the second column of pipes: they then enlarged the hole to the bottom, and again put in the column extracted. They were obliged to draw them out again, and to enlarge the hole repeatedly, to attain the depth of 151 fathoms 4 feet 11 inches, in order to maintain the diameter of the hole at 7·874 inches. Arrived at this point, it became necessary to introduce a third column of tubes, which was 8 fathoms 2 feet in length: it was continued to the bottom of the hole, and the diameter of 6·496 inches preserved through the marls and saliferous clays. From 153 to 164 fathoms there was no more wasting: the marls and saliferous clays, containing gypsum and anhydrite, were firm, but the breaking of the rods became excessively frequent. At 168 fathoms 2 feet 2 inches the wasting recommenced: at 172 fathoms 2 feet 2 inches they attempted to introduce a fourth column of tubes, but it would not descend to the bottom of the hole: they then lifted it out, and decided to continue the boring of the diameter of 6·496 inches.

At the depth of 183 fathoms 4 feet 9 inches, a bed of hard grit was reached, and after having bored 3½ or 4 fathoms into it, they resolved to extract the third column of tubes, to enlarge the hole to the grit bed, and to re-descend this column, after being lengthened, down to the grit. This was executed: the third column, having now a total length of 39 fathoms 4 feet 8 inches, was put in its place after the enlargement of the hole, and the base of the column reached the depth of 182 fathoms 3 inches. They continued to pierce the grit with the hole 6·496 inches in diameter. The wasting having recommenced beneath the bed of grit, they descended a fourth column of tubes which was of the length of 21 fathoms, 3 feet 4 inches which attained the bottom of the hole at the depth of 203 fathoms 5 feet 5 inches the diameter of the hole being now 5·37 inches. At the depth of 219 fathoms 1 foot 3 inches, it became necessary to put in a fifth column of tubes, of the length of 18 fathoms 4 feet 5 inches, and the diameter of the hole was reduced to 3·937 inches. They continued to bore, but the hardness of the beds of gypsum occasioned frequent ruptures of the rods, which suggested to Kind the idea of trying wooden rods. This was in January, 1839, the boring having reached the depth of 256 fathoms 5 feet 7 inches. The wooden rods immediately rendered the ruptures less frequent, notwithstanding that they were only used in the upper part of the hole, and that the method of joining these rods was far from being as secure as that which Kind has since adopted. At last the boring, having attained the depth of 292 fathoms 2 feet 9 inches (534·85 mêtres), was stopped on the 22nd March, 1839; and they were in course of extracting the fifth and fourth columns of pipes, when the failure of funds stopped the work. The whole expense had not reached 110,000 francs, or £4,441 5s., and two-thirds only of this sum had been employed in the direct work of the boring.

The boring executed at Besch, on the Moselle (district of Trèves), was performed with wooden rods, by the aid of a simple lever or brake. From the 24th July, 1840, to February, 1841, with 243 days' work of 12 hours each, this boring reached the depth of 156 fathoms 3 feet 8 inches (286·50 mêtres), through beds of limestone, grit, and gypsum. The rock did not waste until at the depth of 154 fathoms, where a bed of running sandy gravel was met with, which obliged them to put down a column of tubes, which twice required to be brought out in order to be lengthened. The diameter of this hole was 6·3 inches. There is certainly one great advantage possessed by wooden over iron rods—viz., their lightness; because it will be remembered, that since the rods are generally immersed in water, their being of any weight at all is owing to the joints, and such other iron work as is thought necessary to add to their strength. The extra size of the hole is decidedly advantageous, because, in the first instance, if running strata be met with, it allows margin for the insertion of tubing and the subsequent introduction of iron rods; it will also allow much more satisfactory specimens of coal, or whatever mineral may be sought, to be brought to the surface for examination.

It will sometimes happen, that notwithstanding the general disposition of the strata with regard to rise and dip may be pretty evident, yet a stratum or bed of coal found in one borehole will not always be proved in the situation where by calculation it ought to exist. This will result in general from the intersection of the district by faults; and since it is of the first importance, in the establishment of a shaft for the purpose of working any stratum, that it should be placed so as to have the greatest possible extent to the rise of the water-level from the shaft, every precaution should be taken to define as distinctly as may be the locality in which the winning ought to be made, so as to answer this end. There will probably be, in every coal country, some top seam or seams which have about them sufficiently characteristic marks, to prevent their being mistaken for others, and the best way to attain the object above specified is to put down a series of boreholes to such top seams. By a judicious management of such borings, no very great expense need be incurred—the cost being well expended if it lead to the prevention of a winning being made in an improper place. Cases, however, have occurred, and may occur again, in which, notwithstanding all this precaution, errors have arisen; and an instance of an erroneous conclusion, from data as accurate as human skill could possibly have established, will hereafter be related.

We must now proceed to our ***third*** case—viz., that in which we have coal worked in adjoining properties.

Under the circumstances previously named, it has been supposed that the site of the winning would be altogether governed by the position of the coal seams, it being assumed that, the country being an average one, a railway to the colliery might be constructed to any part of the royalty indifferently. Now, however, the case may be somewhat varied, because, since we have coal worked in adjoining properties, there will in all probability be a railway already constructed to such working, and it may be a matter of moment to have the winning on the royalty to be worked placed so as to be convenient for such railway. This, however, is merely mentioned as one of the considerations which may guide us in the selection of the site for the colliery, but which must in a great measure be made subservient to that mentioned under the second case.

If coal is worked on both sides of the royalty, and by a careful levelling across it, made between the pits at work, the strata appear to lie in a regular course, the situation for a winning may be selected at once and without further expense; still, before commencing to sink, it will be prudent to bore in such situation to the seam of coal, if not at a great depth, and to a top seam known at the adjoining collieries, if the depth to the desired seam should be considerable.

If coal is only worked at one side of the royalty, a series of borings should be made to the top seam, in order to define by such boreholes a situation eligible for the winning. Much of this, however, must be regulated by circumstances, and no positive rules for proceeding can possibly be laid down. As the situation for a winning will rarely happen to be confined to a very limited portion of the royalty, we may regulate it so as in some degree to suit the railway, and also, if possible, so as to have it upon a sloping surface, in order to obtain a ready deposit for the rubbish drawn out during the sinking, and also for refuse made subsequently in carrying on the works.

The above are general rules, but there are nevertheless cases in which the whole of them may require to be set aside. We may be compelled to adopt, knowingly, a most inconvenient situation for a winning, the question being between either having the winning thus inconveniently placed, or having it at an outlay of more than it is worth, after having been established.

In certain districts, the lower new red sandstone contains a bed of very soft sandstone, which is found in so disintegrated a state, that the large feeders of water which are met with in sinking through it cause it to waste away, and run into the pit bottom with the water. By wearing the leather of the buckets, and preventing the feeders from being pumped, on the one hand, and in consequence of the sand running into the pit as quickly as it is taken out, on the other, the expenses for extra machinery (so as to allow of one portion being continually suspended for refitting) and labour are magnified to an enormous amount; and in such cases as this, the question becomes as to where is the best situation for passing through "the sand," and borings should be made in different parts of the royalty to establish this point before commencing to sink.

Much the same directions apply to quicksands near the surface: they are always troublesome, not altogether from the difficulty and expense of sinking through them, but from the insecurity which they cause to the engine-houses and heavy machinery placed upon the colliery. There is no doubt of being able to combat and overcome the difficulties met with in making such winnings, but the safest direction which can be given concerning them is, if possible, to keep out of their way.

An instance has been mentioned in which even accurate boring produced erroneous conclusions. The circumstance was as follows :—At Cornforth colliery, 6 miles south-east of Durham, two boreholes were put down in the situations indicated on the section (plate 33) as No. 1 and No. 2 :—

SECTION No. 1.

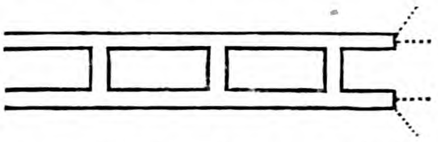
	FAS.	FT.	IN.
Soil and clay	1	5	0
Limestone	21	4	6
Red shale and sandstone ...	9	1	9
Coal strata	6	1	3
Coal ... 1ft. 11in.; Band ... 1 4; Coal ... 4 8 ...	1	1	11
	40	2	5

SECTION No. 2.

	FAS.	FT.	IN.
Soil and clay	—	–	–
Limestone	23	3	6
Red shale and sandstone ...	9	3	4
Coal strata	7	4	6
Coal ... 1ft. 1in.; Band ... 1 0; Coal ... 4 4 ...	1	0	5
	41	5	9

This, of course, was sufficient to satisfy any one that the strata between these two points were almost flat, and at the position marked No. 2 the pit was sunk. On the coal strata being reached, however, it was found that instead of being nearly level, they were lying at an inclination of about 18°, their ascent being to the south at the rate of 1 in 3. At this stage, and still more so on exploring in the direction of borehole No. 1, considerable doubts were expressed as to the accuracy of the boring; and although it was known that at about 14 fathoms beneath, another seam would be found, it was taken for granted, that even supposing the seam in No. 1 borehole to be the lower seam of No. 2, a more favourable account of it had been given than the fact would be found to justify. However, as it was expected that the lower seam would be of pretty good quality, a level was driven from the bottom of the pit to cut it, and one of the working places in this seam intersected the borehole; and it was satisfactorily shewn that the section of the coal, &c., corresponded exactly with the section given in the boring account. All borings are not, however, as accurate as the above: a great liability to error arises from all tender coal boring much harder than it proves to be in reality, for its tenderness or strength when worked is in a great degree owing to the less or greater distance between the cleavages or cleats, which has nothing to do with the resistance which the coal offers to the chisel; and from the difficulty of distinguishing any change in quality of the coal, should one portion of the seam differ from the rest. These errors may to a considerable extent be avoided by the careful use of Mr. Stott's instrument.

Besides boring vertically to prove the nature of the stratification, it is frequently necessary to bore horizontally, particularly in coal adjoining to old wastes containing water. For this purpose, a lighter description of rod is sufficient, and the breadth of the chisel should not exceed 1¼ inch. The safest plan of driving a pair of exploring drifts against an old waste is to keep them very near together (say 5 yards apart), and not more than 5 feet in width each, and out of each drift to bore one front and one flank hole, as shewn in the figure. The flank holes may be bored every 10 yards. The length of the front holes, to be kept in advance of the face of the drifts, will depend upon circumstances,



for it must be regulated by the vertical depth of the water contained in the waste, and also by the nature of the coal in which the boring is made. Of course, also regard must be had to the quantity of water contained in the waste. If it be intended to draw the water off, and the quantity is not of any very great consequence, the same care is not so positively requisite as if the contrary were the case; but still it is well in all practice, both of this and similar operations, to take equally great precaution, because the trouble is very little greater, and the result always satisfactory and safe.

In a moderately hard seam, the front holes may be bored out of the face of the drifts 6, 7, 8, 9, or 10, &c., yards in advance, for 5, 10, 15, 20, or 25, &c., fathoms of pressure, the holes being bored forward 2 yards for every 2 yards taken out of the face. This will always ensure 4, 5, 6, 7, or 8 yards barrier against the water. The quantity of water which such boreholes as those above described will run per minute may be calculated as follows:—

Let P = the pressure in feet;
„ d = the diameter of the borehole in feet;
„ l = the length of the borehole in feet;
„ v = the velocity at the point of issue in feet per minute;
then

$$v = 2337{\cdot}5 \sqrt{\frac{Pd}{l}}$$

and

$$6{\cdot}25v \times {\cdot}7854d^2 = \text{gallons of water per minute.}$$

The actual discharge of a borehole in the Five-quarter seam at Towneley colliery was 125 gallons per minute; the length of the hole being 25 feet; its diameter, 1¼ inch; and the pressure of the water, 66 feet. Of another borehole in the Towneley seam at the same colliery, the discharge was 140 gallons a minute; the length of the hole being 11 feet, and its diameter 1½ inches, from which it would appear by the above formula that the pressure was 36·4 feet. After the waste has been proved, the boreholes must be plugged up with long fir plugs, which may be made 4 or even 6 feet long, pointed and slightly tapered so as to admit of easy insertion: some of these, with a mall, must be in readiness. It may sometimes be necessary, when the pressure is very great, to have cross-pieces fastened to the plugs, so as to apply the force of two or three men, to enter them into the boreholes. The probable direction of the workings may be pretty accurately conjectured by the course of the water-level, but to prevent any accidents, it is preferable to drive, from some situation 10 or 12 yards back from the face, two pairs of drifts in a water-level direction, each pair skirting the waste, and to bore one front and one flank hole out of the drifts nearest to the waste, these being kept the leading drifts. Should these shew no indication of holing, at certain distances, other drifts may, with the precautions first named, be driven against the waste, until its position is accurately determined.

It is imperative on every one having charge of such proceedings as those above described to attend most minutely to these instructions, as any neglect may be attended by most serious or fatal consequences : so apparently trivial an oversight, even, as not having the plugs ready, might, in boring to the dip, involve the necessity of putting in dams, or possibly occasion the drowning up of the colliery.

Various plans of dams have been devised, having for their object the resistance of great pressures of water. I shall, however, only describe that which is, beyond all comparison, the best, and which, under modifications according to circumstances, may be applied in all cases. I allude to the frame-dam (plate 34, figure 1). Before putting in a dam, it is necessary to select with great care a situation where the strata are in a perfectly sound state, and free from slips and troubles of every description. As, of course, in preparing such a place for the insertion of the dam, no gunpowder is admissible, on account of its liability to shake the stone or coal, the whole of the work must be performed by the pick or hack, and the sides, as well as top and bottom, dressed perfectly smooth. The dam consists of pieces of fir, carefully dressed with a taper, diminishing from that end of each piece next to the pressure of water to that end next to the workings which it is designed to protect; and as in proportion to the radius of sweep of the dam will be the ratio of taper, it will be necessary to determine upon this, and after projecting it upon a floor at the surface, the pieces of timber of which the dam is to be formed may be dressed there, and properly numbered before being taken into the mine.

The length of the pieces of wood must depend upon the pressure, and also upon the area, of the dam itself: they may vary from 4 to 8 feet in length, and the radius of the inner circle may be from 18 to 30 feet. Since it has been found that, notwithstanding the most severe wedging, the pressure is sometimes sufficiently great to compress the wood still closer, thus tending to force the whole dam forward, it is advisable so to increase the area of the dam, by extending it further into the solid, that its seat may be continued of its tapering form, say 3 feet, further back than the face of the dam, as shewn in the plate. While the dam is being put in, it is necessary to have three metal pipes inserted in it:—one *(a)*, about a foot from the bottom, sufficiently large to allow the feeder of water to pass, or, if the feeder be very large, perhaps two may be preferable; another *(b)*, about 18 inches in diameter, two feet from the bottom, for the purpose of allowing the ingress and egress of the workmen during the insertion and wedging of the dam; and a third *(c)*, which may be an inch in diameter, and placed near the top, the use of which is to allow the exit of any confined gases, and which will be found materially to ease the pressure on the dam after it is finished. This last should, if practicable, be continued of lead or iron tubing to such a level as will outset the water. After the sides, bottom, and top have been accurately dressed, a layer of tarred flannel may be placed next to the stone or coal, and the pieces of wood built up, inserting the pipes as above until the whole is closed up; after which, the wedging is commenced on the inside, with fir wedges, 12 inches long, 3 inches broad, and 1 inch thick at the head. After these have been driven in at all the joints, sides, and round the pipes, other wedges are driven in, of diminished size, as long as they can be entered, an iron chisel being used to prepare places for their insertion. After the wedging is finished, the workmen drive the plug into the pipe through which the water has been flowing: they then pass out by the 18-inch pipe before alluded to, drawing after them the plug which has been placed conveniently for so doing, and the work is completed.

A dam of this description, 6 feet square and from 6 to 8 feet thick, is able to resist a pressure of from 50 to 100 fathoms of water; but when a less substantial one will answer the required end, it may be made of less thickness. Dams may, for slight pressures, be constructed of balks set edgeways upon each other, and opposed laterally to the pressure (plate 34, figure 2); or they may be formed of two rows of three-inch planks set upon one another, the space between them (say 18 inches) being filled with clay beaten tight in, the planks being kept in their places between two rows of props (plate 34, figure 3). For all permanent work, however, the frame-dam as above described will be found incomparably superior.

Many instances might be adduced in proof of the necessity of careful boring against old wastes; and, upon the general use of boring, it may be stated that its great value consists in its enabling us to determine the position of the strata, rather than the value of individual seams of coal. Mr. William Brown, a celebrated viewer of former days, used to say that a colliery well bored was half won; and so far as its establishment of the best position for effecting the winning is concerned, no doubt he was right.

The site having been determined upon, we shall now proceed to describe the process of sinking a pit through strata which we may assume to be as follows (plate 35):—

		FAS.	FT.	IN.
1.	Soil, gravel, and clay ...	3	0	0
2.	Broken metal ...	2	0	0
3.	White post with water	8	0	0
4.	Grey metal ...	4	0	0
5.	Soft blue metal ...	2	0	0
6.	White post with much water	6	0	0
7.	Grey metal stone, strong ...	5	0	0
8.	Grey metal with post girdles ...	10	0	0
9.	Blue metal ...	7	0	0
10.	White post with water ...	12	0	0
11.	Grey metal ...	8	0	0
12.	Blue metal ...	2	0	0
13.	Coal ...	1	0	0
	Total fathoms ...	70	0	0

We will also suppose that the diameter of the pit when finished is to be 11 feet.

Perhaps the first consideration in commencing the establishment of a winning is the nature of the road to it; and if the communication with the shipping place or other market for the coals is to be by railway, it will be found to facilitate matters much if it can be made before breaking the ground, so that by its means the whole of the materials, machinery, timber, &c., required for the sinking may be brought to the place. An arrangement of this nature will have very considerable effect in lessening the outlay, the expense of carting forming a very large item, owing to the usually imperfect nature of country roads. If, however, some miles of railway require to be formed, and it be of importance, as is most frequently the case, to have the colliery brought into operation as speedily as possible, it will, notwithstanding what has been said above, be found necessary to commence sinking forthwith, and to have the railway and winning forwarded simultaneously. If nothing can in consequence be brought by railway, some attention should be paid to the roads, in order that the carriage of materials may meet with as little impediment as may be.

Sinking is usually performed by contractors, who provide all labour, or whatever may in addition be specified and agreed upon, at a price per fathom which varies according to the circumstances of the case. The following may be taken as an example of the usual conditions for sinking a pit such as that above described :—

1. The pit to be sunk to the depth of 75 fathoms from the surface, viz., 70 fathoms to the thill of the seam of coal, the remaining five fathoms being for standage for the water.
2. To be 11 feet in diameter when finished: the contractor to take out all extra space necessary for putting in timber, walling, or tubbing, wherever the same shall be required for securing the sides and keeping back water, without any extra price per fathom. The contractor also to put in all timber that may be so required, free of charge.
3. Contractor to find all gunpowder, oakum, shot-paper, candles, and sinkers' flannels, the owners only providing ropes, kibbles, corves, tubs, gear, and sharping the same, timber, and nails.
4. Contractor to sink the pit with a jack engine, to be erected by the owners, and to keep the pit free from water during the time of actual sinking, timbering, and contract work, unless the water should exceed thirty 60-gallon tubs per hour.
5. The pit to be divided by a temporary brattice composed of buntons and deals, leaving a clear space of 7½ feet for drawing the stones. The buntons to consist of Memel planks and battens placed alternately, 3 feet apart centre and centre, and properly secured to the shaft at the ends, the stringing planks into which they are to be inserted being spiked to wooden plugs driven into holes drilled into the wall sides at least 12 inches for this purpose. The buntons to be clad on the fore side with inch deals of suitable lengths and breadths, planed so as to make an air-tight brattice, and nailed to each bunton with two good hammered pit single-tack nails. This brattice to be carried down regularly with the sinking of the pit, so as to keep the bottom at all times well ventilated.

The object in having the alternate buntons of Memel plank, is to allow of their application to the permanent purpose of forming the guide buntons, when the time has arrived for fitting up the shaft with cages, &c.

6. The contractor to find and provide all labour except enginemen and firemen's wages, and the preparation of cribs and other timber.
7. No shots to be put in within 12 inches of the wall side without the viewer's express leave: the whole of the shaft sides being properly dressed down with hacks.
8. The contractor to finish the work to the satisfaction of the viewer, who shall at all times have access to inspect the work: the sinking and other necessary operations to be continued by the contractor from 1 o'clock on the Monday morning until 11 o'clock on the Saturday night, such a number of men being continually employed in the bottom or elsewhere, as shall, in the opinion of the viewer, be adequate to the due performance of the work.
9. The contractor to discharge any man of bad character, or who shall be considered incompetent, if required to do so by the owners or their viewer.
10. If the sinkers are required for any shift work in the shaft, to be paid   per shift of four hours: and if required for any other purposes, such as lowering pumps, &c., to be paid   per shift of eight hours.
11. The contractor to make out fortnightly on the measuring day, and deliver at the colliery office an accurate account of the strata passed through during the fortnight, together with average specimens of the same.
12. The work to be measured or estimated by the viewer every fortnight, on the Monday; and the contractor to be paid on the Friday following, less 10 per cent. to be kept in hand until the work is finished.

The conditions, besides the above, may embrace any other description of work or manner of doing it, at the option of the viewer, who will do well to have invariably a clear understanding with the contractor before the work is commenced, as the absence of such often leads to disagreements which might easily have been avoided.

It is sometimes, however, preferred to do the whole of the work by day's-work or shift, a master sinker being appointed by the viewer to constantly superintend the work, in order to see that it is properly done, and no time lost.

Previous to commencing to sink, it is necessary to have in readiness a stock of sinking corves, hacks, drills, mauls, wedges, and shovels, &c.—(Plate 36.)

1. Sinking Corves (figure 1) should be made of well-seasoned hazel, and of the capacity of 10 pecks: care must be taken in making them to have the bottoms of the corf bows well secured by washer and cotteril, so that there may be no chance of their drawing out: the top of the bow should also stand high and angular, being just rounded to receive the hook: the reason being, that should the ascending corf come in contact with the descending one, the bow may not only operate in warding it off, but also from the nature of

the suspension from the hook, prevent the full corf from being canted, and any stones thrown out into the pit, whereby the sinkers in the bottom of the pit might be killed or seriously injured.

A round iron kibble of similar capacity to the sinking corf may be substituted for it with advantage, as with it not only the stones, but a considerable quantity of water may also at the same time be drawn out of the pit. Wooden kibbles are also sometimes used, but as they are made square, they are objectionable on account of the liability of their angles to come in contact as they pass in the shaft: they are therefore less safe than either corves or iron kibbles, and on this account should not be adopted.

After the corf or kibble is brought up to the surface, or a little above it, it is drawn by the waiter-on towards a tram (figure 2), upon which by a reversed motion of the gin or engine, it is lowered: it is then replaced by an empty one. The tram with the full corf is then put away by the waiter-on to the refuse heap, and there teemed.

2. Hacks should be made of good tough iron, of the length of 18 inches, and weighing 7lbs. each (figure 3). Much depends upon having these well sharped, and some skill is necessary to enable a blacksmith to do so properly: the points must be steeled: if they are not hard, they wear off, instead of cutting a hard stone; and if they are too hard, they are often at the same time brittle, and then the points snap off. The hack-shafts are made of sound, tough ash, about 2 feet 6 inches long. There ought to be a good stock of hacks, so that as they become blunted they may be at once replaced by sharp ones.

3. Drills (figure 4) ought to be made of the best iron, Swedish is preferable: they are used in drilling or boring holes into the stone for the insertion of gunpowder for the purpose of blasting. They are made of different lengths, varying from 18 inches to 4 feet, the different sizes being put in successively as the drilling proceeds. The cutting edge of the drills must be well steeled, and should be made, for the 18 inch or first drill *(a)*, 2 inches; for the 28 inch or second drill *(b)*, $1\frac{3}{4}$ inches; for the three feet or third drill *(c)*, $1\frac{1}{2}$ inches; and for the 4 feet drill or jumper chisel *(d)*, $1\frac{1}{2}$ inches in breadth on the edge. The reason why drills should be made of the best iron is, that by repeated beating on the head by the maul, if the iron is bad, it splits and turns over, and is thus liable to cut the hands of the workman who turns it; or it is liable to give off dangerous splinters of iron from under the stroke, or to snap into pieces.

When it is intended to drill a hole, a place is marked off with a hack, and one man sits down holding the drill in both hands between his legs, and another with a maul (figure 5) strikes it repeatedly, the first man turning the drill round all the while. If the hole is in wet stone, means require to be adopted for keeping the gunpowder dry, which are as follow: sometimes tin cartridges are used, which consist of cylinders made of a size suitable to contain a sufficient quantity, say from a quarter to half a pound of gunpowder, with a small tin stem to allow of its being ignited: when these cartridges are used, however, the powder is not by any means so effective as when it can be applied without their aid; and most usually the paper cartridge, by being well greased, is found to answer the purpose. When the paper shot is used, in order as far as possible to keep the hole dry, it is filled with strong clay, and a round bar with a hole near the top, called a bull (figure 6), is driven in, the object being to fill up the chinks or crevices through which the water may be oozing, with clay, in order to dam it back. After the bull has been driven in, it is carefully drawn out again by a cross bar (a common drill will do) put through the hole in the bull which is for this purpose. The cartridge is then placed upon the point of a pricker, which is a taper piece of iron, pointed at one end and having a ring at the other (figure 7), and then thrust into the hole; this being done, first a little oakum, and then small pieces of metal or shale are put in, and by means of a beater (figure 8) and hammer (figure 9) the hole is tightly stemmed or tamped up. The pricker is then steadily withdrawn, which forms a port-hole to allow of the communication of fire to the powder, which is done by a straw of sufficient length filled with fine powder; a small piece of candle end (or match) is then placed by means of a piece of clay, in such a position that when flame is applied to the point of the wick, the flame may travel under and ignite the straw. The sinkers, with the exception of one, having now been drawn away, either out of the pit or up to some place of safety, and the sinker left at the bottom having ascertained by calling and receiving an answer that all is ready, applies a light to the match, shouts "bend away!" and is rapidly drawn up the shaft. The gunpowder then, if all has been rightly managed, explodes, and blows up the stone as intended. In a sinking pit, it is scarcely possible, on account of the wetness, for the pricker point, by coming in contact with sandstone or post at the bottom of the hole, to ignite the powder: but if the stone is at all dry, as a measure of precaution against such an accident, prickers made of copper ought to be used, and as a still greater precaution, copper beaters as well.

4. Wedges are, as their name indicates, wedge-shaped pieces of iron, 7 or 8 inches long, and tapered to a point. They are used for breaking to pieces large stones displaced by gunpowder, or for taking off that portion of the stone next to the wall sides, which ought, with rare exceptions, never to be taken off with gunpowder: they are used by their point being placed in a small hole made with a hack, and then driven down by a maul.

5. Sinking Shovels are of a pointed shape (figure 10).

The corves or kibbles are suspended to the rope by a spring-hook (figure 11), which should be constantly examined, and the spring kept in perfect order.

After all the preliminary arrangements have been made, the sinking is commenced by marking off a circle on the ground, 13 feet in diameter, and with hack and shovel digging up and casting out the soil and clay to the depth of (say) 6 feet. A crib, which ought properly to be made of oak, about 5 inches square, and having an inside diameter of 12 feet, is then sent down in segments (figure 12), and put together on the bottom by the cleats being nailed on to the adjoining piece, and Scotch deals, 1 inch thick, placed vertically behind it to pass down half its thickness, the length of these deals being (say) 9 feet. Another crib is then laid upon the first one, and, after being put together, is raised 3 feet above it, and supported by props, as shewn in plate 37. A third crib may then be laid on the last, and raised in the same manner; and also a fourth, which will be as high as the top of the Scotch deals, or backing deals, as they are called. Each crib must be supported by props placed upon the one beneath. The timber, being now three feet above the surface, will afford height for teeming the clay and rubbish which is got out of the pit, until a foundation is obtained for the walling by which it may be permanently secured. A temporary stage being erected upon the clay and timber, a jack-roll may be set which will be sufficient to draw the rubbish until the top of the white post, No. 3 on the section, is reached. After the first timber described above has been set, the sinking will be recommenced in the bottom, and another fathom of clay may be taken out, the sides of the pit being in a line with the *inside* of the first crib laid. After this has been done, the sides under this crib must be shorn out, and a crib laid on the bottom, as at first; then the backing deals are to be put in behind this last, and the first crib laid, and another crib, rested on props, to be put in between these two last cribs, and then another tier of props to be placed on the last crib, to support the cribs which were first put in.

During the time the clay is shorn out beneath the fourth crib, unless means were used to prevent it, the top length of timber might slip down into the pit; and to prevent this, it is usually hung by deals or battens, nailed on the inside, from the temporary stage abovenamed. This process is continued until the stone head, which in this case will probably be found to be No. 3, is reached. If the clay should not stand very well, although there is little fear of this when the cover is thin, instead of sinking 6 feet each time before putting in more timber, it may be found convenient only to sink 4 feet, before making all secure.

In some instances, however, instead of the surface clay, &c., being so easy to pass through as in the case here described, it is found to occur not only of great thickness, but wet or filled with sandy and incoherent partings, or containing beds of quicksand, or sometimes of soft clay like mud, and then is only sunk through with extreme difficulty, and by using much care.

A case of this kind occurred at Framwellgate Moor colliery, near Durham, where 24 fathoms of alluvial cover, containing beds of quicksand were passed through. Plate 3 shews a detailed section of this deposit, and plate 38 exhibits the plan of proceeding. The diameter of the pit where commenced was about 30 feet, and the upper clay, being dry, was passed through with ordinary timbering: the cribs were put in 6 inches square. Beneath the clay, however, greater difficulties were anticipated, and it was on this account that the pit was commenced of so large a size, with the intention of piling through the sand. Accordingly, when the top of the sand was reached, other two cribs, each 6 inches square, were laid 3 inches inside of the two cribs at the bottom of the clay; and piles of fir, 6 inches × 3 inches in section, were driven between these two courses of cribs as far as their length, or the nature of the sand would permit. After a course of piles had been driven all round the pit, (the piles being bevelled to the circle to allow them to be driven close together,) the sinking inside of the piles was recommenced; and as the sand was drawn from the pit, cribs were laid within the piles about 6 inches from each other until the whole of the sand as far as the bottom of the piles was drawn out. The next process was to lay down two other cribs, 6 inches in diameter less than the last, and to recommence piling, and so continue until the bottom of the sand was attained. The reduction of the size of the pit by each length of piling was thus about 18 inches, and after the stone head was reached and the walling put in, the net diameter of the pit was 14½ feet.

The following account of sinking the Norwood new pit through the "wash" of the river Team, already referred to (page 5), affords a pretty good illustration of the difficulty of passing through such deposits. The pit is 20 yards from the river side:—

September 13, 1851.—Commenced sinking pit, 13 feet 6 inches diameter inside of timber (14 feet 8 inches full size), and went on till 8 o'clock at night, when a 10-feet length of timber was put in, which made 1 fathom below the surface, with 4 feet outset.

September 15.—Went 1 fathom; put in English elm cribs 6 inches × 4 inches in section and 1½ feet apart, with 1-inch Scotch deals set close together round the shaft for backing deals; 4 stringing planks, 6½ inches × 2½ inches, put into the shaft and spiked to the cribs.

September 16 to 23.—Sunk and timbered 1 fathom each day: cribs 5 inches × 4 inches, and 18 inches apart.

September 23.—Sunk and timbered 1½ fathoms.

September 24.—Sunk and timbered 1½ fathoms. Cribs were now put in 11½ inches apart, and the size of the cribs 5 inches × 5 inches.

September 25.—Pit sunk half a fathom, making 10½ fathoms by two o'clock P.M., when, on account of the heavy rain, the waiters-on and sinkers came away. At half-past 4 o'clock, the river having overflowed its banks about 2½ feet, began to find its way into the pit; and at 6 o'clock there were 18 feet of water in the bottom. The sinkers commenced puddling clay round the top of the pit, and drawing the water out, which was reduced to 12 feet by 9 o'clock. They recommenced drawing water at 2 o'clock on Friday morning, when the water had again risen to 18 feet, from having passed through the clay. It was all got out by 8 o'clock in the morning, when sinking recommenced, and 1 fathom of loamy clay, with beds of sand from 1 to 3 inches thick, were passed through.

September 27.—Pit sunk and timbered 1 fathom.

September 29.— Ditto ½ ditto, clay swelling very much.

September 30.— Ditto 1 foot, ditto.

October 1.—Put in other 4 stringing battens, all the way down the shaft: Norway battens, 20 feet × 6½ inches × 2½ inches.

October 2.—Owing to the continued pressure of the clay and sand against the cribs, several of them broke, and at 10 o'clock A.M. the sinkers had to come out of the bottom, when two fathoms broke away between 8 and 10 fathoms down: several of the others being thrust much out of shape, and having every appearance of instantly giving way. At 11 o'clock commenced filling the pit with ashes, and at 5 o'clock P.M. the top of the ashes was 35 feet 8 inches from the surface.

October 3.—Removed clay from the top of the pit, to lighten the pressure.

October 4.—Continued removing clay.

October 6.—Sinkers commenced doubling cribs from the surface: the cribs being now six inches apart: size of cribs, 5 inches × 5 inches.

October 6 to 11.—Do. do. do.

October 11.— Do. do. do., and put two balks across the top of the shaft (as seen in plate 37 *d.*) to suspend the cribs from by 4 double iron chains: balks 45 feet long × 13 inches × 13 inches. These balks were supported at each side of the shaft upon a square pile of sleepers, 9 feet long × 10 inches × 5 inches : the chains being fastened to the cribs with clams made of $\frac{3}{4}$ inch square iron, and with spikes 6 inches long, made of iron $\frac{5}{8}$ths inch square.

October 13.—Commenced at midnight to take out ashes and double the cribs : at 6 fathoms from the surface, cribs put in 4 inches apart : at $6\frac{1}{2}$ fathoms, put in 2 inches apart : clay and ashes got out to $6\frac{1}{2}$ fathoms.

October 14.—Four men busy puddling clay round the pit to keep out the tide : clay and ashes got out to the depth of 7 fathoms, 3 feet, 8 inches.

October 15.—Put in cribs 6 inches × 6 inches, 1 inch apart : sinkers continuing to take out ashes : found the old cribs squeezed to within 18 inches of each other : clay and ashes taken out to the depth of 8 fathoms ; also clay puddled round top of shaft.

October 16.—Clay again began to spunge out at the sides of the pit as the sinkers cut it out : this continued all day.

October 17.—Clay and ashes got out to the depth of 9 fathoms.

October 18.—Clay and ashes got out to the bottom of the broken cribs, at 10 fathoms : Norway battens nailed round the pit, and commenced, as the cribs above began to give signs of weakness, at 20 feet from the surface, to put in another course of cribs inside of the battens : these cribs were put in 6 inches × 6 inches of oak, and 2 feet 7 inches apart, and at the bottom, three inside cribs were put in, thus diminishing the size of the pit inside the timber to 12 feet, at which size sinking was continued.

October 19.—Finished putting in cribs at 8 o'clock A.M., putting in 5 cribs and one length of battens.

October 20.—Put in 7 more inside cribs, inside of the battens up the shaft, and hung other 4 chains, 16 fathoms long to suspend the cribs by.

October 21.—Put in cribs close together : clay and ashes got out to the depth of 10 fathoms 1 foot. At this point the clay swelled so much that it was impossible to make ready for a length of timber with backing deals, however short (the last length or two had been 18 inches) ; and on

October 22, the bottom of the pit was higher up than it was 12 hours previously, notwithstanding that the sinkers were sending out clay as fast as possible. It was therefore resolved merely to cut out the clay beneath the last length, at the sides of the pit first, and put in the crib in pieces without either cleats or backing deals, taking the clay out of the middle of the pit afterwards ; surface settling down considerably ; clay and ashes got out to 10 fathoms 3 feet.

October 23.—Clay and ashes got out to 11 fathoms.

October 24.—Clay and ashes got out to $11\frac{1}{2}$ fathoms.

October 25.—Clay and ashes all out, and pit bottomed at 12 fathoms at 6 o'clock A.M. ; pit sunk 3 feet ; cribs put in, 6 inches × 6 inches, close together.

October 26.—Pit sunk 4 feet 10 inches ; cribs put in close.

October 27.—Pit down to $13\frac{1}{2}$ fathoms ; got a blower of fire-damp in the clay, which filled a Davy lamp with flame 8 feet up the pit.

October 28.—Pit down to $14\frac{1}{2}$ fathoms.

October 29.—Pit down to 14 fathoms 5 feet 8 inches, in sand and gravel, with water.

October 30.—Pit down to 15 fathoms 3 feet, sand, running a little.

October 31.—Pit down to 16 fathoms 2 feet, in sand and gravel.

November 1.—At 9 A.M., got into soft blue metal at 17 fathoms.

These cases, though an exception to those generally met with, sometimes occur in flat districts, through which rivers pass. After reaching the stone head, no time should be lost in getting the shaft secured either by walling or metal tubbing, if the strata yield water ; for, by the continued pressure against the back of the timbering, it begins to shew weakness ere long, and when this is the case, and the cribs begin to twist and break, the chances of losing the pit amount almost to certainty. In fact, in nearly all cases of the closing of a pit in course of being put through such a deposit, it is preferable to remove the position of the sinking altogether, 50 or 100 yards away, when this can be done, and commence anew from the surface with double or treble strength of timber, rather than to open out the closed pit, as in many instances it will be found that the latter method, even when successful, will be attended with more expense.

The actual cost of ordinary timbering through clay for a pit which, when finished, was 14 feet 9 inches in diameter, was as follows (1840):—

	£	s.	d.
Backing deals, 52 feet 8 inches to a circle = 316 feet to a fathom, @ 14s. per hundred feet	2	4	2
Cribs, 5½ inches square, of Hambro' oak, took 15 feet to a circle, which includes all waste, and 15 feet at 3s. 6d. × 2 ... ... =	5	5	0
Lath deals, 14 to a circle, 6 inches × 1 inch, Scotch fir, = 42 superficial feet per fathom, at 2½d. ... ... =	0	8	9
Punch props	0	0	10
Workmanship, preparing backing deals	0	5	0
Sawing and making cribs, 10s. each, including nails, cleats, &c.	1	0	0
Total cost per fathom	£9	3	9

After having sunk through and timbered the clay and broken metal, and brought in the diameter of the pit on entering the white post to its net size of 11 feet, sinking may be continued for a few feet into it, when at the first sound stone the wall sides must be shorn back, until the diameter of the pit is 13 feet, the bed upon which the walling is intended to rest being accurately levelled. A large crib, which may be of metal (*see* plate 37*f*) or oak, is then laid upon some half-inch fir sheathing placed upon this bed, and a packing of fir is put in between the back of the crib and the pit wall, and some thin oak sheathing between the joints, this sheathing being tapered to suit the circle of the pit. The packing is then wedged until no more wedges can be driven in, after which the walling is to be commenced.

In putting in walling a cradle is required, which is a circular stage, about six inches less in diameter than the net size of the pit: it may be made of two battens, covered across with boards 1¼ inch in thickness: towards the end of each batten, a bolt with a nut at the bottom and a ring at the top passes through, by which the cradle is attached to the two cradle ropes, which are 6 inches in circumference, and may be attached for convenience to two winches, one set at each side of the pit. Afterwards, the suspension of the cradle may either be conducted in the same manner, or by a single rope and crab.

Shafts may either be walled with ashlar stone or brick. The stones should be dressed true to the circle, both on the face, beds, and joints; they should be free from all imperfections; they ought not to be less than 9 inches in the bed and 8 inches at the joint, and must be well set in good lime. In putting in this walling, the timber ought to be carefully taken out, and behind the walling the spaces should be filled and firmly beaten up with clay.

The following was the cost of walling in the pit referred to last page :—

		£	s.	d.	£	s.	d.
278 Superficial feet of freestone per fathom: stones 9 inches in bed and not less than 8 inches at joint; price delivered, 7d. per superficial foot, in pit					8	2	2
Dressing at 3d. per running foot, and assuming 8 courses to the fathom					4	15	8
Settting :—							
1 Charge man, ... 3 shifts (8 hours) @ 3s. 8d.	=	0	11	0			
3 Sinkers, ... 3 do. (do.) @ 3s. 6d.	=	1	11	6			
2 Waiters-on ... 2 do. (12 hours) @ 3s.	=	0	12	0			
2 Masons at bottom, 3 do. (8 hours) @ 4s.	=	1	4	0			
1 do. at bank, 3 do. (do.) @ 3s. 8d.	=	0	11	0			
1 Gin driver, ... 2 do. (12 hours) @ 1s. 6d.	=	0	3	0			
Candles at night, 2lbs. ... ... @ 7d.	=	0	1	2			
		£4	13	8			
9 Feet of walling were put in for the above = per fathom					3	2	5
Total cost per fathom					£15	17	3

During the time in which the walling is being put in, a horse gin (Plate 39 figure 1) or preferably a small steam engine, which, on account of its future application to underground haulage, may be 20 horses power, and similar to the drum engine hereafter described, must be put up for the purpose of drawing the stones and water, until the permanent machinery can be got ready: and at the same time, the engine houses should be set out and proceeded with, with all dispatch.

The pulley frames and shearlegs (Plate 39 figure 2) may now also be erected, the height of the pulley frames to be 60 feet, and the shearlegs 72 feet. The pulley frames should be made of good clean Memel, 14 inches square, and the shearlegs also of similar size, with two fish pieces on each leg 40 feet long, 6 inches thick at the bottom, and 3 inches at the top, and 13 inches broad, the whole being bolted together with 1 inch round bolts, passing through both fish pieces and legs.

Previous to the application of the heavy machinery, the water is drawn by the small engine before alluded to, in iron tubs of the capacity of 100 gallons each: if a gin only is used, the tubs must of course be of smaller size, say 30 gallons. These tubs are of rather peculiar construction (Plate 36 figure 13): they are in the form of a barrel, the bow by which they are hooked passing down to a point on the outside rather more than half-way down, where the axle is fastened to the tub, the correct principle being to have the centre of gravity of the tub when full of water a little above, and of the empty tub a little below, the axis on which it is turned: there is also another less bow to each tub which passes freely beneath the bow first mentioned, and is fastened to the top of the tub. At one side of the tub adjoining the moveable bow, is a spring catch, which when the tub is travelling in the shaft either full or empty, attaches the tub to the bow, but which, on being pressed back by the waiter-on at the surface, allows him, by means of the fixed bow, to pull over the tub and empty it into a cistern, from the bottom of which the water is conducted away by a pipe or box : after emptying it, he pushes it back, when the catch springing into its place, secures the tub in a vertical position, in which state it is again sent down the shaft to be re-filled.

As the sinking progresses, the water will in all probability be found to increase in stratum No. 3, and as the boring indicates a large increase at stratum No. 6, it will be well to stop back by metal tubbing all the water that we possibly can as we descend ; and since in stratum No. 4 we shall most likely meet with a good foundation, we may put into the shaft a column of tubbing to reach up as far as the wedging crib underneath the walling already described.

A few feet beneath this crib, the pit is laid out to the necessary size for metal tubbing, viz., 12 feet, and is continued of this size to the bottom of the white post: it is then to be brought in to the net size of 11 feet, or better, about 4 inches less, and sunk that size in the grey metal, particular care being taken not to injure the shaft by the improper use of gunpowder. A good bed having been obtained, the pit is continued about 6 feet further to allow the tub to dip and fill itself, and then a scaffold being laid, the wall must be carefully shorn back with hacks, so as to cut out a level bed for the crib: the full diameter on the crib bed may be 13 feet 6 inches, which allows 13 feet for the crib, which is to be 12 inches in the bed, 6 inches high, and closed at both front and back.

The following is a very particular account of the cost of putting in a wedging crib in magnesian limestone, in the year 1841 :—

This wedging crib lies at the depth of 51 fathoms from the top of the present outset, which is 8 feet 3 inches above the surface. Commenced at 50 fathoms to reduce the pit gradually from 16 feet 3 inches to 14 feet 4 inches, and then sunk down 4½ feet below the most likely point for the crib bed, so that the water tubs might dip themselves: the water was eighteen 150-gallon tubs per hour ; after the tubbing was wedged, the water was half a tub per hour.

A scaffold was then laid, and the pit walls shorn down till the crib bed was reached. The principal point to be attended to is to have the back sound and good, and if this be the case there is no fear of carrying the water. After getting the crib bed properly levelled, laying the crib was commenced: the crib consisted of 10 segments, 14 inches in the bed at the under side and 13¾ inches in the bed at the upper side, having a hang of a quarter of an inch, to prevent the crib from rising during the wedging: there was also a prop or stay placed upon each joint for the same purpose. Each segment had two holes in it at the under side for letting out the air in casting: the height of the crib was 6½ inches, close at front and back, and the thickness of metal was 1¼ inch. English oak sheathing, tapered from 1⅛ to three-quarters of an inch, was put in between the joints, and some American fir sheathing, half an inch thick, was laid upon the crib bed for the crib to rest on : there are

2 inches of packing between crib and wall. The diameter of the crib as laid down was 14 feet 11 inches, and after being wedged, 14 feet 9½ inches: it took 7 courses of 6-inch wedges, 5 courses of 4-inch wedges, 1 tier of spiling (half wedges), and 1 course of iron wedges.

The expense of forming the crib bed and wedging the crib, including the cost of the crib, wedges, &c., was as follows:—

	£	s.	d.
Shearing down the bed, including all expense of sinkers (9 men in the bottom), waiters-on, and hack carriers: took 122 hours, stone very hard	32	2	6
Laying crib, putting in packing, and making ready for wedging	2	6	6
Wedging: 10 men in a shift, including waiters-on and hack carriers (35 hours)	10	4	11
Packing: Memel 2 inches broad × 6½ inches high = 28 feet of 2-inch plank, @ 5d. ℔ foot	0	11	8
3,030 6-inch wedges, 2,160 4-inch wedges, and 490 spiles = 70 feet Memel plank, @ 7½d. per foot	2	3	9
Making wedges, 5,435 @ 7d. per hundred	1	11	8
290 Iron wedges (laid angleways) = 36lb. @ 1¼d.	0	3	9
Bottom sheathing for crib to rest on = 63 superficial feet of American fir, @ 1½d. ℔ foot	0	7	10
Joint sheathing of English oak, took 10 pieces = 1 foot	0	4	6
Should the crib approach to its net size sooner than expected, an iron wedge is driven into the joint sheathing.			
Crib: 10 segments, each weighing 7c. 1q. 17lb. = 74c. 0q. 2lb. @ 6s. 9d. ...	24	19	7
Laying out for tubbing size below the crib, and cleaning out bottom for contractor to commence sinking	11	19	7
Entire cost	£86	16	3

After the wedging crib has been wedged until it is no further practicable to drive in any more wedges, the setting of the tubbing is commenced with as follows:—

In the case of the 11 feet pit, the sinking of which we are now describing, the wedging crib not being more than 15 or 16 fathoms from the surface, it will not be necessary to have the tubbing more than half an inch in thickness, and the height of the segments may be 24 inches. (Plate 39, figure 3.)

All the tubbing before being put in should be well tested by punching at all its edges to ascertain that the metal is sound and free from honeycomb. Fir sheathing in the first place is laid upon the wedging crib, the thickness of the sheathing being half an inch, and its breadth 4½ inches, and a course of tubbing set upon it round the pit: pieces of wood, or plank ends are then put behind the joints of the segments, and fir sheathing between the joints, that behind the joints being composed of what are termed baff-ends, which are pieces of wood about an inch thick, and spares, which are baff-ends roughly sharpened at one end, by means of which, driven in between the baff-ends, the tubbing is secured firmly in its place. Upon this first course sheathing is again laid, another course of tubbing set upon it, and in this manner, backing up the empty space behind with soil, &c., the whole is proceeded with up to the stone which was left under the wedging crib where the walling was put in. This stone is then taken out, of size sufficient for the tubbing, which still leaves sufficient support for the crib, and the whole of the tubbing having now been put in, care being taken all the way up to equally break the joints, the wedging is commenced. Putting in the tubbing and wedging the same is all performed with the cradle.

The following account shows the cost of putting in a fathom of metal tubbing in the same pit as the wedging crib already alluded to:—

	£	s.	d.	£	s.	d.
This tubbing consisting of 10 segments to a circle, each weighing 4c. 1q. 12lb., and being 18 inches high, there were 4 courses to the fathom = 171c. 1q. 20lb. @ 6s. 9d. per cwt.				57	17	1
Painting tubbing, two coats on fore side = 31 yards @ 6d.				0	15	6
264 pieces of bottom sheathing, and 80 pieces of end sheathing ½ inch thick = 96½ superficial feet of American fir @ 1½d.				0	12	0
Workmanship, making sheathing				0	1	6
3 spares and 2 baff ends to each segment, = 240 square feet of 1 inch Scotch fir, @ 14s. ℔ hundred feet				1	13	7
(Baff ends 1½ feet long, spares 6 inches to 8 inches, sharpened at side next wall, and each 6 inches broad.)						
Making spares and sawing off baff ends				0	7	0
Laying tubbing ready for contractors				0	2	6
Backing with soil, limestone marl, &c.				0	4	0
Wedges: took 3 wedges to an inch, or 8,856 wedges ℔ fathom = 80 feet of Memel plank, @ 7½d.				2	10	0
Making 8,856 wedges, @ 5d. ℔ hundred				1	16	11
(These wedges were 4½ inches long, 1½ inches broad at top, and ½ inch thick.)						
Putting in and wedging tubbing:						
1. Putting in.	£	s.	d.			
4 men in bottom, viz., 1 chargeman and 3 sinkers, and 3 men at bank for bringing the tubbing to the pit, also soil, &c., from where the same was laid, being in as convenient a place as possible. The contractors paid the foregoing 6 men, 2s. ℔ shift of 4 hours, who put in 3 courses in 4 hours, or 1 fathom in 5·4 hours. The contract price was, ℔ fathom	1	1	8			
2. Wedging.						
11 men in bottom, viz., 1 chargeman and 10 sinkers: the tubbing was wedged twice in going up, and a third time in going down again, until in fact it was perfectly tight; it took one man constantly to send away the water tub through the hole in the cradle. The third course of wedging is angled, so as both to lift and thrust. The above men wedged $2\frac{1}{5}$th courses thrice in four hours, or 1 fathom in $7\frac{1}{8}$th hours, so that it took 12½ hours to put in and wedge 1 fathom of this metal tubbing. The contract price was	2	3	4			
				3	5	0
				£69	5	1
Deduct ½ inch sheathing for 4 courses = 2 inches, or 1-36th part of cost of metal ℔ 6 feet				1	12	2
Cost of one fathom				£67	12	11

The following description of different varieties of tubbing which have been adopted in the North of England previous to the application of that of metal, is extracted from Mr. Dunn's Treatise on the Winning and Working of Collieries :—

1. Plank Tubbing was used in the sinking of Hebburn and other deep collieries about the year 1790. It was constructed as follows:—The shaft was first widened for the length of the intended tub, if not already anticipated in the sinking. The ledge upon which the two foundation wedging cribs were intended to rest, and upon which the tub was to be built, was first levelled and polished with great care, its surface also being covered with flannel and white lead, or some other such substance. This preparation being ready, the first wedging cribs were laid, consisting of the best oak cut into segments, and 8 or 9 inches broad, each joint being lined with thin deal placed endways for the purpose of wedging. The cribs were then wedged throughout every joint, as well as between them, and also the space between the cribs and the rock, the whole being wedged with wood so long as a chisel would enter. Next followed the ordinary spiking cribs of similar dimensions, adjusted by a centre line to the same range, being of similar lengths, but not so broad, and placed at intervals of from 18 to 30 inches, according to the expected pressure. These cribs were wedged sufficiently to sustain them firmly in their places to abide the spiking which was to attach them to the planking which constituted the tubs, and which usually consisted of 2½ or 3 inch deals applied in lengths of 10 or 12 feet, being first well planed and the joints bevilled to the circle of the shaft, after which they were fastened to the cribs by iron spikes.

2. Crib or Solid Tubbing. The labour in constructing, and the difficulty of ensuring tightness in the plank tubbing, led to the introduction of solid wood tubbing, which possessed the advantage of having neither planks nor spikes, and therefore, when once tight and of sufficient strength, no incident could arise to produce leakage, whilst at the same time it presented a smooth circular surface for the general purposes of coal drawing.

The foundation of the wedging cribs is prepared in the same manner as that above described : this is then succeeded by segments of wood 6 or 8 inches square, of elm or oak, prepared in indefinite lengths, and retaining between each joint, whether horizontal or vertical, a lining of endways slit deal. These courses so prepared are built or walled upon each other, and carefully adjusted to the centre of the shaft by a hanging line. As the building proceeds upwards, the space between each crib and the rock is carefully packed with small coal or other soft material, so as to maintain the cribs steadily in their position. The building finished, it is surmounted by the ordinary stone walling before described, and the successive wedgings take place in the sheathing so long as any leakage appears, the wedges used for this purpose being clean fir, well seasoned, an iron chisel being used to perforate the wood, and the better to introduce the wedges. In case of faulty cribs giving way by severe wedging, they are cut out and replaced by sound ones.

The wedging completed and the roughness adzed off, the shaft so constructed forms a perfect cylinder ; and it is not uncommon to see a tub of this description sustain a pressure of 50 fathoms of water, or 130lb. to the square inch.

This tubbing is incomparably more safe and durable than the plank tubbing, especially in collieries where the water is corrosive.

It frequently happens that a detached piece of tubbing requires to be inserted into a portion of the shaft apart from the walling, in which case the shaft is widened to the required length, and the top and bottom are squared and levelled for the reception of the two wedging cribs.

In Belgium and in the north of France, the tubbing (cuvelage) is constructed of pieces of oak, which are formed so as that when piled up they may form a polygonal shaft of 10, 12, or15 sides, according to the diameter of the pit. The vertical height of each course varies from 9·84 to 19·68 inches, depending upon the size of the trees from which it is taken: as regards the thickness, it ought to vary with the pressure of the water, and consequently with the depth where the crib is placed. The rule followed in the Department of Nord, and founded on experience, is as follows :—

From	0·	fathoms	to 8·20	fathoms of depth	4·334 inches.
„	8·20	„	to 16·40	.... „	4·724 „
„	16·40	„	to 21·87	.... „	5·118 „
„	21·87	„	to 27·34	.... „	5·512 „
„	27·34	„	to 32·81	.... „	5·905 „
„	32·81	„	to 38·28	.... „	6·299 „

(Combes' Traité de l'exploitation.)

In estimating the thickness of metal tubbing, in segments 2 feet high, required to resist any pressure of water, it is necessary to take into consideration the diameter of the pit, and the vertical depth of the water pressing against the tubbing. The following formula gives results which may in practice be safely relied upon :—

Let x = the required thickness in feet;
P = the pressure or vertical depth, in feet;
D = the diameter of the pit, also in feet;

$$\text{Then } x = \cdot 03 + \frac{P \times D}{50{,}000.}$$

Whence for various sized pits we have at different depths the thicknesses as under :—

Depths.	10 feet Diameter.	11 feet Diameter.	12 feet Diameter.	13 feet Diameter.	14 feet Diameter.	15 feet Diameter.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
10 fathoms	·504	·518	·532	·547	·561	·576
20 „	·648	·676	·705	·734	·763	·792
30 „	·792	·835	·878	·921	·964	1·008
40 „	·936	·993	1·051	1·108	1·166	1·224
50 „	1·080	1·152	1·224	1·296	1·368	1·440
60 „	1·224	1·310	1·396	1·483	1·570	1·656

It is necessary in upcast shafts, where mines are ventilated by a furnace, to guard the metal tubbing against the destruction occasioned by the sulphurous acid produced during the combustion of the coal, which, being absorbed by the moisture of the shaft, and trickling down the tubbing, corrodes it in a most remarkable manner—almost entirely, in fact, separating the iron from the carbon, and rendering the metal so soft that it may easily be cut with a knife. The trouble and expense occasioned by this circumstance are often very great, and serious accidents might possibly be the result; for supposing a segment of tubbing to be so weakened as no longer to be able to withstand the pressure, we have in the first place the probability of a large quantity of water being sent down the pit before the faulty segment can be replaced, and in the second, of the ventilating currents being reversed, whereby the foul air of the goaves may be forced back into districts working with unprotected lights.

Two methods may be adopted in order to preserve metal tubbing: either a lining of wood or of brick may be placed next to it:—if of wood, it may consist of deals, 2 inches thick, properly bevilled to the sweep of the pit, and by means of wooden treenails, fastened to the tubbing, by being driven into auger holes in the plugs: if of brick, the bricks should be made of such a size and shape as to suit the diameter of the pit, and may be built upon the wedging cribs, the latter, where the tubbing is put in, being made 4 inches deeper in the bed, and the diameter inside of the tubbing being made 8 inches greater than the finished size of the pit, so that the net diameter of the pit may be 11 feet, as required within the brickwork.

It has been found necessary in many instances, in close-topped tubbing, to put a pipe into one of the segments, which is either allowed to remain open and run as much water as it will, which may be conveyed to the pumps or standage, or else the pipe is continued up the shaft as far as the level of the water behind the tubbing: the consequence of this not having been done, has often been the bursting of the tubbing, a similar result having also followed the closing up of such pipe. Perhaps the principle of the hydraulic ram may in some degree explain this, as the sudden closing of the tubbing or pipe at once throws the pressure which is due to the column of water upon the tubbing, with a certain velocity proportioned to the velocity of issue and the quantity allowed to escape through the pipe. That some such cause as this is the correct one, is apparent from the fact that when the water is outset to its level by a pipe, and the pressure is laid gradually on the tubbing, as is observed by the water in the pipe gradually rising, no fracture or displacement of the tubbing takes place, notwithstanding that there is evidently (after the water has risen to its level) the same pressure on the front of the plug-hole, and opposed to that behind the tub, as if the plug-hole were closed by a plug. It is the opinion generally received that the gas contained in the strata is the cause of this, and that unless it is allowed vent it must have the effect of bursting the tubbing; but it is clear that since the tension of the gas must be exactly equal to the pressure of the water under which it is generated, it cannot exert any greater pressure upon the tubbing than the water itself. It must be admitted, however, that the subject requires investigation, and as the insertion of the pipe has been founded on experience, it ought not to be neglected.

In the case of several wedging cribs and separate pillars of tubbing, pipes have been taken from the top course of the under to the bottom course of the upper column throughout the whole; and although it is evident that the effect of this is to throw the pressure of the water behind the highest tubbing upon the lowest, yet when we consider that in all probability, through lapse of time, the mean level of the whole will be the same, this is not productive ultimately of any undue pressure upon the tubbing.

It is probable, by the time the depth of 15 or 20 fathoms has been reached, that the ventilation will be faulty, and it will be therefore proper to adopt some artificial means of causing a circulation of air. An old method of effecting this consisted in having a box or spout 6 inches square internally to pass down the shaft, there being near the bottom another short spout at right angles to it: by pouring water down the inside of the spout, a certain quantity of air was carried down with it, which passed out of the short box, airing the bottom of the pit. This method was of course objectionable on two grounds—the first being that it was inefficient, and the next that it occasioned an addition to the quantity of water to be drawn to the surface.

Another plan consisted in having a box—say 12 inches square—made of half-inch deals, placed in the shaft, the ventilation through it being caused by a caphead at the surface, which, being moveable upon a pivot, was by means of a vane kept always facing the wind.

In ordinary cases, however, especially when the pit is required to be of some considerable depth, a brattice, which consists of a wooden partition, is usually put into the shaft, which, in consequence of the ample room which it affords to the descending and ascending currents, produces the desired effect. There is no reason why, under such circumstances, there ought to be a constant and uniform current of air in one direction; and it usually happens that extraneous circumstances, such, for instance, as change of wind, prevent any uniformity in the direction of a ventilation of this nature. All that is needed, however, is a tolerable circulation of air.

In the present case—viz., that of a pit 11 feet in diameter—the brattice put in will only be a temporary one, to answer the purpose of ventilation during the sinking, and also during the period of making a communication between it and any other shaft or shafts by which the ventilation is ultimately intended to be carried on. A brattice of this description may be constructed in the following manner:—

Norway battens, for side planks or stringing planks, are taken of any length, 7 inches broad and 2½ inches thick: they have, at intervals of 3 feet, places prepared on one side to receive the ends of other battens which traverse the pit, and are called buntons. The stringing planks having been spiked down the opposite sides of the shaft, and the buntons put in their places, Scotch or larch deals, 1 inch in thickness, and previously planed at the joints, are nailed securely upon the buntons so as to make an air-tight division. For a more permanent brattice, either one or the other of the two following may be adopted:—

1. The bunton brattice, which resembles that just described, put in more substantially.

In this case, the stringing should consist of 3-inch planks: the buntons the same, and the upright planks for the brattice should be 2 inches in thickness, properly slivered with oak.

2. The plank brattice is, however, the best: it consists of 3-inch Memel planks, planed smooth at the edges, and built edgeways up, plank upon plank, being retained in their places by 4 stringing planks—viz., two at each end of the brattice planking, one of them being at each side of the brattice: the brattice planks are kept secure, either by iron dowells or oak slivers. The following was the cost in 1840 of putting in the main brattice at the same pit already alluded to:—

	£	s.	d.
1. 7 planks to a fathom, 11 inches × 3 inches × 14 feet 8 inches, @ 7·3d. ℔ foot ...	3	2	5
2. 21 dowells to a fathom, 6 inches long of ¾-inch round iron = 16·8lb., @ 2d. ℔ lb., including workmanship	0	2	10
3. Stringing consists of 2 three-inch Memel planks on each side, 7 inches broad = 24 feet ℔ fathom, at 4¾d.	0	9	6
Fitting up stringing	0	1	0
4. Planing planks, boring dowell holes, jointing one end of planks (the other being left for the sinkers to saw off), per fathom	0	3	0
5. Spikes for attaching stringing to pit wall, 10 inches long, 3 feet off each other; or 8 ℔ fathom = 15·2lb. @ 2½d. ℔ lb.	0	3	2
6. Putting in brattice: 1 chargeman and 2 sinkers in bottom, and 2 men at bank for bringing planks to pit in each 4 hours shift. Contract price	0	7	6
Cost per fathom	£4	9	5

Where tubbing is put in with the intention of putting in a plank brattice, it is cast with grooves for the purpose of receiving the planks, thus saving the stringing.

The brattice may be put in to within about 4 fathoms of the bottom of the pit: if it is taken lower down, it will be damaged by the shots. It is also necessary to put diagonally a few deals from the bottom of the brattice to the wall side, in order to prevent the corves or tubs from coming in contact with the bottom of the brattice as they are drawn up the shaft.

The sinking may now be resumed in the grey metal No. 4, in which, as we expect much water in No. 6, the diameter must be kept sufficient to allow more tubbing to be put in. On reaching the soft blue metal, we may probably find it necessary to put in some timber; and Nos. 4 and 5 being thus passed through, we reach No. 6, which, according to our boring, is a white post, with much water.

In this stratum the pit is still continued full size for tubbing, and sunk as far as the quantity of water will permit. With the means laid down, it might be possible to contend with 50 or 60 gallons a minute; but if the water should exceed this greatly, more powerful means must be applied.

These means may either consist of a pumping engine, or of a winding engine, also adapted for pumping, or of both.

I.—The Pumping Engine.—Pumping engines are constructed of various forms, but from the mass may be selected the three following, viz.:—(1) The Cornish or Ram Engine;

(plates 40 and 41); (2) the Beam or Lifting Engine, also applied as a forcing engine (plates 42 and 43); (3) the Lever or Crank Engine, applied in the same manner as No. 2 (plates 44, 45, 46, 47, 48, and 49).

1. The Cornish Engine acts by forcing the water up the pipes by means of a ram, the spears effecting this by their extraordinary weight, the entire duty of the engine being to raise the spears again after each desent. This engine has thus the great merit of being independent of any auxiliary staples, and of the application of the balance-weight, through the medium of which, in fact, it works, to the strengthening of that most important part of the machinery—namely, the spears. The application of the steam is somewhat peculiar: it is only admitted above the piston, the steam valve and the exhaustion valve at the bottom of the cylinder being opened together—these engines being usually worked expansively with the steam shut off at about one-sixth or one-seventh stroke. After the piston has made its full stroke, the exhaustion valve is closed, and another valve, placed in a communication between the upper and lower parts of the cylinder, is opened, which equalizes the pressure upon each side of the piston, and allows the spears to descend again into the shaft, forcing up the water as before described. Engines for pumping upon the Cornish plan are not used in the north of England; at Walbottle and Harton collieries are combinations of the ram or plunger, and bucket methods of pumping, but the engines are of similar construction to those next described.

2. The most common form of engine, erected exclusively for pumping in the northern coal mining district, is the ordinary Beam Engine, which is applied in many different ways. In very deep winnings, the manner of applying the engine is represented in plate 42, in which care is required so to arrange the sets of pumps that the engine, whether in ascending or descending, shall have the same amount of work to perform. It is evident, however, that from the variety of movements made by the vertical and diagonal spears, this method of pumping cannot be considered as perfect. For moderate depths, the best plan probably is to have a staple sunk in the engine-house, and the high set of pumps placed in it, attached either to the main beam within, or prolonged over the cylinder, or to a lever beam between the cylinder and back wall of the engine-house.

3. The third form of engine which I shall mention is the Crank or Rotatory Engine. This is well adapted for moderate depths and large quantities of water, but whether equally so when the depth is considerable, a little more experience will be necessary in order to determine, as the strain on the main shaft becomes a somewhat serious matter. There is a great advantage in having a fly wheel attached to a pumping apparatus, as by means of it the column of water is raised vertically in an increasing ratio of speed from nil to its maximum, and again in a diminishing ratio from its maximum speed to nil; the relative speeds exactly suiting the changes from the down to the up stroke in the pumps, and *vice versa*. In the case of all direct lifting engines, the inertia of the column is not, as in the case of the crank engine, overcome gradually, but all at once, thus evidently incurring, under the same strength

of materials, a much greater liability to rupture with the former than with the latter. This engine is also capable of double adaptation to both pumping and coal drawing, as shewn in the plates.

If an engine to work on the Cornish principle, or to pump with a combination of forcing and lifting sets, be erected, no staples will be required; but for a winning of the depth of 75 fathoms, if any of the other engines be determined on, it will be necessary to have a staple for the high set, to be sunk as far as No. 4, in its proper position according to the description of engine applied. It will probably be found advantageous, under the circumstances of the present case, to work with the sinking set of pumps attached to the end of the beam next to the pit, the other end of the beam being weighted to balance the engine, until the white post (No. 6) is passed through, a wedging crib laid in No. 7, and the metal tubbing placed in the pit up to the pillar of tubbing first put in, and wedged completely tight.

The sinking with pumps is conducted as follows :—The lowest pump or windbore, called also the snore-hole piece (plate 50, figure 1), being placed at the bottom of the pit, immediately beneath the end of the beam, and the rest of the pumps, viz., the clack-piece (plate 50, figure 2), the working barrel, bucket door piece, common pumps (plate 51, figures 1, 2, and 3), and hogger pump (plate 52, figure 1), being placed vertically upon each other in this order by means of the crabs (plate 53), and temporarily steadied in the shaft, are collared to what are termed ground-spears (plate 52, figure 2), one on each side of the set, by means of iron collarings or hoops. At the top of each of these ground-spears is one of a pair of 5 or 7-fold blocks called ground blocks, the others being placed on buntons at the top of the pit. Through these blocks a pair of ropes are rove, the surface end of each being taken to a ground crab, which is of similar construction to the main or tail crab (plate 53). These ropes, which are called ground ropes, may be 7 inches in circumference. After the set is properly placed, the spears (plate 52, figure 2) are put in by the crabs, and attached to the engine. The clack (plate 52, figures 4 and 6) is then put in its place: the bucket is in the next place attached by means of the bucket sword (plate 52, figure 5) to the bottom rod of the spears (plate 52, figure 3) and the clack and bucket doors being screwed to their places, the engine may be set to work. If at any time the water should overpower the engine and rise above the bucket door, the bucket, when it requires changing, may, by means of the spears, be drawn up through the set, which ought to be consequently an inch larger in diameter than the working barrel; but in order to change the clack, which also requires to be drawn to the top of the set, it is necessary to introduce the fish-head (plate 52, figure 7) attached to the bottom of the spears, the spring catches *a, a,* of which raise the clack by its bow, *b, b,* when passed through it and drawn up again.

At the bottom of the windbore are what are termed handholes, *a, a,* above which are three or four tiers of holes, the upper tier or two of which must be plugged up when the men are in the bottom, so that the water may not be too deep, but at the same time it must be borne in mind that sufficient waterway must be allowed, otherwise the engine will be what is termed wire-drawn, and will not have the space between the bucket and clack kept solid, which will occasion the weight upon the descending spears to be increased to such a degree as, in all probability, either to break them or damage the engine. Care must also be taken to prevent any chips or pieces of wood from getting to the snoreholes, as if they pass through they may get into the clack-falls, and stop the engine from pumping. The engine should not be driven harder than is just necessary to keep down the water, otherwise it will be what is termed "working on air," and, for a similar reason to that given above, liable to injury. As the sinking progresses, the pumps are lowered by the ground crabs; and when the hogger pump is nearly down to the surface (or delivery drift), it is taken off by means of the main crab, and lifted over the top of the spear, which, to facilitate its detachment, is clammed to the front of a piece of wood termed a Y, which, instead of the spear itself, is attached to the engine beam. Another common pump is then put upon the column, and the hogger pump replaced over all.

After the tubbing has been placed in the shaft and the brattice continued down, the sinking may be recommenced and continued down to the depth of 36 or 37 fathoms: the pumps may be lowered in case of need, but in all probability they will not be required. A drift must then be driven out of the pit to a point under the staple, and from the bottom of the staple a borehole must be put down upon the drift, to prevent the necessity of drawing any water in the staple during its sinking. The staple after being sunk must be secured with walling, and the water stopped by tubbing, in the same manner as the pit. The diameter of the staple may be 6 feet.

After the staple has been finished down to (say) 10 or 12 feet below the drift, the high or permanent upper set of pumps may be placed in it and attached to the engine, and the whole of the pumps, excepting a few of the lower ones, which will shortly be required, may be taken out of the pit.

The remainder of the sinking is then completed, the sinking set of pumps being continued down as before, but delivering the water into the drift to the staple, instead of at the surface. If any soft description of shale be met with, it must be secured either with timber or walling, in either case the pit requiring to be laid out or increased in size. If it be secured with timber, an increase of 18 inches in diameter will be required, in which case a lining of timber, similar to that described above, may be put in, with the exception that the backing deals should be of larch, and the inside diameter of the cribs 11 feet 4 inches, so as to admit of the pit being finished with a lining of 2-inch plank spiked to the inside of the cribs.

The best plan, however, is to secure the shaft by putting in stone or brick walling, because the timber will in the course of a few years decay, and the comparative cost of the two is not widely different. If the stone is very bad it will be necessary to secure the stone in sinking through it, and for this the timber used in sinking through the clay, will do very well.

In all probability there will not be much difficulty in reaching the coal: in No. 10

(see section) some water will be met with, but it will not be advisable to tub it back, as if this is done it will find its way through joints of the strata down into the seam, and be found much more troublesome there than in the shaft; besides, it would be sure to pass into the workings when the pillars were worked, and would be to pump eventually.

The water met with here should therefore be collected by a ring crib, which may be made of wood or metal. This is similar to a wedging crib, but is open like a spout on the upper side, from which the water is boxed down the shaft into the sump by means of deal boxes, called waste boxes.

During the sinking of the pit with the pumping engine, the erection of the winding engine, of which plates 44 to 49 inclusive present suitable forms, must be proceeded with.

Instead of permanently drawing the water with pumps when the feeders are trifling and the depths great, it is unquestionably most advantageous and economical to draw the water by means of the winding engine and water tubs, and to dispense with pumping apparatus altogether. For this purpose the tubs may be made of similar size to the cages which traverse the shaft, closed at the sides and bottom, and fitted up with grooves to work in the guides. They should also be constructed with a valve at the bottom, which opens as the tub descends into the water, and which, by means of a catch placed at the surface, is again opened and the water delivered, previous to the tub being again sent down the shaft. A feeder of watei of 50 gallons per minute, at the depth of 200 fathoms, which would require the constant action of an engine with an 8-inch working barrel and 6-feet stroke, at 4 strokes per minute, could be drawn after two days' accumulation, in 12 hours, in tubs holding 600 gallons each, by the winding engine.

Where shafts are sunk for the purpose of working mineral veins, it is customary to sink a vertical shaft for the pumping apparatus; but the drawing shafts are generally in the vein itself, thus certainly having an advantage in the produce of the sinking being valuable, and saving cross driftings to the veins, but on the other hand incurring a great sacrifice of wear and tear, and constituting a much less safe arrangement as regards the workmen who descend and ascend by means of ladders.

The pit, after having been sunk and properly secured, requires to be fit up with guides, by which the cages pass up and down the shaft. Many different modes of arrangement are adopted, but for a pit such as already described, the plans shewn in plate 54 will be found convenient in practice. In this case the pit, figure 1, 11 feet in diameter, is divided by a brattice of 3-inch planks into two shafts, one for pumping and the other for drawing coals. The buntons to which the guides are bolted are 9 inches × 3 inches, and 6 feet apart: the guides are 5½ inches × 3 inches: the whole made of Memel plank. The cage (figure 2) consists of an upper and lower compartment, to enable two tubs to be drawn at once: the weight of this cage should not exceed 10 cwt. The coal tub (figure 3) will hold 8 cwt. of coals, and by such an arrangement 800 tons of coals may, by using activity and despatch, be drawn in 12 hours. It has been proposed to use wire ropes for guides, and although in deep pits and at high speeds, there must be a great liability to vibration, and consequent risk of the ascending and descending cages coming in contact, yet no doubt the proposition is worthy of consideration, on account of its economy and increased safety in other respects, arising from the absence of all joints and fastenings in the shaft: at low speeds, there can be no question of the advantage of the application.

During the whole of the time of sinking, the erection of dwelling-houses for workmen, shops for joiners, blacksmiths, &c., have been in course of erection, which, with the necessary skreens, branches about the pit, &c., having been completed, the colliery is ready for work.

CHAPTER V.

Strength of Materials : Ropes : Pulleys.—Power of Engines.

A TREATISE of the present nature would be incomplete without a short chapter upon this subject; but in order to render it of a more specially useful character, it is entirely composed of such rules and modes of calculation as have from time to time been adopted by practical men, in their application to circumstances in which the mining engineer is ordinarily placed.

The late Mr. W. Emerson found that a cylinder whose diameter is *d* inches will carry permanently as follows :—

Iron	$135\,d^2$ in cwts.
Good rope	$22\,d^2$ „
Oak	$14\,d^2$ „
Fir	$9\,d^2$ „

A very easy rule for calculating the proof strength of hempen rope is—"square the circumference in inches, and divide by 10, which will give the number of tons which may be safely appended to the rope." Thus, a 10-inch rope will carry 10 tons, a 12-inch rope 14·4 tons, &c. According to Mr. Emerson's formula, a 10-inch rope will carry permanently 11 tons 2 cwt.

The following table shews the comparative absolute strengths of hempen and wire ropes and chains, with the loads which in practice may be safely appended to them in shafts; the table shews also the weight of each per fathom. The working load is calculated at one-third of the proof strength, in order to insure against any sudden jerks or strains, such as are incident to ropes working in shafts :—

HEMPEN ROPES.		WIRE ROPES.		CHAINS.		BREAKING STRAIN.	PROOF STRENGTH	WORKING LOAD IN SHAFTS.
Circumf.	lb Weight ℔ Fathm.	Circumf.	lb Weight ℔ Fathm.	Diameter.	lb Weight ℔ Fathm.	Cwts.	Cwts.	Cwts.
Inches.				*Inches.*				
$3\frac{1}{2}$	$2\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{5}{16}$	$5\frac{1}{2}$	60	$24\frac{1}{2}$	8
$4\frac{1}{4}$	$4\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{1}{2}$	$\frac{3}{8}$	8	100	36	12
5	$5\frac{3}{4}$	2	$3\frac{1}{2}$	$\frac{7}{16}$	$10\frac{1}{2}$	140	50	17
$5\frac{3}{4}$	7	$2\frac{1}{4}$	$4\frac{1}{4}$	$\frac{1}{2}$	14	170	66	22
$6\frac{1}{2}$	$9\frac{3}{4}$	$2\frac{5}{8}$	6	$\frac{9}{16}$	18	240	$84\frac{1}{2}$	28
7	$11\frac{1}{4}$	$2\frac{7}{8}$	7	$\frac{5}{8}$	22	280	98	33
8	15	$3\frac{3}{8}$	9	$\frac{11}{16}$	27	360	128	43
$8\frac{3}{4}$	19	$3\frac{5}{8}$	$10\frac{1}{2}$	$\frac{3}{4}$	32	420	153	51
$9\frac{1}{2}$	21	$3\frac{3}{4}$	$11\frac{1}{2}$	$\frac{13}{16}$	37	460	$180\frac{1}{2}$	60
10	23	4	14	$\frac{7}{8}$	43	560	200	67
$10\frac{3}{4}$	28	$4\frac{3}{8}$	16	$\frac{15}{16}$	49	640	231	77
$11\frac{1}{2}$	$30\frac{1}{2}$	$4\frac{1}{2}$	18	1	56	720	$264\frac{1}{2}$	88

A sufficiently close approximation to the working load of round wire ropes in shafts, is to multiply by 5 the weight of the rope per fathom in pounds, for the load in hundredweights: in the working load is included the weight of rope hanging over the pulley.

As the flat wire rope is manufactured, viz., by laying four or six round ropes side by side, and stitching them with wire, it is evident that it has not the same probability of bearing the strain as uniformly as a round rope of equal material; because, should any strand be in the least degree stretched unequally with the rest, the rope is possessed of so little elasticity that the whole of the strain will be thrown either upon it or upon the remaining strands: the consequence is, that for similar loads, a greater weight per fathom of flat than of round rope is required, probably in the proportion of 5 to 4 at least, exclusive of the weight of the stitching.

The square of the circumference of round hempen rope in inches, is equal to the weight in hundredweights of 486 fathoms; or, to find the weight of any hempen rope in hundredweights, multiply its length in fathoms by the square of the circumference in inches, and divide by 486.

The square of the circumference of round wire rope in inches, is equal to the weight in hundredweights of 128 fathoms; or, to find the weight of any wire rope in hundredweights, multiply its length in fathoms by the square of the circumference in inches, and divide by 128.

There is a very decided advantage in the application of springs to wire ropes; for their rigidity is such, that without them not only is there a great strain laid upon the rope at starting, but also a similar strain is experienced by the whole of the machinery attached thereto. It is to be regretted that a more perfect description of spring than that hitherto used, has not been contrived: the present spring, made of two volute steel springs placed in a box, being not only liable to rupture, but retaining its elasticity for a very short time.

There is no doubt but that, could a perfect spring be applied, lighter ropes might be used, and with greater safety, than the strong ones used at present: for it is almost invariably found, that a wire rope breaks either when taking, or immediately after having taken, its lift from the pit bottom; a fact almost entirely attributable to the want of elasticity in the rope. It is also especially necessary that a winding engine working with wire ropes should be furnished with a counterbalance weight, in order to aid it at "the lift," thus in a measure avoiding the necessity of starting the engine at speed, which, particularly in the case of its having too little power, is often needed in order to overcome the inertia of the load.

The dimensions given to rope rolls, or drums, and pulleys, more especially in the coal mines of the north of England, have of late years undergone a rapid change. Instead of the pigmy wheels of twenty or twenty-five years ago, the diameter of which, when it amounted to 6 or 7 feet was considered to be remarkable, and which was more usually confined to 4 or 5, we see them ordinarily 8 or 10 feet, often 12, and in some cases 14 or even 16 feet in diameter. Of the advantage of large pulleys every one must be satisfied, particularly in the case of round wire ropes, which, when of considerable weight and thickness, are much injured by being bent over pulleys of small diameter.

It must, however, at the same time be borne in mind that unless we have also large rope drums, the large pulleys must be of little comparative use. The best arrangement is to have the diameter of both as nearly equal as possible: if any rule can be given for the apportionment of drums and pulleys to round wire ropes, perhaps the following may be found practically to work well:—

Assume 10 feet as the minimum diameter of drum and pulley, for any rope not exceeding 6lbs. weight per fathom, and add 6 inches to the diameter for every additional pound per fathom.

This would give, for a 10lb rope, a drum 12 feet in diameter.

12	„	13	„
14	„	14	„
16	„	15	„
18	„	16	„

Until lately, pulleys have usually been made altogether of metal: they are, however, very heavy, especially when of large diameter: they are now frequently constructed with metal naves and rims, the spokes being of malleable iron.

There is certainly a superiority in this principle, so far as lightness and the less liability of the spokes to break is concerned; but owing to some difficulty in adjusting the length of the spokes so as to be perfectly tight fixed into the rim, by its contraction, there is frequently a spring or working on the rim which must render it liable to break.

The following formula is applicable in order to determine the weight in pounds avoirdupois which may be safely placed upon the middle of a rectangular beam of timber, supported at both ends.

Let L = the length in inches between points of support.
B = the breadth in inches.
D = the depth in inches.

$$F = \begin{cases} 1{,}672 & \text{for English oak.} \\ 1{,}632 & \text{,, pitch pine.} \\ 1{,}341 & \text{,, red pine.} \\ 900 & \text{,, larch.} \end{cases}$$

$$W = \frac{F \times 4\,D \times B\,D}{4\,L}$$

The beam will bear three times the weight thus calculated, if laid uniformly along its entire length.

To calculate the nominal power of a condensing steam engine, square the diameter of the cylinder in inches, and divide by 30: thus, a condensing steam engine with the cylinder 55 inches is 100 horses power.

In this calculation of the power of a condensing engine, the pressure on the safety valve is assumed at 3·18lbs. per square inch, and the effective force on the piston at 7½lbs. per square inch.

To calculate the nominal power of a high pressure or non-condensing steam engine, square the diameter of the cylinder and divide 13·6 : thus a high pressure engine with a cylinder 36·84 inches in diameter is 100 horses power.

In this calculation of the power of a non-condensing engine, the pressure on the safety valve is assumed at 25lbs. per square inch, and the effective force on the piston 16·66lbs. per square inch.

To find the quantity of water in gallons per minute an engine of any given horse power will pump from a given depth—

Let H = horse power of engine ;
F = depth in fathoms ;
G = the quantity of water in gallons per minute ;

$$\text{Then } \frac{550\ H}{F} = G$$

Thus, let it be required to find the number of gallons of water per minute an engine of 100 horses power will pump from the depth of 100 fathoms, we have—

$$\frac{550 \times 100}{100} = 550, \text{ the number of gallons required.}$$

To find the number of gallons lifted each stroke by an engine, having the diameter of the working barrel, the length of stroke, and the number of strokes made per minute, square the diameter of the working barrel in inches, multiply by the length of stroke in feet, also by the number of strokes per minute, and the product by ·034. Thus, an engine pumping 6 strokes per minute, with a 6-feet stroke and a working barrel 20 inches in diameter, will raise—

$$D^2 \times 6 \times 6 \times {}\cdot034 = 489{\cdot}6 \text{ gallons per minute.}$$

The subjoined table has been constructed for the purpose of shewing the power of winding engines required for raising loads from mines. To the calculated power is added 50 per cent., this increase being considered necessary to overcome the friction of the conductors in cage shafts, and also to give the engine sufficient command of its work, as in overcoming inertia at the lift. It is presumed that the weight of the rope is so balanced as to require no exercise of engine power, further than to set it in motion.

Assuming the quantity required to be 600 tons drawn daily, the load, speed in shaft, and power of engine, may be adjusted to the depth as follows :—

DEPTH.	LOAD.	SPEED.	TIME OF DRAWING AND CHANGING.	POWER OF ENGINE.		
Fas.	Cwts.	Feet ⅌ Second.	Seconds.	Calculated.	Allowed for Friction, &c.	TOTAL H.P.
50	2 Tubs = 16	10	60	33	17	50
75	2 Tubs = 16	12·8	60	45	22½	67½
100	2 Tubs = 16	15	60	49	24½	73½
125	2 Tubs = 16	16·6	60	54	27	81
150	3 Tubs = 24	15	90	73	36½	109½
175	3 Tubs = 24	16·1	90	79	39½	118½
200	3 Tubs = 24	17·1	90	84	42	126
225	4 Tubs = 32	15	120	98	49	147
250	4 Tubs = 32	15·8	120	103	51½	154½
275	4 Tubs = 32	16·5	120	108	54	162
300	4 Tubs = 32	17·1	120	112	56	168

CHAPTER VI.

THE WORKING OF MINES.

Rock Salt: Ironstone: Coal: Board and Pillar Working: Longwork: Underground Haulage: Working Coal by Machinery: Copper, Lead, and Tin.

The varied circumstances under which different minerals exist, would appear to lead easily and naturally to much dissimilarity in the methods pursued in their extraction: as has been already explained, some minerals are found in horizontal layers or strata of extraordinary thickness, such as rock salt: some, on the contrary, are discovered in thin bands, such as the ironstone beds of the coal measures: some, such as the ordinary seams of coal, exist in the form of strata of moderate thickness: and some are found in fissures or veins, such as those minerals or ores from which the greater part of the metals (excepting iron) are procured.

Still, the chief principles involved in the extraction of the whole are similar: the sinking of shafts, the drainage, the raising of the mineral, and the ventilation of the mines, all require their modicum of care; and we find that, notwithstanding the apparently opposite requirements of such widely contrasted elements, the mode of management of the whole is possessed of one (very nearly) general character, with variations only in detail.

1. ROCK SALT.

The general principle upon which rock salt is mined, is to obtain as much salt as is consistent with the maintenance of the superincumbent strata: pillars of salt being left for this purpose.

The rock salt pits (says Williams) are immense excavations, some of which are not less than 320 feet in diameter; and in digging out the salt, massy pillars are formed out of the rock for the purpose of supporting the roof, which is also of the same material, a thickness of about 20 feet of the salt being left for the purpose.

Among the most interesting accounts of the English salt mines is that of Sir George Head, contained in his Tour through the Manufacturing Districts of England, in 1835. Whilst at Northwich, he visited the Marston pit, which had been at work for a period of 60 years, and may be considered inexhaustible.

Having waited, says he, with my conductor a few minutes till the Engineer had put a little steam on, we stepped into a round tub, and standing upright, holding by the chains, were let down very easily. I cannot express the delight I felt at the scene around me, which surpassed any thing I had anticipated; creating those sensations I remember to have felt when first I read of the pyramids and catacombs of Egypt. Here was a magnificent chamber, apparently of unlimited extent, whose flat roof presented an area so great, that one could not help being astonished at its not having long since given way: yet there was no apparent want of security, it being sound and durable as if formed of adamant. Here and there, pillars in size like a clamp of bricks in a brickfield, tendered their support, presenting to the view an array of objects that broke the vacancy of uniform space. My idea of the extent was, as if an area equal to the site of Grosvenor Square were under cover. In the mean time, the glistening particles of crystal salt on the walls, and the extreme regularity of the concentric curved lines traced by the tools of the workmen, were very remarkable. Occasionally, the mark of the jumper chisel was observable, where recourse had been had to blasting the solid rock. I made a few blows against the side of the mine, with one of the heavy pointed pick-axes in ordinary use, and found it as hard as freestone.

Under foot, the whole surface was a mass of rock salt, covered with a thick layer of the material, crushed and crumbled to a state that exactly resembled the powdered ice on a pond that has been cut up by skaters.

At one part there is a vista of 200 yards in length, which has been dignified with the name of Regent-street.

The salt, after being prepared by the solution of the rock and evaporation, is formed by wooden moulds with holes in the bottom, to allow the remaining water to pass through, into cubical blocks, and in this state shipped.

A considerable quantity is prepared from the brine springs, some of which are so strongly saturated as to hold in solution the greatest possible quantity of salt. To the water of others, rock salt is added while boiling in the pans. From these springs, the water or brine is raised from a shaft, by a pump worked by an ordinary steam engine.

There does not appear to be anything worthy of especial remark in the mode of mining salt, the whole process appearing to consist in a system of wide excavations, leaving such pillars or barriers as are sufficient for the support of the roof.

2. IRONSTONE.

Ironstone usually being either stratified or existing in the form of nodules in strata of shale, may be worked either by what is termed the "Long Wall" method, as practised in Staffordshire and elsewhere, or by the "Board and Pillar" method, as adopted in the Newcastle coalfield.

1. The Long Wall.—The great distinguishing feature of this mode of extraction consists in removing the whole stratum out of the mine, as our operations advance. In order to effect this, we proceed as follows :—Supposing we have two shafts sunk to the ironstone bed, the first operation is to form a communication between the two, for the purpose of ventilating the mine. After this has been done, certain excavations require to be made which are intended to serve as passages for bringing the ironstone to the drawing shaft, for conveying a current of air into the workings, and also for allowing the return of the air which has ventilated the working places, to the upcast shaft.

The manner of laying out such workings will be seen on referring to plate 55, figure 1.

Let *A* be the downcast shaft, used also for drawing the produce of the mine, and *B* the upcast.

In the first instance, then, we connect *A* with *B*, and then commence driving the drifts *Ab*, *Ac*, &c., which have the effect of placing pillars of stone round the shafts, which act as barriers for their preservation against the effect of any injury which they might sustain from the extraction of the ironstone. After having completed these barriers, we turn our attention to the winning out of a face of work, which we do as follows :—From the points *b* and *c* we drive in a water-level direction, the drifts *b e*, *c f*, accompanied by consort drifts *g h*, *i k*, forming communications between each pair as it advances, at stated distances—suppose 40 yards—taking care as every new holing is made, to close up with a strong stopping of brick or stone the previous one. This (proper means being applied at the bottom of the upcast shaft) will cause the necessary circulation of air. After these have been continued a certain distance—say 150 yards—in each direction, and at the same time other excavations, *l m*, *n o*, &c., having been completed, the working of the mine may be prosecuted upon the wall faces *l m*, *n o*, and the ironstone conveyed to the shaft by a railway or tramway, laid as represented by the blue shade.

The red lines and arrows represent the air stoppings and circulation of the air.

The wall face being divided into suitable "stints," a certain description of workmen called "holers" is distributed along the face of work. The business of these men is to undermine the ironstone to the extent of (say) 30 inches ; these men are followed by another set, called "builders up ;" they are armed with a sort of pick called a dresser, having only one sharp end, the other being short and forming a hammer ; their duty is to get down the ironstone which has been undermined by the holers, and to build up behind them the stone which falls with the ironstone. Sometimes the holers both undermine and get down the stone, and build it up themselves, and then their stint is arranged accordingly.

At the same time that the refuse is thus built up to support the roof, and stout wooden or metal props placed under dangerous places, the "loaders" and "pitchers" are at work. Their duty is to load the skips, and also to take up the rails and lay them down again as the work advances.

It is necessary to leave gateways through the waste or excavated part as the work proceeds—these gateways being pillared at the sides partly with stone taken from the roof of the gateways, which are thus made of extra height, in order to prevent their being so reduced by the thrust as to render them useless. As the wall face advances still further (plate 55, figure 2), and the gateways become in consequence inconveniently long, a cross-heading is prepared, *x y*, along which the ironstone is conveyed after being brought thereto by the gateways. *

We must not omit describing an important part of the economy of every mine, as without a due attention to it the workings are always liable, especially when burdened with much water, to be suspended: I allude to the standage, which is a reservoir for the mine feeders, the lowest point of which is on a level with the bottom of the engine sump. The standage consists of a portion of workings excavated on the dip side of the shaft, with the bottom of which it is connected by a water-level drift, in which is placed a dam with a pipe in it, through which, under ordinary circumstances, the water flows to the engine.

When from any cause, however, the pumping is stopped, the pipe is plugged up, and the water allowed to accumulate in the standage, until pumping can be recommenced, when the plug is withdrawn. *

2. Board and Pillar, called also Post and Stall Work.—In this instance the preparatory workings, so far as the holing about of the shaft pillars and the draining of the water-levels are concerned, are similar to those above described. In place, however, of carrying the whole of the face of work together, boards or excavations 4 or 5 yards wide are turned away at distances of 2 yards or upwards apart, and driven as far as is considered convenient, the rubbish being stowed away or pillared up by the side of the board as it advances, or in case of there not being sufficient stowage for it, it is sent to the surface and teemed into the refuse heap.

After these boards have been driven as far as is thought proper, they are communicated with each other by means of narrow holings called walls, which have the effect of leaving a portion of the mine in the form of pillars, which may afterwards be worked away. Plate 55 figure 3 shows the arrangement of workings upon this plan, the blue lines showing the position of the tram ways, and the red lines and arrows, the stoppings and direction of the currents of air.

In some places the beds of ironstone lie so near the surface that they are worked as quarries: an instance of this occurs at present in the north-east of Yorkshire, at the Eston mines.

3.—COAL.

The first authentic record which we have of coal being worked in the vicinity of Newcastle-upon-Tyne, is, that King Henry III., by his letters patent under the great seal of England, dated at Westminster the 1st day of December, 1239, in the 23rd year of his reign, upon the good men of Newcastle's supplication, thought it fit to give them licence to dig coals and stones in the common soil of this town, without the walls thereof, in the place called the Frith, and from thence to draw and convert them to their own profit, in aid of their fee farm rent of

£100 per annum, and the same as often as it shall seem good unto them: the same to endure during his pleasure; which said letters patent were granted upon payment of twenty shillings into the hamper.

Edington, in his Treatise on the Coal Trade (1813), states regarding the working of these mines, "it may be seen to this day where their watercourse comes out to the surface at Gallowgate, from near the bottom of the moor: the High Main run out, the only coals they wrought were the Metal coals, which lie about five fathoms below the High Main, the seam about 32 inches thick, pretty good, and about 4½ fathoms below lay the Stone coal, about 30 inches, pretty good."

Not many years afterwards, we find that coal was wrought in Scotland, in lands belonging to the Abbey of Dunfermline, viz., in the year 1291, a charter granting the right of digging coals in the lands of Pittencrief having been granted in favour of the Abbot and convent.

It is probable, however, that coal was wrought long previous to the above dates, and the author of the Britannia Romana tells us that a colliery was established not far from Benwell (the Condercum of the Romans) during the period in which that people lived in Britain.

Notwithstanding the early date at which the working of coal commenced, and the enormous extent to which it is now carried, the following extract from a memorial to the Crown by Sir Kenelm Digby, in 1661, shews that a coal fire was not always as popular as at present:—

"This coal flies abroad, fouling the clothes that are exposed a-drying on the hedges, and in the spring time besoots all the leaves, so that there is nothing free from its contamination; and it is for this that the bleachers about Haarlem prohibit, by an express law (as I am told), the use of coals for some miles about town. Being thus incorporated with the very air which ministers to the necessary respiration of our lungs, the inhabitants of London, and such as frequent it, find it in all their expectorations, the spittle and other excrements which proceed from them being for the most part of a blackish and fuliginous colour; besides, the acrimonious soot produces another sad effect, by rendering the people obnoxious to inflammations, and comes in time to exulcerate the lungs, when a mischief is produced so incurable that it carries away multitudes by languishing and deep consumptions, as the bills of mortality do quickly inform, &c., &c."

In working coal, as in the case of other minerals, the object has been and is to obtain as much coal as possible from a given area, and the greater or less proportion of coal obtained would naturally at first depend altogether upon the nature of the roof: thus a very bad roof would not only necessitate the excavations to be driven of a less width, but also the pillars to be left of a greater strength than would be required by a roof of a firm description. The quantity obtained in the earlier stages of mining was also dependent upon the depth, for as this increased, the additional weight of superincumbent strata demanded that the pillars should be left of greater size. The dimensions of the pillars found in old workings at Butterknowle, near the south-west outcrop of the lowest seam of the Newcastle coalfield, where the depth is not more than 7 or 8 fathoms, are about three yards square; the width of the excavations being about three yards, and the whole driven beneath 8 or 10 inches of top coal, and accurately arched, the object of the arching being to prevent the use of props. At the date of these workings, probably about 200 years ago, the whole of the extraction was performed by horses and gins, the pumping of water being performed by the same means. The pits were of moderate depth, and 20 or 30 tons were esteemed a great day's work from a single pit. The great difficulty that seems to have been met with in the prosecution of these old mines, appears to have been the working of coal to the dip of the shaft levels; and although we occasionally find that when the waters have been light, the workings have been extended to the dip, by means of rag wheel pumps, yet these instances are not of frequent occurrence, and seem generally to have been attended by the precipitate abandonment of the colliery, the tools of the workmen having been left behind. From such working apparatus as has been discovered, it appears that the coal has been conveyed in barrows from the hewer to the shaft, whence the origin of the present terms barrow-way and barrow-man. Iron picks were in use of much the same form as those at present employed; the shovels were made of wood; the application of gunpowder to the working of coal was at this time unknown. Some of the work performed by these old miners surprises us by its beauty, and by the patient toil with which it has been executed. We have in various places, among which may be mentioned Tanfield Moor and Beamish, instances of very long water-courses, driven sometimes in stone and sometimes in coal, the width of which does not exceed 18 inches; and it is truly a wonder how the work has been performed, the sides of the drifts being as smooth and straight as though they had been chiselled. There are also instances of very deep levels finished with the same precision: one of these I remember to have seen in the old workings at Tyne Main, the depth of which was 16 feet, and the width at the top not more than three feet.

As the coal became exhausted at moderate depths, and it became necessary to obtain the supply from deeper winnings, the means in use were found inadequate to the purpose, but as has ever been and ever will be the case, the prospect of gain so stimulated man's ingenuity as to enable him to meet the emergency. Pits were sunk near to running streams, and their waters made to perform the work no longer practicable by old means; and eventually the steam engine was applied to mining, great improvements since its introduction being suggested at different times by the various circumstances occurring in practice.

Coals were formerly all drawn to the surface in corves containing about 10 pecks, but as the power of the machinery increased, the dimensions of the corf were also enlarged, and at the introduction of the tub and cage system, the size of the corves usually was from 20 to 30 pecks, two or three being drawn at a time. The system of drawing coals in cages was introduced into the Newcastle district by Mr. Thomas Young Hall about 20 years ago, the first pit fit up on this principle being the Glebe pit at Towneley colliery, near to Ryton.

Notwithstanding that at first the plan was not very highly thought of, it has now completely superseded that of drawing coals in corves, now I believe quite, except under particular circumstances, exploded. The saving effected in the North of England by this introduction may, on a rough estimate, be taken at £50,000 (2,000,000 scores of 6 tons, at 6d. per score) per annum, as the difference between the annual cost of the corves and tubs alone, to say nothing of other mining improvements consequent upon the change.

As regards the most economical method of working coal, some difference of opinion exists: the board and pillar, and long wall method, each possessing its advocates: the general principles of these two systems have been already explained, when treating of the working of ironstone; their application to the working of coal is, however, of sufficient importance to demand a little further explanation.

* The system almost exclusively adopted in the Newcastle coalfield, and also with certain modifications made use of pretty generally in Scotland, Lancashire, and elsewhere, is that termed the board and pillar, or post and stall method of working coal.

The situation of coal pits varies so much, together with the position of the seams of coal, dykes and slips, that no rule can be laid down for the form of the pillars of coal, left near the shaft, which are called the shaft pillars.

Suffice it to say that the drift intended for the main outlet or rolleyway from the colliery workings to the shaft, should be driven with about 3-16ths of an inch rise per yard each way from the shaft, and as straight as possible, in order that it may be adapted to the application of machinery as the tractive power to be used upon it. The shaft walls should seldom be less than 40 yards square, and should increase in proportion to the depth or tenderness of the coal to be worked. If we suppose the minimum to be 40 yards, and 5 yards to be added for every additional 10 fathoms of depth above 80, we should have for a depth of .... 100 fathoms, 50 yards,

150 „ 75 „

200 „ 100 „ &c.

Pillars of this large size may be subdivided, and it would be neither safe nor expedient to form them by one holing. During the holing of the shaft walls, a fire lamp placed at the bottom of the upcast will cause an excellent current of air to traverse the places as they proceed: the diameter of such a lamp may be 3 feet. If, however, the nature of the seam of coal is to produce much inflammable gas, the ventilation (in the absence of ~~a furnace which is as yet inapplicable~~ a permanent ventilating apparatus) may be performed by a steam-jet apparatus, and the whole of the preparatory workings should be effected under the employment of safety lamps. After the shaft walls have been holed, the permanent ventilation of the colliery ought to be established as soon as practicable.

The rolleyway drifts must now be continued in each direction from the pit, and two other drifts should be set away, parallel to them, out of the shaft walls, one on the rise and one on the dip side of the rolleyway drifts.

To prevent confusion, it may be as well to state that as the workings at each side of the shaft will probably correspond with each other, we shall follow those which proceed to the north, supposing the water-level line to be north and south, and the full rise to be west at the rate of 1 in 24, or $1\frac{1}{2}$ inches to the yard. I shall also assume that the coal pit is 150 fathoms in depth, 15 feet in diameter, divided by a plank brattice 3 inches thick, into an engine or pump shaft, and a coal shaft: that the direction of the brattice is north and south: that the upcast shaft is also 150 fathoms in depth, 10 feet in diameter, and situated 75 yards west of the coal pit. According to the rule for the size of the shaft pillars, they will be each 75 yards square.

We have then three drifts, viz., the rolleyway, the high water-level, and the low water-level drift, proceeding parallel to each other, in a northern direction, and as these are the main drifts of the mine, they must be driven with great care, and about 7 feet wide. (Plate 56, figure 1.)

The thickness of the pillars of coal left between the high water level and the rolleyway, and also between the rolleyway and low-water level, may, in this case be 25 yards, but of course for a less depth, other things being the same, a less thickness will be sufficient. It will be commonly found that the thickness of the pillars of coal to be left, will depend much more upon the nature of the thill stone or floor of the coal than upon any other circumstance, for when the thill is soft, it is very liable to heave or swell up, especially when wet, when the pillars of coal are not sufficiently strong for the support of the superincumbent pressure.

These drifts will require to be holed across for air every 30 or 35 yards, but the longer these pillars can be made, the stronger and better they will be.

At the holing of every new pillar, a stopping of brick or stone, (behind which, for its support, as well under ordinary circumstances as under the contingency of an explosion, 6 or 8 yards of solid stowing should be placed,) or, if required, a pair of trap doors should be inserted in the last holing, or stenting wall, as it is termed in the north of England, to cause the current of air to pass to the face of the drifts. (Plate 56, figures 1 and 2.)

The doors, *F D*, should not be air-tight, to allow a portion of air to pass along the centre drift; the arrows represent the course of the current of air. Figure 2 shows the mode of conducting the air into the face by brattices, which, if the seam generates much fire-damp, must be carefully put in, and, if necessary, plastered at the joinings of the deals with hair and lime.

Since the main drifts are driven in a water-level direction, they may happen to be either headways, boardways, or cross-cut, according to the direction of the strata as compared with the course of the cleavage of the coal. Should they happen to be headways, the boards may be turned away out of the higher drift, as shewn in plate 56, figure 3, the first pillar being of large dimensions, in order to act as a barrier to preserve the main drifts from any thrusts or creeps occasioned by the working away of the pillars beyond, such thrusts or creeps not only being the cause of much expense in keeping these main drifts open, but also prejudicial to the ventilation, by the injury they occasion to the stoppings required to carry the air round the workings.

If the course of the waterlevels should be boardways, a pair of winning headways should be set away to the west, at a sufficient distance from the shaft to allow of a good shaft siding between the shaft and the point where the headways are set away, say 100 yards. These headways should contain between them the same thickness of coal as that left between the waterlevels, or 25 yards; and out of the back headways, the boards may be turned to the north as above described (plate 56, figure 4). The boards should always be turned narrow out of the winning headways or waterlevel drifts, thus often preventing an expense consequent upon the fall of the roof in wide excavations.

Should the inclination of the seam be trifling, the same process may be carried on to the dip, or east side of the main drifts, and thus more pit-room obtained.

It will be sufficient for our present purpose to suppose that the course of the waterlevel drifts coincides with the cleat of the coal, as represented in plate 56, figure 3.

Since we have assumed the coal to lie at the depth of 150 fathoms from the surface, we shall probably find it convenient to drive the boards five yards wide, with 20 yard walls intervening, forming 25 yard winnings: the walls may be holed at 24 yards, 2 yards wide.

At a proper distance north of the shaft, which in the present case may be 200 yards, the west workings must be formed in the manner shewn in plate 57; the centre drift being the future outlet for that portion of west coal intended to form a district, the width of which may be 400 yards or thereabouts. After the west workings have advanced a few pillars, they will present the appearance shewn, and then, under favourable circumstances, the working of the pillars may be commenced in the situation marked *A*.

The circumstances which will regulate the working of pillars are as follows:—

1. The nature of the mine as regards the production of inflammable gas: because if this be produced in large quantity, the utmost care and judgment will be called into requisition to prevent the possibility of its forming such a compound with the air current as would ignite at a ventilating furnace. In a very fiery mine, the pillars ought not to be worked away before having reached a considerable distance from the shafts, but the first excavations should be preserved as air-ways, through which the return air may be well coursed or "dashed," so as to be thoroughly mixed below the firing point, before its passage over the furnace. Risks of this kind are removed by the use of a separate channel for the goaf air into the upcast, or by the use of any mechanical ventilator, or by steam ventilation.

2. The nature of the coal: if the coal be of a tender description, but required to be wrought as large as possible, the working of pillars should be delayed, and their strength made considerable; because if they be worked away, the probability is that those left for the support of the waggonways will be completely destroyed by the pressure: this assumes the roof to be good. In the case of a very bad roof, the pillars should be worked away behind

the whole, not only from economy in the first instance, but also, because, when the roof is bad and falls freely in the goaves, it soon sustains the superincumbent pressure, and relieves the pillars next to the rolleyways.

The advantages of following up the pillars behind the whole, consist in the concentration of the working districts, and the greater facility of keeping a limited extent of workings well ventilated than an extent spread over a wide area.

Various plans are adopted in removing pillars, and no rule can be laid down for the selection of any one in preference to others, as what may suit the circumstances of one situation, may in other cases be quite inapplicable.

1. The pillars may be taken off in lifts from each headways-course, a place being driven next to the goaf, half the length of the pillar, and about 6 yards in width.

   This plan, except under a very good roof, is objectionable, on account of the quantity of props that it usually requires, the time occupied in removing each lift being considerable.

2. Another plan consists in laying the tramway down the old board adjoining, and driving over a narrow wall in the pillar, and then bringing the lifts back towards the headways-course. This plan can only be adopted when the stone in the board has not fallen, and although it is attended with (as regards the last lift) less waste of timber (the props being taken out and the roof allowed to fall as the coal is worked back), still there is a considerable quantity used; and moreover, there is the additional expense of driving so much narrow work, to say nothing of the inferior size of the coal such work produces.

3. Another plan is to split the pillar, as it is termed, by driving a narrow place or jenking down the middle of it to the next headways course, and to bring back simultaneously the portions of coal left at each side, between the jenking and the boards. By this plan there is a considerable saving in timber; but as it has the effect of weakening the support of the strata above, it is often attended by a lifting up or partial creeping of the thill, which is troublesome and expensive.

4. Another way is to drive a narrow place alongside of the board when it is fallen, or to make use of the board itself when it is not, and bring back the whole of the pillar at once: this plan is preferable to the last, as regards the liability to produce creep, but it consumes more timber; and the fact implied by an increased consumption of timber under such circumstances is, that the coals are produced in a less marketable state, and that the working places are less safe.

5. The best method, however, consists in making, in the first instance, the pillars of such dimensions as to allow, after driving a jenking up the middle, the portions between the jenking and boards to be of a fair proportionate size to the depth of the mine: by this plan, no ill effects as regards creep can possibly be produced. After the jenking has reached the far end of the pillar, the whole of the wings on each side may be brought back simultaneously, chocks or metal props being used in double rows, for the support

of the roof, the back row or that next to the goaf being shifted between the front row and the coal as the face advances.

The chocks consist of hard wood, and should be about 2 feet long, 8 inches broad, and 6 inches thick: they are built up, two upon two, crosswise, the bottom two being placed upon about 18 inches of small rubbish, which, being picked out, occasions the easy removal of the chocks when so desired. The pillars of chocks will be placed at distances apart according to the nature of the roof: under an ordinary roof, they may be placed 9 feet apart, centre and centre; and when the back row is moved forward, it is necessary to use a few strong props to secure the person employed in its removal.

If, instead of chocks, metal props are used, they may either be set upon the thill, in which case, if any heaving takes place, they require to be drawn by the aid of a powerful lever, or they may be set each upon a chock placed upon small rubbish, and drawn as above described. These metal props weigh about half a hundredweight to the four feet length, and will support, without breaking, 60 tons each, if properly formed. The best section is that shewn in the diagram.

In every colliery, whether it be determined to follow up the pillar working close behind the whole, or to bring the pillars back, it ought to be a peremptory rule to regularly work such a proportion of pillars as will not allow of their accumulation. In the case of following up, this is easily managed; and in that of bringing back, it is only necessary at stated distances to forewin the pannels, the previous one being in the course of pillar working, when that before it is progressing in the whole mine.

As regards the ventilation of workings when the pillars are not removed, this must be effected by "coursing" the air; or, after it has been carried along the face of the boards, traversing it up and down the back pillars, until it reaches the main return air-courses.

The plan of coursing the air was contrived by Mr. James Spedding, of Workington, in 1760, according to Mr. Buddle, one of the most able pitmen of his day.

Air is usually coursed "two and two," or "three and three," according to the greater or less quantity of fire-damp evolved, the meaning being that the current in the former case is conducted up two boards and down two, by means of stoppings of stone called sheth stoppings placed in every second wall in each headways course; every alternate line of walls in which the stoppings are placed being open at the top, and the others being open at the bottom, of the sheth of boards, so as to afford the air a free passage. The going headways at the face is frequently made a part of the course, doors called sheth doors being substituted for the stoppings; but it is far better, as mentioned above, to conduct the air singly along the face headways course, by means of board end stoppings, and course the air behind them. When the pillars are worked away behind the whole, there are comparatively no old workings to course, and consequently the expense of building so many stoppings, and keeping so large an extent of air-course in a proper state of repair, is saved.

In the ventilation of fire-damp mines conducted on the following-up system, the great point to be attended to is the regulation of the pressures of the air currents in such a manner, that, in case of any leakage of stoppings next to the face, the air may pass from the whole into the pillar workings; and the greatest care should be taken that the contrary should on no consideration be allowed to take place.

A reference to plate 58 will shew how easily a grave error may be inadvertently committed. In both cases the currents of air may be quite sufficient for all ordinary, and even some extraordinary circumstances; but let us suppose that the stoppings "*a*" in figure 1 and "*a*" in figure 2 are injured, and that a sudden discharge of gas from the goaf takes place, and enquire what will be the consequence in each case.

In figure 1, the distance from the point "*x*," where the air is divided, to the point "*a*," whether measured along the back pillars, or along the face headways course, being equal, the pressure on the stopping "*a*" might be supposed to be indifferent, either to or from the whole workings; however, when we consider the effect of the regulator, the probable contraction of the face air by the brattices of the boards, and the resistance offered to it by the motion of the tubs, we shall conclude correctly that the pressure will in this case be out of the broken into the whole.

In figure 2, however, with precisely the same distribution of air into whole and pillar workings, we see that no possible contingency could occasion the passage of the pillar air into the whole headways course at the point "*a*." This is a most important matter; and I do not know any part of his profession in which the skill and forethought of the colliery viewer is put to a more severe test, particularly when workings become extensive, and the air is many times divided and subdivided.

The Long Wall method of working coal, practised in the Staffordshire collieries, so closely resembles the Long Wall method of working ironstone, already described, and illustrated in plate 55, that any further mention of it is unnecessary.

The following calculation shews an approximation to the probable saving by working the long way, so far as the per-centage of round coals from a given area is concerned:—

1. By Board and Pillar Work.—Suppose the extent of royalty to be 1,000 acres, and the barrier to be 22 yards, then the proportion left underground in barrier, and of course irrecoverable, is ... ... 4·00 ℔ cent.

Suppose the winnings to be 12 yards, and to be holed at 26 yards, 2 yards wide; also that in working the pillars, 1 yard in width for the whole length of the pillar is lost (and this is a very moderate computation), this amounts to ... ... 8·33 ℔ cent.

The coal which is rendered unavailable by troubles, &c., cannot be taken at less than... 2·66 ℔ cent.

Coal lost underground ... ... 15·00 ℔ cent.

If the mine is wrought by separation—viz., the workmen separating the round from the small coal, and only sending the former to the surface, the proportion of small left underground, and skreened out at bank, will be at least on the average equal to........................ 30·00 ℔ cent.

And if the coal is filled up altogether ... ... 33·00 ℔ cent.

Carried forward ... ... 15·00 ℔ cent.

Brought forward ... ... 15·00 ⅌ cent.

And supposing in three-fourths of the mines the whole to be sent to the surface, the average quantity of small coal taken out may be 32·25 ⅌ cent., or of the whole area ... ... 27·41 ⅌ cent.

Total loss by barriers, pillar-working, and skreening ... ... 42·41 ⅌ cent.

2. By Long Work.—By the long wall, the loss by barriers and troubles will be the same as in the former estimate, viz. ... ... 6·66 ⅌ cent.

There will be a considerable proportion of round coal in the kirvings, but since when the juds fall some small will be made, we may take the whole of the kirvings to be small coal. On the supposition that the thickness of the seam is 4½ feet, and the average height of the kirving (or undermining) 8 inches, the produce of small from the coal worked will be 14·8 ⅌ cent., and of the whole area ... ... 13·81 ⅌ cent.

Add additional loss in transit from workings, over skreens and into waggons ... 8·00 ⅌ cent.

Total loss by barriers, working, and skreening ... ... 28·47 ⅌ cent.

According to the above estimate, the produce of round coal from 1,000 acres worked by the board and pillar method, as compared with the same extent worked by the long way, would be in the proportion of about 58 to 71.

The circumstances under which the long wall system is most applicable are as follow :—

The seam should not be fiery; or, if fiery, should be worked exclusively with safety lamps.

Thin seams are most economically worked by long wall.

The roof should be of such a nature as to be taken down without much difficulty, and should consist of tolerably hard stone.

A seam of coal containing a strong stone band is well adapted for working by the long way.

The depth from the surface is immaterial.

There are several intermediate methods of working coal, partaking of both principles explained above; for instance, in several of the northern collieries, the plan of leaving very large pillars, say 50 yards square, with the intention of working off such pillars by long work has been adopted, and with considerable success, both as regards the produce of round coal and the cost of propping; also in many of the southern collieries, instead of carrying the face forward and following it by roads through the goaf, the plan of at once driving excavations to the extremity of a district, and bringing the wall-face backward towards the shaft, is most approved of. The method of working a very thick seam of coal, such, for instance, as that found in Staffordshire, varies from either of those just mentioned. A section of the Ten-yard coal is as follows :—

	FT.	IN.
White coal	3	0
Tow (or tough) coal	2	3
Benches and Brazils	4	6
Carried forward	9	9

		FT.	IN.
Brought forward	...	9	9
Foot coal	...	2	3
Slip batt	...	2	3
Slips	...	2	3
Stone coal parting	...	0	4
Stone coal and patchells	...	4	6
Penny coal	...	0	6
Springs and slippers	...	4	6
Humfry batt	...	0	4
Humfries	...	2	3
Total	...	28	11

The manner of working this seam consists in driving a pair of drifts from the shaft, and after these have reached as far as the winnings are required to extend, other excavations are turned away out of them, narrow, and after proceeding a few yards are laid out wide, in a manner not unlike that adopted in the rock salt mines, small pillars 7 or 8 yards square being left at stated intervals for the support of the roof. In conducting these workings, immense quantities of small coal are left underground, which, on account of the warmth generated by the decomposition of the iron pyrites contained in the coal, soon begin to heat, and would ultimately burst into flame, were not the precaution taken of keeping each district isolated, and capable of being stopped up by a dam, as soon as indications of the heating of the rubbish are observed.

The working of so large a seam, says Mr. Dunn, by a single process, is attended with many difficulties; and although a considerable quantity of roof coal be left on, yet it frequently breaks away, as also huge masses of coal, in the course of working, so that there is a continual loss of life accruing from falls of coal alone; and when so immense a space becomes inadequately supplied with air, the consequence is obvious in respect to fires and explosions. In former times, the gas which accumulated in the upper recesses of this large seam was fired from time to time to the imminent loss of life, but that barbarous practice has been long since laid aside.

In the working of the 30-feet seam, the small coal necessarily produced and left below during the process of mining, and the loss of coal in pillars and barriers, amount, in the opinion of well-informed persons in the district, to considerably more than one-half of the whole contents of the mine; and according to others, two-thirds. The thickness of small coal left amounts to 8 or 10 feet.

The first process of extraction consists in undermining the bottom part of the seam with light picks, building up small supports of stone called "cogs" to support the mass of coal. A sufficient quantity of coal having been thus undermined, the next operation, done by the same men, is to cut upwards between the mass of coal which is intended to fall, and that which is intended to stand as a pillar to support the roof of the mine. This cutting or separating the coal from the pillars must be performed on both sides of the mass which is to be let fall, and also at the end, where it joins on to the remaining solid mass. It would not be safe, however, to cut it in this way completely off from the pillars, so that small supports are still left, called "spurns," which connect the mass to be thrown down with the pillars. The coal is cut through until the parting is reached which forms a natural division of the lower bed from the next above it, or sometimes two beds are cut through at once, but always to a natural parting, the cutting being made perpendicularly up the face of the pillar. After the cutting up is completed and the men have withdrawn, the most skilful, with a long pricker, cuts and tears away the spurns and cogs, when the mass of several tons falls together. In this manner, after holing out the lower beds, those above are successively brought down. Where, instead of having a seam of coal of the enormous thickness just described, we have the thickness of the bed not more than perhaps 14 or 16 inches, the board and pillar system, from its expense, is generally inapplicable: the usual way of working is either to make height in the middle of a place, and work from it on each side as far as the miner can reach, or to work it by the long way, stowing as much rubbish as possible, and drawing the remainder to the surface.

The various alterations and improvements which have taken place in the mode of conveyance of coal underground, from the face of work to the shaft, have contributed so materially to increase the quantities produced at individual mines, that a brief sketch of them may not be inappropriate in this place.

The first method which would be adopted, is that which does not require any particular sort of carriage or description of road; a simple basket, filled with coal, and carried upon the back from the face to the shaft, and in some instances to the surface, constituting the whole apparatus. This rude system (the coal being carried by women) was prevalent in parts of Scotland until within a very recent period, when it was suppressed by Act of Parliament, 5 and 6 Victoria, cap. 99.

The next means used appears to have been the wheelbarrow, which we discover by the old materials found in recently opened ancient workings to have been in general use about the seventeenth century.

Next came the sledge, or sled as it is commonly called, which consisted of a wooden box resting upon iron shoes, and drawn along the pavement of the coal. These were probably in common use one hundred years ago.

The next improvement was the substitution of planks for the floor of the coal, for the sledge to slide upon.

The attaching of wheels to the sledge soon suggested itself, thus constituting very nearly the tub now used, but it was many years before the tub so nearly stumbled upon was applied as at present. Shortly, however, after the contrivance of the tram with wheels, the application of corves and rolleys took place; and although it soon became the custom for a single corf upon its rolley to be drawn by one horse, yet with the exception of the introduction of metal and iron rails, little improvement subsequently took place until within a very few years of the present date.

The first step in advance was the attachment of several rolleys together, each rolley carrying at first one, and afterwards two, corves; a horse-load becoming, as the ways improved, four or six corves of 6 cwt. of coals each.

Corves were found, however, to be both expensive and clumsy; and about the year 1835, coal tubs, in pretty much their present form, were generally introduced, the only difference, in fact, being that they were at first constructed with sharp-edged or tram wheels, instead of flanched wheels as at present. The tubs attached to their wheels were placed upon rolleys, capable of carrying two or three at a time, and drawn by horses to the shaft: upon well-constructed rolleyways a horse load by this means was usually from 8 to 12 tubs, although in some instances 18 or 20.

About the year 1841 or 1842, the plan of drawing the tubs along the rolleyways to the shaft upon their own wheels suggested itself, which is the plan now adopted, thus very nearly returning to the single corf rolley, or more remote sledge on wheels, above named. The advantages resulting from this change are very great, for not only can a horse draw a greater number of tubs by not having the dead weight of the rolley to draw, but, what is of perhaps greater value in practice, in case of accidents from tubs getting off the way, much less damage is done in the first instance, and much less time lost in putting matters right.

One of the greatest improvements in the method of bringing out coals from the hewer to the horse road, consists in the substitution of small ponies for barrowmen or putters, the ponies drawing one tub at a time, and being managed by little boys from 14 to 15 years of age. The chief saving is in working to the dip, the ponies being able to bring out their load in moderate inclinations where, with putters, extra assistance would be necessary.

Machinery is now much employed in the transit of coals underground; and the form of engine generally best adapted to such work consists in having two horizontal cylinders, the engine working in the manner of a locomotive, but simply turning drums instead of wheels. (Plate 59.)

The steam to such engines is frequently supplied from boilers placed aboveground, and piped down the shaft. It is found that there is exceedingly little loss of pressure—probably, with proper care, not more than 1lb per square inch in a distance of 500 yards.

When applicable, however, the cheapest method of conveyance is by self-acting inclined planes: they may be introduced under any circumstances where the inclination is not less than 1 in 36, or, if very great care be used in their construction, 1 in 40.

As regards the labour of separating the coal from the mine, notwithstanding that many attempts have been made to apply machinery to this purpose, no improvements whatever have been effected since the commencement of working coal, but, as regards the size of the coal produced, rather the reverse. The pick, the maul, and the wedge, are the same tools which (made perhaps of a different, mayhap better, material) were employed in the days of

William the Conqueror. Facilities have certainly been given to the increase of quantity by the use of gunpowder, but at the expense of a much greater quantity of small coal made and wasted, and of a much more friable and shattered state of the large coal left.

A machine was, as I have heard, invented by the late Mr. William Brown, of Benton, and called in common parlance, " Willie Brown's Iron-man ;" but as this instrument only did the work of one man, and required three or four to work it, the economy of its use was not so obvious as to bring it into general favour.

Mr. Waring, of Neath Abbey, in Glamorganshire, has patented a coal-cutting machine, which, in preparing coal for bringing down with wedges, powder, or otherwise, appears to cause considerably less waste than the ordinary method of undermining with picks. It would perhaps be premature to express any decided opinion upon the merits of this contrivance.

4. COPPER, LEAD, TIN.

In commencing a copper mine from the surface, a vein or portion of a lode containing ore is seldom met with at a less depth than 10 or 20 fathoms from the surface. A shaft is first sunk, and at about 10 fathoms in depth a horizontal level or gallery is driven by two sets of men working in opposite directions, the ores and stuff being raised by a windlass. When this level is driven about 50 fathoms, two shafts are made at either extremity for airing the mine: this level can be carried on to any extent.

The engine shaft being sunk deeper, similar levels are driven at every 10 fathoms in depth, the shaft being always sunk to a greater depth than the lowest level. The mine being thus divided into right-angled masses of 50 fathoms in length and 10 in height, these masses are again subdivided by small perpendicular shafts or winzes into masses of about 10 fathoms in height and 16 in length—the mine being thus finally divided into pitches.

Levels are about 3 feet wide and 6 or 7 feet high, and cut in the body of the vein.

Each pitch is now let to a tributer, who, with his para or gang, break, raise, and pay for dressing the ores, the weekly or monthly produce being made into heaps of about 100 tons each.

Samples of it are sent to assayers to determine the value according to the produce or quantity of fine copper contained in 100 parts of ore, and the samplings are then sold at the weekly ticketings, and the tributers receive a certain share of the value of the ores for their labour. The tributer may not for many months earn a remunerating profit, but if the indications of the lode be favourable, he will at every letting renew his bargain, in the hope that the lode may eventually become rich. If before the completion of his term his expectations become realized, he and his gang are often able to work out ore to the value of £60 to £100 each, sometimes more; but at the next renewal the rate of tribute is re-adjusted, and fair wages earned until the lode fails.

Should the pitch or compartment turn out bad, the miner at any time has a right to abandon his bargain, by paying a fine of 20s. The quantity of timber used annually in the Cornish and Devon mines is very considerable, amounting to about £50,000, and consists almost entirely of Norwegian pine.

The discovery of gunpowder forms a grand epoch in the history of mining, but it is difficult to ascertain the exact time when blasting first came into use among the Cornish miners. It was first used in Hungary or Germany about 1620, and was introduced into England at the Ecton copper mine by German miners, brought over by Prince Rupert. It was not known in Somersetshire until the year 1634, after which it was introduced into Cornwall. The annual quantity of gunpowder used in the Cornish mines has been estimated at 300 tons of 2,000lbs. each.—(Watson's Compendium of British Mining.)

The ores of lead and tin, being found lying in a similar position to that of copper, are worked in the same or nearly the same manner as above described. Plate 21 is a plan of part of the workings of the silver-band lead mine at Cronkley, in the manor of Lune, in Yorkshire.

CHAPTER VII.

On the Gases and Ventilation of Mines.

It appears that the volume of air inhaled by a man is about 19 cubic mêtres in 24 hours, or 792 litres an hour. The volume of carbonic acid gas exhaled is about $\frac{1}{33}$ part of the volume of the air inspired; consequently, a man exhales 570 litres per day, or 24 litres per hour, of carbonic acid gas; and a litre being 0·264 gallons, the quantity of air inspired by a man is 209 gallons hourly, and the quantity of carbonic acid gas expired 6·336 gallons per hour.—(Annales des Mines, first series, volume 10, pp. 45-47.)

According to Sir Humphrey Davy and Dr. Henderson, about 5 cubic inches of azote are consumed every minute by an ordinary-sized man; Allen and Pepys say that azote is given out by the lungs; and Ellis has laboured to shew that in respiration the natural azote of the atmosphere is untouched in quantity and unchanged in quality.

The combustion of candles or lamps absorbs a quantity of oxygen, which depends on the nature and weight of the substance burnt in a given time. There are at the same time produced, carbonic acid gas and watery vapour. The combustion of a lamp of the largest size employed in mines consumes less oxygen than the respiration of one workman.

The oxygen of the air is also absorbed by the chemical decomposition of many substances which are ordinarily found in mines. Thus, under the compound influence of air and moisture, sulphurets are transformed into sulphates, as in the case of iron pyrites, which we find transformed into sulphate of iron; and we know that vegetable and animal matters in the same circumstances undergo a putrid fermentation, in which the oxygen of the air disappears, combining with some of the elementary principles of these substances—the products being dissipated into the surrounding air: these are chiefly carbonic acid gas, carbonic oxide (?), gaseous compounds of carbon and hydrogen, azote, and ammonia. These gases are mixed with other substances, which chemical analysis has been unable to isolate: they have usually a sickly odour, and exercise over people who respire them an action in the highest degree deleterious: they have received the name of miasmata.

The gases due to the chemical decomposition of certain substances are principally those which are formed by the deflagration of the powder employed in the works of the mines—varied, most probably, by the charge of powder, and perhaps, also, as it is more or less damp, and the combustion consequently more or less perfect, they form a composition of carbonic acid, azote, oxide of carbon, watery vapour, carburetted hydrogen, and a little sulphuretted hydrogen.

The solid products of the detonation, which are composed of unburnt powder, sulphate of potash, and sulphuret of potassium, are projected in very minute particles into the surrounding air, which is obscured by them. The fumes of powder, blasting powder especially, have a disagreeable odour, and irritate powerfully the organs of respiration; consequently, it is indispensable to expel them by the prompt renewal of the air in the place where the blasting has taken place.

The gases met with in mines, which, when insufficiently diluted with atmospheric air, are productive of deleterious effects upon the workmen, or capable of forming with it an explosive compound, are as follows:—

1. *Carbonic Acid*, called also stythe or black damp.
2. ~~*Byhydruret*~~ Bihydruret *of Carbon*, called also fire-damp, mixed occasionally with ***Hydruret of Carbon or Olefiant Gas***, according to some continental authorities.
3. ***Sulphuretted Hydrogen***, rarely.
4. *Oxide of Carbon?*

1. Carbonic Acid consists of 2 atoms of oxygen and 1 atom of carbon; its specific gravity, as compared with air is 1·524; weight of 100 cubic inches, 46·576 grains; water absorbs nearly its own volume of this gas; caustic alkalies and alkaline earths absorb it very rapidly. It is unfit for the support of combustion and respiration: atmospheric air mixed with one-tenth of this gas becomes unfit for the support of combustion, and lights burn badly in an atmosphere containing from 5 to 6 per cent.: air containing about 8 per cent. of carbonic acid cannot be respired without danger. This gas appears to act on persons who respire it in the manner of poisons, and it is necessary, in order to prevent its effect being fatal, that persons asphyxiated by this gas should remain in it a very short time: when they recover from it they remain unwell, particularly with violent headache, for some days.

Carbonic acid is frequently disengaged in mines, from the fissures and cavities of the strata, and is formed, moreover, by the respiration of the workmen and horses, and also by the combustion of lights and deflagration of gunpowder.

On account of its great specific gravity, carbonic acid has a tendency to accumulate in greater quantity in the low parts of all excavations, notwithstanding the general property possessed by gases of intermixing or diffusing themselves throughout each other, when contained in any isolated space.

2. ~~Byhydruret~~ Bihydruret of Carbon or Fire-damp is composed of 2 atoms of hydrogen and 1 atom of carbon; its specific gravity is 0·555, and the weight of 100 cubic inches is 16·92 grains; it is insoluble in water, and is not absorbed by alkalies. When mixed with atmospheric air in the proportion of from 1-30th to 1-15th of the total volume, the flame of a

candle plunged into the mixture is elongated according as the proportion of inflammable gas approaches 1-15th of the volume. The flame of the wick is surrounded by a halo of pale blue, which is most perceptible towards the point. The combustion only takes place around the wick, and does not extend to the surrounding mass. When the fire-damp forms 1-14th of the total volume, the inflammation extends throughout the whole gaseous mass, but without loud detonation. The rapidity of the inflammation increases with the proportion of the inflammable gas, until it amounts to 1-9th or 1-8th of the total volume: in these latter proportions the mixture is explosive in the highest degree. If the proportion of fire-damp is increased still further, the mixture becomes less and less explosive; and when the mixture contains more than one-third of the volume of gas, it is no longer inflammable, but any flame immersed in it is, on the contrary, extinguished.

The contact of iron or coal at a red heat is not sufficient to produce the inflammation of fire-damp mixed with air: the presence of flame is necessary.[1]

Azote or carbonic acid, added even in small proportion to an explosive mixture of air and fire-damp, weakens or even prevents explosion—1-7th of carbonic acid added to a mixture the most explosive sufficing to render it the contrary. Byhydruret of carbon mixed with atmospheric air can be respired without danger, so long as it constitutes less than one-third part of the total volume; beyond this proportion it causes asphyxia by insufficiency of oxygen.

Fire-damp is disengaged from the mud in marshes and from all stagnant waters, whence it may be easily obtained by stirring up the mud with a stick, and placing an inverted bottle full of water over the bubbles as they arise. In some localities it flows from the fissures of the soil, and gives rise to natural fires which exist in many places. Borings executed in exploring for rock-salt have sometimes produced abundant jets of this gas. But it is principally found in mines of coal, escaping from the cells of this mineral with a slight noise, analogous to that produced by boiling water. It is generally disengaged in the greatest abundance in places which are in the neighbourhood of faults, near which the nature of the coal is altered. There are also, in the interior of coal-beds, cavities where the gas is pent up under considerable pressure, and from which it escapes suddenly whenever the side of the

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[1] This, the generally received opinion, ought not to be too confidently relied on, as is shewn by the following experiment, made by Mr. R. Simpson and myself at Townley colliery, May 27th, 1853:—

The gas experimented on passed through a drowned drift in the Three-quarter seam, and was conveyed by means of a pipe in the shaft to the surface: it then passed through naphtha into a gasometer, and thence to various burners in the shops and elsewhere. There was also a cock between the top of the shaft and the naphtha vessel, whence, when opened, the gas issued in its natural form. The first experiment consisted in placing a bolt about 2 inches in diameter, heated to a cherry red, in contact with the naphthalized gas in the smith's shop. The gas was immediately inflamed: in a short time, however, the iron, still at a good red heat, ceased to possess the power of exploding the gas. Precisely the same effects were produced when the iron was applied to the gas issuing from the cock between the pit and naphtha vessel.—(Transactions of the North of England Institute of Mining Engineers, volume 1.)

cavity nearest to the workings is weakened by their approach, so as no longer to be able to withstand the internal pressure.

The following facts have been recorded of the volumes and pressures of gas yielded under circumstances of this nature at Walker colliery.—(See Report on the Ventilation of Mines and Collieries, by John Phillips, Esq., F.R.S., page 8.)

The first was experienced, Nov. 13th, 1846 : on this occasion a mass of coal was displaced, 8 feet long on one side, 4 feet on the other and nearly 6 feet high. This, with the disintegrated or danty coal which slipped from the dyke, must have weighed about 11 tons. A discharge of fire-damp ensued: the two men working in the place secured their lamps (one of which had been partially covered with the fall of coal, but continued to burn; the other, nearest the issue of gas, had been put out), drew down the wick of that which continued to burn, hastened to apprise the other men in the pit, extinguishing the lamps as they proceeded, and finally retired to the shaft. The extent of airways fouled at the same time contained about 41,681 cubic feet, and in from 15 to 20 minutes after the eruption, there were no longer any traces of fire-damp. The air moved in this part of the mine at the rate of 6·24 feet per second, the quantity passing per minute amounting to 10,483 cubic feet. A second discharge of fire-damp took place on the 10th December, 1846, at a different point of the same slip : in this case the gas came off from the danty coal with a violent noise, like the blowing off of high pressure steam, and fouled the air-courses for an extent of 641 yards in length, with an area of 86,306 cubic feet. The air was circulating at the rate of 5½ feet per second, and the quantity was about 16,000 cubic feet per minute. After 12 or 15 minutes all appearance of gas had ceased, excepting near the point of issue of the blowers.

A similar discharge to that at Walker was the cause of the explosion of Jarrow Colliery, in the year 1830. (See Mr. Buddle's account of this explosion, in the Transactions of the Natural History Society, of Newcastle-upon Tyne, volume 1.)

According to Sir H. T. de la Beche and Dr. Lyon Playfair, the analyses of fire-damp obtained from the coal mines of the North of England presented the following results :—

CONSTITUENT PARTS.	Wallsend: from Pipe on Surface.	Wallsend Bensham Seam.	Jarrow Bensham Seam.	Hebburn Bensham Seam, 161 fms. in depth.	Jarrow Low Main.	Jarrow Five-Quarter Seam.	Gateshead Oakwellgate Five-Quarter Seam.	Coal 24 feet below Bensham Seam, Hebburn.
Byhydruret of carbon	92·8	77·5	83·1	86·0	79·7	93·4	98·2	92·7
Nitrogen...............	6·9	26·1	14·2	12·3	14·3	4·9	1·3	6·4
Oxygen	0·0	0·0	0·6	0 0	3·0	0·0	0·0	0·0
Carbonic acid.........	0·3	1·3	2·1	1·7	2·0	1·7	0·5	0·9
Hydrogen	0·0	0·0	0·0	0·0	3·0	0·0	0·0	0 0
Total	100·0	104·9	100·0	100·0	102·0	100·0	100·0	100·0

The general result of this examination is, that the only inflammable constituent present in the explosive gas of these collieries is byhydruret of carbon. There is not a trace of olefiant gas, and only in one of the eight gases analyzed is there any hydrogen.

When byhydruret of carbon cannot be procured from its natural source, it may be obtained artificially by distilling in a coated glass flask at a red heat the following mixture:—

1 part stick potassa;
1 part dried acetate of soda;
$1\frac{1}{2}$ part quick lime;

all rubbed to fine powder, and well dried.

It is necessary in this place to make some remarks upon the hydruret of carbon, or olefiant gas: it is composed of 1 atom hydrogen, and 1 atom of carbon: its specific gravity is 0·972, and the weight of 100 cubic inches 29·646 grs. It burns with a red flame, of which the illuminating power is much greater than that of byhydruret of carbon. A considerable quantity of this gas is contained in that obtained from coal by distillation, (or common street gas) as appears from the following analyses by Dr. Henry:—

CONSTITUENTS IN VOLUME.

No.	Specific Gravity.	Hydruret of Carbon, or Olefiant Gas.	Byhydruret of Carbon, or Fire-damp.	Carbonic Oxide.	Hydrogen.
1.	0·620	12	64·53	7·33	15·84
2.	0·630	12	57·49	13·35	17·16
3.	0·500	7	55·80	13·95	23·25

Common gas, from its mixture with olefiant and hydrogen gases, is much more inflammable than fire-damp, being easily ignited by iron at a low red heat.

It results from the analyses of M. Bischoff, of Bonn, that olefiant gas is mixed with the fire-damp of many coal-mines—a circumstance which has led this chemist to conclude that the inflammable gases of coal-mines are mixtures in different proportions, according to locality, of fire-damp, olefiant gas, and also of other gases in small quantity.

M. Bischoff has not been able to detect olefiant gas in the inflammable gases of the mines of Gerhard and Wellesweiler, in the coal basin of Sarrebrück, except in such small quantities that the result might be attributed to error in his analysis. It is not the same with the inflammable gas produced by a pit sunk in the principality of Schaumberg in calcareous strata of the lias formation, containing a bed of coal. Here the absorption by chlorine mixed with the gas in an opaque glass flask was considerable, and the eudiometric analysis indicated not less than 16 per cent. in volume of olefiant gas, 79 per cent. of fire-damp and 4·79 per cent. of other gases. Besides, the wire-gauge, capable of arresting the flame of the gas collected in the basin of Sarrebrück, was not sufficiently fine in its texture to stop the flame of the gas obtained in the pit at Schaumberg, and the miners of this locality were, in consequence, obliged to use lamps constructed with gauze finer in the mesh than that used in other coal districts.

Particular experiments have been instituted by Professor Graham on this subject, a notice of which was contained in the "Mining Journal" of June 13th, 1846, from which the following is extracted:—

Killingworth gas: specific gravity		0·6306
Byhydruret of carbon	82·5	
Nitrogen	16·5	
Oxygen	1·0	
		100·0

79 measures of this gas mixed with an equal volume of chlorine, left in the dark for 18 hours, and afterwards washed with alkali, were reduced to 75 measures, from which the presence of 4 measures of olefiant gas might be inferred; but in a comparative experiment made at the same time on 25·3 measures of pure gas of the acetates mixed with an equal volume of chlorine, a contraction occurred of 1·3 measure, which is in exactly the same proportion as with the fire-damp. It was observed that phosphorous remains strongly luminous in this gas mixed with a little air, while the addition of 1-400th part of olefiant gas, or even a smaller proportion of the volatile hydro-carbon vapours, destroyed this property. Olefiant gas and all the allied hydro-carbons were thus excluded.

This, I think, coupled with the results arrived at by Sir H. de la Beche, Dr. Lyon Playfair, Turner, Sir H. Davy, and several other skilful analysts, must be considered conclusive upon this point as regards the fire-damp of English coal-mines yet experimented upon. It would perhaps be as well, however, to have analyses instituted of fire-damp from other localities, in addition to those already examined, before accounting the question as completely set at rest.

3. Sulphuretted Hydrogen.—This gas is characterized by the odour of rotten eggs. It is composed of 1 atom of sulphur and 1 atom of hydrogen: its specific gravity is 1·1805, and the weight of 100 cubic inches is 36·008 grains. It is soluble in water, which is capable of absorbing three times its volume of this gas; alkaline solutions absorb it rapidly; chlorine decomposes it by combining with the hydrogen, forming a deposit of sulphur. Mixed with air, it takes fire at the approach of flame, the products of the combustion being water and sulphurous acid.

When present even in small quantity in a gaseous mixture, it blackens the white oxide of lead and bismuth, which enables us easily to detect its existence. It is sufficient to expose to the mixture in which it is contained, slips of paper which have been dipped in a solution of acetate of lead, and allowed to dry.

It exercises upon the animal economy an influence deleterious in the highest degree: a bird perishes in air containing 1-1500th part of its volume of this gas: 1-800th part is sufficient to kill a moderate-sized dog, and 1-250th part will destroy a horse.—(Thénard.)

The later researches of M. Parent Duchâtelet would, however, seem to shew that the poisonous effects of this gas have been somewhat exaggerated, at least in the application of these results to man. He observed that workmen breathed with impunity an atmosphere containing 1-100th part of sulphuretted hydrogen, and he states that he himself respired, without serious symptoms ensuing, air which contained 3 per cent.

An atmosphere containing from 6 to 8 per cent. of this gas might speedily kill: although nothing certain is known of the proportion required to destroy human life.—(Taylor, Manual of Medical Jurisprudence.)

This gas is formed whenever sulphur in a very comminuted form is brought into contact with hydrogen in a nascent state. Thus, it may form in mines where there is a decomposition of iron pyrites. It has been met with in old colliery workings, but its occurrence is rare.

4. Oxide of Carbon.—This gas consists of 1 atom of oxygen and 1 atom of carbon: its specific gravity is 0·972; weight of 100 cubic inches, 29·64 grains.

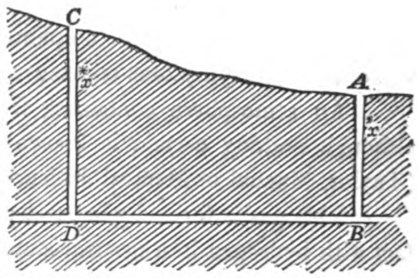
According to the recent work of M. Leblanc, oxide of carbon produces upon the animal economy an action more deleterious than that caused by carbonic acid. It burns with a beautiful blue flame, and gives out but little light: when mixed with common air it does not explode like firedamp, but burns brilliantly; and from this circumstance it appears, that a portion of this gas, contained in any atmosphere, might produce a compound in which a candle would burn brightly, but in which human life must be immediately extinguished; and I am very strongly of opinion that there exist instances of this nature, some fatal accidents having occurred, almost unaccountable excepting under this supposition.

From the properties of the gases above described, we may (excepting in the case of oxide of carbon) penetrate without danger into any atmosphere which we find to possess no disagreeable odour, which will not blacken acetate of lead, and in which a safety-lamp will burn with facility; but as, even under all these circumstances, the atmosphere may, from the presence of oxide of carbon, be unfit for respiration, we are led to the one only practically safe conclusion, that we should under all circumstances be accompanied by a sufficient circulation of fresh air, the means of obtaining which I propose to treat of in the following order:—

1. Natural Ventilation.
2. Artificial Ventilation.
   - a. By *Waterfall.*
   - b. By *Furnace.*
   - c. By *Steam.*
   - d. By *Machinery.*

1.—NATURAL VENTILATION.

When we have two shafts of unequal depths to the same level underground, we have a circulation of air established, the character of which will be as follows:—



Let *A B*, *C D*, be two shafts sunk to the level *B D*, a circulation of air will be established from *A* to *C*, under ordinary circumstances, for the following reason:—It will be remembered that it was stated when treating upon the subject of internal heat, that there is a point, *x*, where the temperature of the earth corresponds with the mean temperature at the surface, and that below this point the temperature increases with the depth. The consequence of this is, that we have a higher mean temperature and lighter column of air, length for length, in the shaft *C D* than in the shaft *A B*, at all times when the surface temperature is as low as, or lower than, the mean temperature of the locality.

As the temperature of the atmosphere however increases, the difference of heat between the two shafts diminishes, and the ventilation becomes gradually more and more feeble until at length, when the temperature of the two shafts becomes equal, it stagnates altogether. It may then happen (especially in pits of small depths), that the ventilation will be reversed, not indeed for any length of time, but only until that which has now become the downcast shall in its turn by the introduction of the hot surface atmosphere again become the warmer of the two.

In pits of great depth, however, where the temperature underground far exceeds any mean, and even equals that of hottest summer, natural ventilation may continue uninterrupted and of considerable power.

The rationale of the motion of a column of air under such circumstances will be explained shortly.

Natural ventilation, however it may be found effectual in deep mines, having few ramifications, accompanied by freedom from inflammable or noxious gases, is quite inadequate to keeping in a safe and healthy state mines where these gases abound: not only on account of its comparative feebleness, but on account of its liability (especially in mines of moderate depth) to be disarranged by changes of atmospheric temperature.

We must, therefore, have, in all mines, artificial means at hand: in some, not perhaps necessary to be used at all times, but immediately applicable under any circumstances affecting the circulation of air produced by natural causes. This then leads us to the consideration of

2.—ARTIFICIAL VENTILATION.

a. The Waterfall.—This may be effected by allowing a portion of water to fall down the downcast shaft, which produces a very good current of air if the water be in any considerable quantity, and the fall great.

The effect of a waterfall, consisting of a quantity of water passing through two holes 1 inch in diameter each, and falling 63 fathoms (the full depth of the pit), may be judged by the following experiment, made at Blackboy Colliery, May 8, 1845.

The colliery was at this time ventilated by a 9-feet furnace, and the experiment was made in one of the working districts, previous to, and after, sub-dividing the portion of air applied to its ventilation.

1. Before splitting the air—

	CUB. FT.	
The quantity passing into the district, with the furnace alone, was ...	8,394	per minute.
After putting on the waterfall, it was...	11,565	„
Increase due to waterfall	3,171	„

2. After splitting the air—

	CUB. FT.	
The quantity passing into the district, with the furnace alone, was ...	11,313	per minute.
After putting on the waterfall, it was	13,687	„
Increase due to waterfall	2,374	„

The reason of this reduced increase will be explained hereafter, when we discuss the important question of resistance.

The following experiment, made at Norwood Colliery, where the depth of the fall was 80 fathoms, also allows us to compare the effect of a waterfall with that of a furnace (June 22, 1850). Furnace, 5 feet wide, and waterfall similar to that first described.

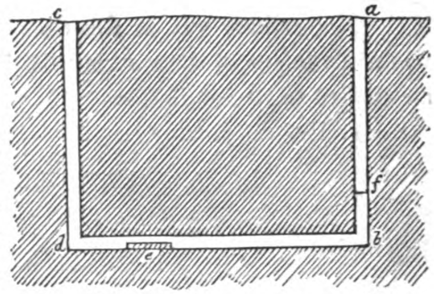
	CUB. FT.	
The quantity of air passing into the district, with the furnace alone, was	9,000	per minute.
After putting on the waterfall, it was...	10,590	„
Increase due to waterfall	1,590	„

The (then) small size of the upcast shaft at the latter colliery, accounts for the diminished increase as compared with the former experiments.

Although, in cases of emergency, the waterfall may be applied as a useful ventilating power, yet it is subject to great objection on two accounts: for it occasions the return into the mine of a considerable quantity of water, which is to be again drawn out, and also produces a dampness in the air, which is very injurious to the timber used in propping, &c., causing its rapid decay. After an explosion, when the furnace is inaccessible, it is a ready way of causing a circulation of air through a mine, but excepting in extreme cases, or when it is necessary to suspend for repairing the ordinary ventilating power, it is a means of ventilation which cannot be recommended.

b. The Furnace.—The system of ventilation usually adopted consists of a furnace or fire placed, near to the bottom of the upcast shaft, for the purpose of rarifying the air contained therein; and would be adopted, in the first instance, in hot weather, on the failure of the ventilation produced by natural causes.

The theory of the action is as follows:—



Let *c d* represent the hot and rarified column of air contained in the upcast, which has passed over the furnace, *e*.

Let *a f* equal that portion of an equal column of cold air, *a b*, which is equal in weight to *c d*: then is *c d* balanced by an imaginary column, *a b*, of which *a f* is cold air and *f b* a vacuum. It is clear then that the velocity of the column *a f* at the point *b*, and, in consequence, that of every cubic foot of air contained in the mine, if the areas are uniform, will theoretically be

$$8 \sqrt{f\,b}.$$

Since, then, upon *f b* the theoretical velocity depends, it may be termed the motive column, in order to find which the following data are necessary:—

$h =$ the height of the upcast column in feet.
$t' =$ the mean temperature of the upcast shaft.
$t =$ .... do. .... cold air.
$x' = t' - 32°$ and $M =$ the motive column.

and the formula is as follows[1]:—

$$M = \frac{h\,(t' - t)}{480 + x'}$$

depending on the circumstance that any aëriform body expands 1-480th part of the volume it

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[1] Here $h - M =$ a column of air at t degrees equal in weight to h at t' degrees.
Let $x =$ the volume of $h - M$, and also of h, both at ... ... 32°.

then $x + \frac{x\,(t - 32°)}{480} = h - M$ ... ... *a.*

but $x + \frac{x\,(t' - 32°)}{480} = h$ ... ... *b.*

or $x = \frac{480h}{480 + t' - 32°}$ ... ... *c.*

∴ By equations *a* and *b*—

$$x + \frac{x\,(t - 32°)}{480} + M = x + \frac{x\,(t' - 32°)}{480}$$

$$\text{or } \frac{x\,(t - 32°)}{480} + M = \frac{x\,(t' - 32°)}{480}$$

$$\text{or } M = \frac{x\,(t' - 32°)}{480} - \frac{x\,(t - 32°)}{480}$$

$$\text{or } M = \frac{x\,(t' - t)}{480}$$

and substituting the value of x, in equation c, we have

$$M = \frac{\frac{480h}{480 + t' - 32}(t' - t)}{480} = \frac{h\,(t' - t)}{480 + t' - 32°}$$

occupied at 32° for every additional degree of Fahrenheit's scale.—(Turner's Chemistry, 6th edition, page 34.)

The theoretical velocity, viz., $8\sqrt{fb} = 8\sqrt{M}$ would be the actual velocity at the bottom of the downcast if the areas of the downcast and upcast were in proportion to the volumes of the cold and hot currents, and if the air moved freely and without friction or resistance against the walls or sides of the shaft and air channels, which is, however, far from being the case.

M. Péclet has given the results of several experiments made by him to determine the ratio between the theoretical and practical velocities of air. (Traité de la Chaleur, volume I., page 379.)

For chimneys lined with brick......... $V' = V \times 2{\cdot}06 \sqrt{\dfrac{D}{L + 4D}}$

Ditto sheet iron... $V' = V \times 3{\cdot}25 \sqrt{\dfrac{D}{L + 10D}}$

Ditto cast iron ... $V' = V \times 4{\cdot}61 \sqrt{\dfrac{D}{L + 20D}}$

Where V' = the practical velocity.
V = the theoretical velocity.
2·06 &c., factors.
D = the diameter, and L = the length of the chimney.

The following experiment was made at Crookbank Colliery (April 27th, 1850), to ascertain how far these formulæ were applicable to the ventilation of mines:—

Depth of downcast	228 feet.
Do. upcast	219 „
Diameter of downcast	9 „
Do. upcast	6 „
Length of a single air-course, formed for the purpose of the experiment, between bottom of downcast and bottom of upcast ...	906 „
Length of channel, from top of downcast to top of upcast	1,353 „
Mean area of do.	36·31 square feet.
Mean temperature of cold air	47° Fahr.
Do. hot air	175° „
Quantity of air per minute	15,948 cubic feet.
Mean velocity per second	7·1885 feet.

From the above data we have—

$$M = \frac{219 \times \overline{175^\circ - 47^\circ}}{480 + \overline{175^\circ - 32^\circ}} = 45 \text{ feet.}$$

$$\text{and } V = 8\sqrt{45} = 53{\cdot}6656 \text{ feet per second.}$$

$$\text{or } V' = V \times 2{\cdot}0295 \sqrt{\frac{D}{L + 4D}}$$

which corresponds very nearly with the first formula of M. Péclet, or that bearing the greatest resemblance to the ordinary air channels of mines.

From the foregoing facts and arguments we draw the following inferences:—

I. That the velocity of the ventilating current increases with the temperature of the upcast shaft.

Because the velocity of the current increases with the length of the motive column, which, other things being equal, depends on the temperature of the upcast shaft.

The converse of this, although not for the same reason, is also true: viz., that the temperature of the upcast shaft, other things being equal, depends on the velocity of the air current; or, in other words, if by using, in addition to the furnace, any mechanical or other means, we increase the quantity of air, we shall find such increase to be in a greater ratio than is due to the mere mechanical agent employed, inasmuch as we shall find a higher mean temperature in the upcast, and the motive column increased in a corresponding degree, owing partly to the more fierce combustion of the furnace, and partly to the more rapid travel of the hot air up the shaft, and consequent higher point which it attains before losing its temperature by absorption, radiation upwards, or whatever cause produces that diminution in heat which takes place so rapidly.

On June 10th, 1853, I made the following experiments at Marley Hill Colliery, with a view of ascertaining to what extent this principle was correct: the increased quantities of air were obtained by various alterations in the run of the air between the down and upcast shafts, these alterations occupying the position of additional mechanical means of ventilation.

	DEPTHS BELOW SURFACE.	TEMPERATURE.			
		DEGREES.	DEGREES.	DEGREES.	DEGREES.
1.	2 Fathoms	91	90½	99½	103
2.	10 "	92	91	99½	104½
3.	15 "	93¼	89½	98	102½
4.	20 "	96½	93	104	109
5.	25 "	97	92	103	108
6.	30 "	97½	95	106	112½
7.	35 "	105	102½	117½	125
8.	40 "	104	101½	117	125
9.	45 "	105	104¾	123½	130
10.	50 "	112	105¾	126	135
11.	55 "	110	108½	130	140½
12.	60 "	122	115	135½	145
13.	65 Fathoms Furnace drift ...	138	136	169½	180½
	Average	104¾	102	117½	124½
Quantity of air in cubic feet per minute...		28,588	27,453	30,511	35,403

II. The quantity of air depends upon the air channels being shortened and made of as large area as possible.

The shortening of the mine channels may be effected, in a great degree, by splitting the air, as it is called, or dividing the main current of the downcast shaft into subordinate currents, each having a separate district to ventilate, instead of causing the main current to travel in an undivided state through the whole of the ramifications of the mine: besides the effect of shortening the run of the air, the other requisite, viz., that of enlarging the average area of the air channel, is also produced by splitting the air.

In splitting the air, two points require particular attention.

1. Not to carry the principle too far, otherwise each split will be feeble and inefficient.
2. To have large channels before splitting the air, and also after the divisions have been re-united.

If any district of a mine evolves so large a quantity of firedamp, that its being mixed with the rest of the return air would raise the whole current to the firing point, the split of air which ventilates such district must of course be taken into the upcast shaft by some other means than by that of the furnace. A drift is therefore driven in fiery collieries from one of the returns into the upcast shaft, by means of which any division of air which is of a dangerous character may be conveyed into it. The point of delivery into the shaft of such drift should not be less than 8 fathoms above the furnace drift end, so as to preclude the possibility of the inflammable gas being ignited by any ascending flame. There are cases in which the whole of the return air must pass into the upcast without contact with any flame: in which case the furnace must be fed entirely with fresh air from the downcast shaft. This was the case at a colliery of which I formerly had the resident management, where the main return would generally fill the safety lamp with flame.

In order to regulate the quantity of air which it is desirable to pass through each district, a description of door is required, which should be 6 feet wide by 3 feet 6 inches in height, fixed in a frame and divided vertically into halves, one of which is moveable behind the other half, which is fixed. This frame is placed in any single return from the districts where the air has the shortest distance to travel, and is opened sufficiently wide to allow the requisite quantity of air to pass through. There ought to be means provided by lock or otherwise of securing the slide in the required position, to prevent any ignorant or mischievous person from altering the proper distribution of the air.

In all firedamp mines, requiring, in consequence, an active ventilation, the necessity of having large airways is paramount to every other consideration whatever:—for it has been established by many experiments made by Messrs. Girard and D'Aubuisson that "the resistance of air increases with the square of the velocity;" and as the velocity is inversely as the area, the resistance is inversely as the area squared. Thus, in two channels of the areas of 20 and 40 square feet, the resistance to the passage of the same quantity of air will be in the ratio of 4 to 1; or in other words, it will require 4 times the power to overcome the resistance in the former case that it will in the latter. From this it will be readily seen that any auxiliary power applied to increase the velocity of a current of air moving in a given channel will produce a less apparent effect when that current moves at a high than at a low speed, owing to greater proportion of the power which is absorbed in overcoming resistance in the former case.—(See experiments with Waterfall, page 175.)

The essentials, then, to produce a good furnace ventilation, may be shortly summed up as follows:—

1. Powerful means of heating the air.
2. Length of heated column, which in shallow mines may be augmented by a tube or chimney of the size of the shaft, and erected over it.
3. Short air courses (equally requisite whatever be the ventilating power employed).
4. Large areas of air channels (ditto).

It would be superfluous in this place to state the lengths or dimensions which ought to be given to upcast shafts or airways: because the circumstances of all mines are so varied, both as regards their extent and the quantity of air they require in order to their being sufficiently ventilated, that no fixed rule would be found applicable to any one mine for any length of time: a few remarks, however, on the construction of furnaces may not be out of place:—

The essential of a complete furnace is that it should possess abundant power of heating to a high degree a rapid current of air of large dimensions.

It is an error to suppose that it is necessary, in order to heat the air to a high temperature, that it ought to be forced through the bars of the furnace: for air should be *forced* nowhere. The fact is, that so great is the radiation of heat from a furnace, that, when properly constructed and attended to, it is capable of heating many times the quantity of air which usually passes over it to as high a temperature as that which ordinarily passes into the upcast shaft.

In the construction of ventilating furnaces the general mistake is to raise the bars too high, which has the effect of contracting the airway above the fire, and thus produces an injurious effect. Where a large furnace is required, the form and dimensions shewn in Plate 60, (figure 1) will be found to work in an efficient manner.

The furnace may be placed near the bottom of the shaft, if used exclusively as an upcast, but should be 50 or 60 yards distant from it if the shaft is used as a winding shaft also, or in cases where gas or dumb drifts are necessary; the drift from the furnace ought to have an inclination upwards towards the pit of not less than 1 in 6.

If the furnace is placed in the seam of coal, we must not omit an arched flue round it, of the full height of the coal, so as to prevent any casualty which might arise from the heat of the furnace causing ignition of the coal.

c. Steam.—In the first report of the North of England Society for Preventing Accidents in Coal Mines, written in 1814 by Mr. Buddle, is a drawing and description of a Steam Ventilator, in which steam is carried down and discharged in a shaft from a boiler placed at the surface: the steam in this case was delivered downwards into the upcast shaft, and the ventilation to be produced was entirely dependent upon the temperature arising from the steam.

The next attempt at steam ventilation was made in Wales, by a person of the name of Stewart, in the year 1828, but the system was not then found to produce the effect required, and consequently abandoned.

The steam blast applied to the locomotive engine having proved so admirably effective in producing that violent draught of air so essential to its wonderful concentration of power, induced Mr. Goldsworthy Gurney to conceive that great benefit would arise from its application, in a somewhat similar manner, to the ventilation of mines; and we find that in July, 1835, before the parliamentary committee appointed to enquire into the causes of accidents in mines, and in October, 1839, in a letter addressed to the committee of a society at South Shields, established for a similar object, that gentleman explained at length his views upon the subject. The form of application as yet best calculated to produce the desired effect is that figured in the report of the last-named committee (see plate 60, figure 2), and consists of a number of jets of high-pressure steam, proportioned to the size of the shaft, directed upwards, and placed near to the bottom of the upcast shaft.

So much importance having been attached to, and so much powerful evidence before various parliamentary committees given in favour of the superiority of, ventilation by high pressure steam, as compared with that by the furnace, the subject has been investigated with the closest scrutiny, and the two powers tested, by most careful experiment, by several practical colliery viewers in the North of England—these experiments are detailed at length in the 1st volume of the Transactions of the North of England Institute of Mining Engineers.

There is no doubt that cases will occur, such, for instance, as in the early workings of a very fiery seam of coal, or in the re-opening of abandoned mines, infested with fire-damp, where the steam jet may be applied with advantage, but in such instances as these no great *quantity* of air is requisite; but as regards the amount of air to be obtained by the furnace and by the steam jet in any form in which it has hitherto appeared, I shall dismiss the subject with the following quotation from the paper communicated to the Institute by its indefatigable president, Mr. Nicholas Wood:—

"In conclusion, the practical result of all these experiments is, that within the limits or range of furnace ventilation, the steam jet acting as a *substitute* is attended with an increase in the expenditure of fuel of nearly 3 to 1, without any corresponding advantage either in the steadiness, security, or efficiency of ventilation; on the contrary, from its simplicity of construction, the steadiness of its action, its less liability to derangement, its economy and its efficiency in cases of emergency, the furnace is a more secure, more safe, and more eligible mode of ventilation than the steam jet.

"And with respect to the steam jet as an *auxiliary* to the furnace, the conclusion is, that the increase of the jets over the furnace is quite inconsiderable—that such increase is extremely unsteady, in some cases nothing at all, when the furnace is urged to its maximum effect; and in the ordinary working state of the furnace (supposing the furnace kept within its limit so as to have adequate spare power in cases of emergency) amounting to only about 2 or 2½ per cent.: that such increase is, however, attended with a loss of power, or increase in the consumption of coal, as compared with the furnace, of nearly 3 to 1—and taking into account the uncertainty of its action, and that the increase of 2 to 2½ per cent. is only obtained when the furnace is about 10 per cent. within its maximum power (see experiment, plate 7, and experiment, table 5)—and seeing, likewise, that when the furnace is urged to its maximum power, in cases of emergency, an increase of 10 per cent. can be immediately obtained by the furnace (see experiment, page 68)—it is quite clear that the steam jet is equally ineligible and inefficient as an *auxiliary* as when applied as a *substitute* for the furnace in the ventilation of coal mines."

d. Machinery.—Several mechanical means of forcing air into mines, or of exhausting it out of them, have at various times been contrived, and in a few instances in this country adopted. On the continent, however, and more particularly in Belgium, where the furnace is considered to be less economical, and is forbidden by law in firedamp collieries, and even associated with dumb drifts, is being abandoned in order to be replaced by ventilators (Mackworth, evidence before committee of the House of Commons, June 23rd, 1853), they are very generally applied to colliery ventilation.

In the first report, by Mr. Buddle, to the society for preventing accidents in coal mines before alluded to, mention is made of an air pump which consists as follows—(plate 60, figure 3)—*a, a, a, a,* is the body of the pump which is square; *b,* its piston; *c, c,* its suction pipe, which communicates by the drift *d, d,* with the upcast *e; f,* a valve or trap door; *g, g,* the intake valves; and *h, h,* the discharging valves.

This pump may be wrought by a steam engine or other machine attached to the piston rod, *k.* It is made of 3-inch fir plank; the piston is 5 feet square; the stroke 8 feet long; and the suction pipe and valves about one-third of the area of the piston. The piston may work with ease 20 strokes per minute, and will draw 8000 cubic feet in that time; but allowing one-fourth less for the inaccuracy of the piston, valves, &c., it will draw 6000 feet per minute. Its power may be increased at pleasure.

A defect in its performance is remedied in another form of air pump, invented by Mr. John Taylor, of Tavistock, and thus described in Brewster's Edinburgh Encyclopedia.

It is represented in plate 60, figure 4. *a,* is a large cistern, nearly filled with water, made of wooden staves, hooped with iron, circular, and from 6 to 8 feet in depth. Through the bottom of this vessel a pipe *b* passes from the mine to be ventilated, and passing up through the water is carried about a foot above it. Upon the top of this pipe is an air-tight valve opening upwards; over this pipe and within the sides of the cistern, a cylinder of plate iron is placed, open at the bottom but close at the top, in which top an air-tight valve is placed also opening upwards. This iron cylinder is made to move in a vertical direction by guides or sliders, and its upper end is attached to a lever or a chain, which is moved either by a water wheel or steam engine. An exhausting machine of this construction may be made from the smallest size to be worked by the hand to any requisite size to be moved by machinery.—(Volume 14, 1820.)

The upper casing and four sets of valves of the former machine, with the airometer working in water substituted for a piston, as seen in the latter, constitute the basis of the machine of Mr. Struvé, which is employed with considerable effect in Wales.—(Plate 60, figure 5.) According to a statement made by Mr. Wood, at a meeting of the North of England Institute of Mining Engineers, on June 3, 1853, a machine of Mr. Struvé's having an airometer 17 feet in diameter, and worked at from 7½ to 8 strokes per minute by a steam engine of 14 horses power, produced a ventilation of 22,000 cubic feet per minute, being 22-25ths of its calculated effect.

In addition to the above may be mentioned the centrifugal ventilator of Mr. W. Brunton; the pneumatic screw of M. Motte; the windmill ventilator of M. Lesoinne; the spiral ventilator of M. Pasquet; the inclined vane fan of M. Letoret; the curved vane fan of M. Combes; the feathering fan of M. Lemielle; and the pneumatic wheels of M. Fabry;—the chief of which are minutely described and illustrated in Mr. Mackworth's evidence, contained in the First Report from the Select Committee of the House of Commons on Accidents in Coal Mines in 1853.

The whole of these machines are liable, however, to one insurmountable objection:—their liability to derangement, and the consequently unventilated state of the mine until they can be repaired. The heat of the upcast shaft of a mine ventilated by furnace is such as to cause a considerable circulation of air for many hours after it has been extinguished; and a proper arrangement with regard to dumb drifts for currents which might chance to be dangerously loaded with explosive gas, will always preclude the slightest risk arising from their passing into too close proximity to the fire.

That air, put in motion, has momentum in common with other bodies, no one will doubt; but that its momentum in mines is almost instantaneously overcome by the friction or resistance of the air channels is equally true. In proof of this, may be stated a fact elicited during the application of the exhausted steam from an underground steam engine to ventilate Belmont Colliery, when each stroke of the engine was distinctly observable in the workings by its effect upon the doors; and in describing the ventilation by Mr. Struvé's machine (before alluded to), Mr. Wood stated that the pulsation of each stroke of airometer piston was distinctly felt in the workings at a considerable distance from the shaft.

CHAPTER VIII.

The Lighting of Mines : Candles : Oil Lamps : Gas : Steel Mills : Safety Lamps.

In the working of mines, where we do not find any fire-damp, we may use throughout the whole of the excavations any species of illuminating power we please: the most usual being the tallow candle or oil lamp.

In the Newcastle district the candle is chiefly used, except near the shafts where more light is requisite, and where in consequence oil lamps or gas lights are substituted.

The pit candle is commonly of small size, weighing from 30 to 50 to the pound; it ought to be made of clean ox tallow, with the wick small and of fine cotton.

In the Scotch collieries, small oil lamps are used, which are carried about by being stuck in the front of the miners' caps.

When gas is used, it may either be manufactured underground, or conveyed down the shaft from a gasometer at the surface. When made underground, the heat from the fires beneath the retorts may be economically applied to aid the ventilation of the mine.

The repeated accidents caused by the explosion of fire-damp in fiery mines, rendered desirable some method of lighting them by an agency, incapable of communicating combustion to the surrounding atmosphere.

The first light used in foul places was supplied by the steel mill, which consists of a brass wheel about 5 inches in diameter with 52 teeth, working a pinion with 11 teeth: on the axle of the latter is fixed a thin steel wheel, from 5 to 6 inches in diameter. The wheels are placed in a light frame of iron, which is suspended by a leather belt round the neck of the person who plays the mill. Great velocity is given to the steel wheel by turning the handle of the toothed wheel; and the sharp edge of a flint, applied to the circumference of the steel wheel, immediately elicits an abundance of sparks and emits a considerable light. When elicited in atmospheric air, they are of a bright appearance, rather inclining to a reddish hue, and as they fly from the wheel seem sharp and pointed. In a current of air mixed with inflammable gas, above the firing point with candles, they increase considerably in size and become more luminous. If played in an atmosphere consisting of freshly discharged gas, and pure atmospheric air in explosive proportions, the sparks become still more luminous, assume a liquid appearance, and speedily produce an explosion. When the inflammable gas predominates in the circulating current, the sparks become of a blood red colour, and, as the proportion increases, the mill ceases to elicit sparks altogether. The mill gives also blood red sparks in carbonic acid.

In addition, however, to its want of security under certain circumstances, the light afforded by the steel mill was at best only an indifferent one, and, as it required the constant employment of a strong lad to work it, was very expensive.

The first safety lamp was invented by the late Dr. William Reid Clanny, of Sunderland, in the year 1813, and tried in the Harrington Mill Pit, in the county of Durham, in an inflammable atmosphere, Nov. 20th, 1815. In this lamp the flame was insulated and supplied with the air necessary for its support by a pair of bellows, the separating medium between the internal and external air being the water through which the air was passed. This lamp was, however, very cumbrous, and was soon superseded by the elegant inventions of the late Mr. George Stephenson and Sir Humphrey Davy.

In the latter part of the year 1815, Mr. Stephenson, then an engineer at Killingworth colliery, directed his attention to the subject, the result of which was his contrivance of a safety lamp; and the process by which he arrived at such a result is explained by himself, as follows :—

"About the month of August, 1815, I was in the habit of making experiments upon blowers, and found that when they were lighted, and a number of lighted candles—namely, four, five, or six—held to the windward of the lighted blowers, the blowers were put out by the burnt air, which was carried towards them. *Hence I conceived that if a lamp could be made to contain the burnt air above the flame, and to permit the fire-damp to come in below in a small quantity, to be burnt as it came in, the burnt air would prevent the passing of explosion upwards, and the velocity of the current would also prevent its passing downwards.*"

Without detailing the various experiments by which Mr. Stephenson arrived at the production of his lamp, it may be simply stated that it is in principle (discarding the wire gauze by which it is now surrounded, as a protection to the glass) as safe as any lamp depending on that portion of it made of glass remaining entire.—(Plate 61, figure 1.)

Sir Humphrey Davy, in 1815 (about the same time with Mr. Stephenson), after having tried without success Kunckel's, Canton's, and Baldwin's Phosphorus, and likewise the electrical light, proceeds in his Treatise on the Safety Lamp to give the details of the various processes and reasonings by which he eventually arrived at the construction of "the Davy," a lamp which, for simplicity and safety under proper management, is still unequalled, and which affords a fine illustration of the great advantage to be derived by practice from the aid of science (plate 61, figure 2.) :—

"In exploding a mixture in a glass tube of one-fourth of an inch in diameter, and a foot long, more than a second was required before the flame reached from one end to the other; and I found that in tubes of one-seventh of an inch in diameter explosive mixtures could not be fired when they were opened in the atmosphere, and that metallic tubes prevented explosion better than glass tubes. I first tried the effect of lamps in which there was a very limited circulation of air, and I found that when a taper in a close lantern was supplied with air so as to burn feebly, from very small apertures below the flame, and at a considerable distance from it, it became extinguished in explosive mixtures; but I ascertained that precautions, which it would be dangerous to trust to workmen, were required to make this form of lamp safe, and that at best it could give only a feeble light; and I immediately adopted systems of tubes, above and below, of that diameter in which I had ascertained that explosions would not take place. In this mode of experimenting I soon discovered that a few apertures, even of very small diameter, were not safe unless their sides were very deep; that a single tube of 1-28th of an inch in diameter, and two inches long, suffered the explosion to pass through it; and that a great number of small tubes, or of apertures, stopped explosion, even when the depths of their sides were only equal to their diameters; and at last I arrived at the conclusion that a metallic tissue, however thin and fine, of which the apertures filled more space than the cooling surface, so as to be permeable to air and light, offered a perfect barrier to explosion, from the force being divided between, and the heat communicated to, an immense number of surfaces.

"My first safety lamps, constructed on these principles, gave light in explosive mixtures containing a great excess of air, but became extinguished in explosive mixtures in which the fire-damp was in sufficient quantity to absorb the whole of the oxygen of the air, so that such mixtures never burnt continuously at the air feeders, which in lamps of this construction was important, as the increase of heat where there was only a small cooling surface would have altered the conditions of security. I made several attempts to construct safety lamps which should give light in all explosive mixtures of fire-damp, and, after complicated combinations, I at length arrived at one evidently the most simple, that of surrounding the light entirely by wire gauze, and making the same tissue feed the flame with air, and emit light.

"In plunging a light surrounded by a cylinder of fine wire gauze into an explosive mixture, I saw the whole cylinder become quietly and gradually filled with flame: the upper part of it soon appeared red hot, yet no explosion was produced. It was easy at once to see that by increasing the cooling surface in the top, or in any other part of the lamp, the heat acquired by it might be diminished to any extent; and I immediately made a number of experiments to perfect this invention, which was evidently the one to be adopted, ***as it excluded the necessity of using glass, or any fusible or brittle substance, in the lamp,*** and not only deprived the fire-damp of its explosive powers, but rendered it a useful light.

"I found that iron wire gauze, composed of 1-40th to 1-60th of an inch in diameter, and containing 28 wires or 784 apertures to the inch, was safe under all circumstances in atmospheres of this kind; and I consequently adopted this material in guarding lamps for the coal mines, where, in January, 1816, they were immediately adopted, and have long been in general use."

Every Davy, to be safe, should of course be in a perfect state: it should always be securely locked when in use, and furnished with a shield, which, in order to combine the necessary protection from currents of gas, by which the lamp is liable to be assailed in every direction, with the requisite transmission of light, should be made of glass or other transparent substance, and extend from the bottom to the top of the lamp, proper arrangements being made for the entrance of the air for the support of combustion.

Since the application of wire gauze by Sir Humphrey Davy, many lamps have been constructed, some of which display great ingenuity, the principal object of which may be stated as being the attempt to combine the safety of the Davy with the illuminating power of the candle.

There can at this day, I think, exist in unprejudiced minds no doubt that this improvement on the Davy, if such it can be called, was arrived at by Mr. Stephenson forty years ago; and the application of glass was condemned by Sir Humphrey Davy himself.

Among the glass lamps may be mentioned the following:—

1. The Clanny lamp, which consists of a lower cylinder of stout glass surrounding the flame, and an upper cylinder of wire gauze of less diameter. In this lamp, the air to feed the lamp passes through the lower part of the wire gauze cylinder, down the inside of the glass cylinder, the burnt air ascending inside of the cold air current, and escaping through the meshes of the upper part of the wire gauze; this then is a lamp protected by a single glass.

2. The Mueseler lamp is extensively used in Belgium, and does not differ much from the Clanny; but in this lamp there is a copper chimney to carry off the smoke from the wick of the burner, and to force the air entering through the wire gauze downwards between the copper chimney and the glass cylinder upon the flame of the burner, the air being admitted through the gauze at the top.

3. The Boty lamp is another modification of this principle, having a glass cylinder with a wire gauze top; but in this the air is admitted through a ring of perforated copper at the bottom of the lamp. In other respects, it does not differ much from the Mueseler lamp.

4. The Eloin lamp has also a glass cylinder: the air is admitted through wire gauze near the bottom of the lamp, and is thrown against the burner by a thin copper cap. No other air enters the lamp than that at the bottom through the gauze, and the space for admission of air being small, it is in consequence easily extinguished. Instead of having a cylinder of gauze for the top, this lamp has a copper or brass top, the exit for the vitiated air being at the top through wire gauze. This lamp has an argand burner, or flat wick: it gives a good light, but the top of the lamp soon becomes excessively hot.

5. The lamp patented by Dr. R. M. Glover and Mr. J. Cail, of Newcastle-on-Tyne, has a double glass cylinder, the air being admitted from the top through wire gauze between the two cylinders, and, passing downwards, enters within the inner cylinder at the bottom of the lamp through a second wire gauze, by which it passes to the burner. The two cylinders are for protection in case of accident; and the air being passed between the cylinders, operates

in keeping the external cylinder cool, and thus removing its liability to crack on exposure to a drop of cold water. The top of the lamp is wire gauze. This lamp, like the Mueseler, has also a chimney, by which, as stated in the specification of the patentees, " currents of air are prevented from affecting the steadiness of the light." This lamp (plate 61, figure 3), although a little complex, I consider to be the best of those dependent on glass for their safety; and, as a surveying lamp, placed in careful hands, I have no hesitation in pronouncing it one of the best lamps which has yet appeared.

As a combination of the safety principle of the wire gauze, the equable currents produced by the double glasses, the brilliant light of the argand burner, with perfect portability, may be mentioned the elegant lamp of Mr. T. Y. Hall, of Newcastle-upon-Tyne.

This lamp (plate 61, figure 4), without presenting (if we may except, as mentioned by Mr. Hall, the cylinder of glass within the gauze, resting upon the dome of the air vault, and closely surrounding the central aperture) any very original features, is chiefly pre-eminent for the beautiful arrangement of its details; and, possessing, as it does, the complete protection of the wire gauze, may be placed in any hands, and may be mentioned as a perfectly safe lamp, when in proper order. To it, however, there is an objection, on account of the number of its parts and the complication of their arrangement, an objection of no inconsiderable importance when we consider the number of persons in whose hands lamps are placed, and the certainty that there will always be some who will not give to them that care and attention without which they are worse than useless.

Proposals have been made to light mines by reflected light. This plan, however, could not probably be found practicable, on account of the obstructions which are continually occurring in the passages.

CHAPTER IX.

Accidents in Mines.

THE chief causes of accidents in mines are explosions of fire-damp, inundations, and falls of stone. There are also accidents arising from the breakage of ropes and chains, and the derangement of machinery.

Explosions may arise from any of the following causes:—

In working in the whole mine, candles being commonly in use, the air, in consequence of bad ventilation, may be gradually loaded with fire-damp to the firing point, in which case we will have a thorough blast, but this is a rare occurrence.

We may have a good ventilation, but a sudden outburst of gas from a blower may rapidly raise it to the firing point. This I believe to have been the cause of many explosions.

The ventilation may wholly cease, from the neglect of doors or injury of stoppings. In this case a district might soon be filled with inflammable air, which would probably result in explosion.

An accident happening to a safety lamp where gas is present may also cause an explosion.

And, as before stated, a good ventilation, mismanaged so as to cause the pressure of the air currents to be from the pillar or lamp districts into those worked with candles, may also be attended with fatal results.

The question is—Are any or all of these causes of accident controllable, and to what extent.

There is no excuse for any accident arising from deficiency of air: because it is quite sufficiently established that a quantity sufficient to meet all ordinary cases may be easily caused to circulate through the workings of a mine, the only requisites being a powerful furnace or the application of some other artificial means of producing ventilation, and, what are of the highest importance, spacious airways.

I believe that, notwithstanding the great quantity of air which we find in many of the collieries of the North of England and elsewhere, a large addition could be made to it by a due attention in this respect. We cannot reduce the resistance in the shafts, &c., so as to make the practical, come any where near the theoretical, velocity: but there is a great margin for the acquirement of an increased quantity through the workings, which is very evident from the construction of the formula relating to the comparison between theoretical and practical velocities. We should always have, if possible, two returns from each district, or, if we cannot effect this, have the single air course continually inspected, so as to preclude the possibility of its becoming at any time contracted and insufficient.

It ought also, generally speaking, to be made a rule to have no timber supports in the return airways, because they are very liable to decay, and, by becoming unable to support the pressure, to break and allow the roof to fall and block up the aircourse. The airways ought, therefore, to be supported by stone pillaring at their sides, which may be constructed of the stone which falls from the roof when the timber props are withdrawn.

As regards the liability to explosion from blowers or "bags of gas" no amount of ventilation can prevent it: the only safeguard against such accidents consisting in the constant and exclusive use of safety lamps in the whole of the working places and returns, naked lights being confined to the rolley ways. In fact, the probability is, that, the greater the ventilation under such circumstances, the greater will the explosion be, on account of the more rapid and extensive formation of explosive compound.

To the safety lamp, then, alone must we look for the prevention of accident in mines subject to sudden outbursts of gas, in which list we may include all which are termed fiery mines.

The only method of preventing accidents arising from neglect of doors or injury of stoppings is, to have an active and intelligent superintendence over such matters. There are, or ought to be, in all fiery mines especially, overmen who, if they cannot immediately detect any deficiency in their air current, are totally unfit for their situations.

An accident may happen to a safety lamp from a fall of stone; and, as far as possible to prevent this, the lamps should be used under strict regulations, printed forms of which should be placed in the hands of the workmen and exposed in conspicuous places about the works.

By far the greatest fatality consequent upon explosions of fire-damp arises from suffocation occasioned by the after-damp.

The following diagram is illustrative of the combustion of fire-damp, of which the product is after-damp, called also choke-damp—

BEFORE COMBUSTION.	ELEMENTARY MIXTURE.		PRODUCTS OF COMBUSTION.
WEIGHT.	ATOMS.	WEIGHT.	WEIGHT.
8 Carburetted hydrogen	1 Carbon	6	22 Carbonic acid.
	1 Hydrogen	1	9 Steam.
	1 Hydrogen	1	9 Steam.
144 Atmospheric air ...	1 Oxygen	8	
	1 Oxygen	8	
	1 Oxygen	8	
	1 Oxygen	8	
	8 Nitrogen	112	112 Uncombined nitrogen.
152.		152	152 Afterdamp

(Williams, *Combustion of Coal.*)

From the above it appears that choke or after-damp consists by weight of 22 parts of carbonic acid, 18 of steam which is condensed, and 112 of uncombined nitrogen; therefore we may call it more correctly a compound of 22 carbonic acid and 112 nitrogen. The specific gravity of such a gas will therefore be 1·066, or so little above that of common air that it may be assumed to form a uniform mixture with it.

The derangement of the air stoppings resulting generally from an explosion causes the air to escape from the downcast to the upcast shaft by more direct channels than the workings where the accident has occurred, the consequence of which is, that in most cases, before the ventilation can be restored, the unfortunate sufferers have ceased to live.

The modes of operation which appear practically (at least to a great extent) to remedy this evil consist in having, when such an arrangement can be effected, the downcast and upcast shafts at opposite extremities of the workings; or in having distinct *pairs* of drifts for intakes or returns, these only being communicated together where rendered absolutely necessary; or, which amounts to the same thing, and possesses the advantage of applicability to existing and extended workings, in having the main returns driven in an upper and adjacent seam of coal, when there is such at no great distance from the working seam. All the necessary artificial barriers between intake and return air courses should, of course, be of the most substantial description. By such precautions as these the force of a blast, by being more confined, might be more powerful; but this possible disadvantage would be many times overbalanced by their certain value in the facility they would afford to the speedy restoration of the circulation of air.

Inundations may happen from one or other of the following causes:—

By incautious workings beneath seas or rivers;

By communication with drowned workings;

Or, by the working out of pillars under drowned wastes.

With regard to the safety or otherwise of working beneath masses of water, whether the same be at the surface or contained in the workings of an upper seam of coal, this must altogether depend upon the situation, the strength and thickness of the coal, and the nature of the superincumbent strata. There may be no danger in working within 20 fathoms of such waters, leaving proper pillars, the removal of which is, of course, out of the question. In the approach of drowned wastes, borings must always be made, as has previously been explained.

With regard to the other accidents arising from falls of stone, breakage of ropes, &c., or derangement of machinery, they fall in a great measure within that category to which we must continue to a greater or less extent liable, in proportion to the number of people employed, and the amount of work they perform. There is no doubt that many accidents might have been, by proper precaution, avoided, but when we reflect that their causes are so numerous, we may well imagine, that even by the most careful, some circumstance, occasioning an accident, may have been overlooked.

All that can be done is, for every one in his own department to give the most unwavering attention to his duties, so that if, notwithstanding this, any accident should occur, he may be clear of that most severe of all punishments, self-condemnation.

In every colliery where inflammable gas is met with, a barometer ought to be placed near the bottom of the shaft, and a daily register kept by the overman of the height of the mercury. He should also, at the same time, test, by experiment, the quantity of air passing into the mine. Instead of the ordinary mercurial barometer, a water barometer might be be easily constructed in the following manner (see plate 61, figure 5):—

Let *A* be a cistern placed at the bottom of the shaft, the level of the water in which is kept constantly the same by a stream of water flowing into it, the surplus being carried away by the waste pipe *B*. *C* is a close topped metal pipe, 36 feet long and 3½ inches in diameter, which is filled with water, plugged up at the surface, and lowered down into the cistern, the bottom of the pipe being allowed to remain 6 inches below the surface of the water when the plug is withdrawn. *D* is a hollow ball of thin brass, which, being passed to the open bottom of the tube, will ascend to the surface of the water in the tube and rise and fall with it. A piece of fine wire cord attached to this ball may be passed round a pulley and conveyed to work the pointer of a dial in the ordinary way. The range of the water as compared with the mercurial barometer being so great, would enable atmospheric changes to be much more easily discoverable, and consequently give earlier notice of the approach of danger.

It is necessary in all mines to have accurate plans, upon which the workings should be registered to within a few weeks of their actual condition: by this means accidents arising from communication with old workings full of water or foul air could never occur.

It may be stated, in conclusion, that few accidents need happen if we avail ourselves to the utmost of those appliances of mining now in our possession. The ventilation we are now able to establish, although there is no doubt but that, in the course of a few years, we shall see it largely increased, is sufficient for most cases, if not for all. Casualties of explosion, so long as unprotected lights are used in the working of fiery mines, will inevitably occur. The machinery of mines, in proper order is safe, so far as the dependence to be placed on the strength and soundness of materials can make it; and ordinary accidents must be averted by carefulness in the general system pursued in carrying on the working of mines.

THE END.

REFERENCE TO THE PLATES.

PLATE.

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