The Story of a Piece of Coal eBook

The Story of a Piece of Coal

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CHAPTER I.

THE ORIGIN OF COAL AND THE PLANTS OF
WHICH IT IS COMPOSED.

From the homely scuttle of coal at the side of the hearth to the gorgeously verdant vegetation of a forest of mammoth trees, might have appeared a somewhat far cry in the eyes of those who lived some fifty years ago. But there are few now who do not know what was the origin of the coal which they use so freely, and which in obedience to their demand has been brought up more than a thousand feet from the bowels of the earth; and, although familiarity has in a sense bred contempt for that which a few shillings will always purchase, in all probability a stray thought does occasionally cross one’s mind, giving birth to feelings of a more or less thankful nature that such a store of heat and light was long ago laid up in this earth of ours for our use, when as yet man was not destined to put in an appearance for many, many ages to come. We can scarcely imagine the industrial condition of our country in the absence of so fortunate a supply of coal; and the many good things which are obtained from it, and the uses to which, as we shall see, it can be put, do indeed demand recognition.

Were our present forests uprooted and overthrown, to be covered by sedimentary deposits such as those which cover our coal-seams, the amount of coal which would be thereby formed for use in some future age, would amount to a thickness of perhaps two or three inches at most, and yet, in one coal-field alone, that of Westphalia, the 117 most important seams, if placed one above the other in immediate succession,

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would amount to no less than 294 feet of coal. From this it is possible to form a faint idea of the enormous growths of vegetation required to form some of our representative coal beds. But the coal is not found in one continuous bed. These numerous seams of coal are interspersed between many thousands of feet of sedimentary deposits, the whole of which form the “coal-measures.” Now, each of these seams represents the growth of a forest, and to explain the whole series it is necessary to suppose that between each deposit the land became overwhelmed by the waters of the sea or lake, and after a long subaqueous period, was again raised into dry land, ready to become the birth-place of another forest, which would again beget, under similarly repeated conditions, another seam of coal. Of the conditions necessary to bring these changes about we will speak later on, but this instance is sufficient to show how inadequate the quantity of fuel would be, were we dependent entirely on our own existing forest growths.

However, we will leave for the present the fascinating pursuit of theorising as to the how and wherefore of these vast beds of coal, relegating the geological part of the study of the carboniferous system to a future chapter, where will be found some more detailed account of the position of the coal-seams in the strata which contain them. At present the actual details of the coal itself will demand our attention.

Coal is the mineral which has resulted, after the lapse of thousands of thousands of years, from the accumulations of vegetable material, caused by the steady yearly shedding of leaves, fronds and spores, from forests which existed in an early age; these accumulated where the trees grew that bore them, and formed in the first place, perhaps, beds of peat; the beds have since been subjected to an ever-increasing pressure of accumulating strata above them, compressing the sheddings of a whole forest into a thickness in some cases of a few inches of coal, and have been acted upon by the internal heat of the earth, which has caused them to part, to a varying degree, with some of their component gases. If we reason from analogy, we are compelled to admit that the origin of coal is due to the accumulation of vegetation, of which more scattered, but more distinct, representative specimens occur in the shales and clays above and below the coal-seams. But we are also able to examine the texture itself of the various coals by submitting extremely thin slices to a strong light under the microscope, and are thus enabled to decide whether the particular coal we are examining is formed of conifers, horse-tails, club-mosses, or ferns, or whether it consists simply of the accumulated sheddings of all, or perhaps, as in some instances, of innumerable spores.

In this way the structure of coal can be accurately determined. Were we artificially to prepare a mass of vegetable substance, and covering it up entirely, subject it to great pressure, so that but little of the volatile gases which would be formed could escape, we might in the course of time produce something approaching coal, but whether we obtained lignite, jet, common bituminous coal, or anthracite, would depend upon the possibilities of escape for the gases contained in the mass.

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Everybody has doubtless noticed that, when a stagnant pool which contains a good deal of decaying vegetation is stirred, bubbles of gas rise to the surface from the mud below. This gas is known as marsh-gas, or light carburetted hydrogen, and gives rise to the *ignis fatuus* which hovers about marshy land, and which is said to lure the weary traveller to his doom. The vegetable mud is here undergoing rapid decomposition, as there is nothing to stay its progress, and no superposed load of strata confining its resulting products within itself. The gases therefore escape, and the breaking-up of the tissues of the vegetation goes on rapidly.

The chemical changes which have taken place in the beds of vegetation of the carboniferous epoch, and which have transformed it into coal, are even now but imperfectly understood. All we know is that, under certain circumstances, one kind of coal is formed, whilst under other conditions, other kinds have resulted; whilst in some cases the processes have resulted in the preparation of large quantities of mineral oils, such as naphtha and petroleum. Oils are also artificially produced from the so-called waste-products of the gas-works, but in some parts of the world the process of their manufacture has gone on naturally, and a yearly increasing quantity is being utilised. In England oil has been pumped up from the carboniferous strata of Coalbrook Dale, whilst in Sussex it has been found in smaller quantities, where, in all probability, it has had its origin in the lignitic beds of the Wealden strata. Immense quantities are used for fuel by the Russian steamers on the Caspian Sea, the Baku petroleum wells being a most valuable possession. In Sicily, Persia, and, far more important, in the United States, mineral oils are found in great quantity.

In all probability coniferous trees, similar to the living firs, pines, larches, &c., gave rise for the most part to the mineral oils. The class of living *coniferae* is well known for the various oils which it furnishes naturally, and for others which its representatives yield on being subjected to distillation. The gradually increasing amount of heat which we meet the deeper we go beneath the surface, has been the cause of a slow and continuous distillation, whilst the oil so distilled has found its way to the surface in the shape of mineral-oil springs, or has accumulated in troughs in the strata, ready for use, to be drawn up when a well has been sunk into it.

The plants which have gone to make up the coal are not at once apparent to the naked eye. We have to search among the shales and clays and sandstones which enclose the coal-seams, and in these we find petrified specimens which enable us to build up in our mind pictures of the vegetable creation which formed the jungles and forests of these immensely remote ages, and which, densely packed together on the old forest floor of those days, is now apparent to us as coal.

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[Illustration: Fig. 2.—*Annularia radiata.* Carboniferous sandstone.]

A very large proportion of the plants which have been found in the coal-bearing strata consists of numerous species of ferns, the number of actual species which have been preserved for us in our English coal, being double the number now existing in Europe. The greater part of these do not seem to have been very much larger than our own living ferns, and, indeed, many of them bear a close resemblance to some of our own living species. The impressions they have left on the shales of the coal-measures are most striking, and point to a time when the sandy clay which imbedded them was borne by water in a very tranquil manner, to be deposited where the ferns had grown, enveloping them gradually, and consolidating them into their mass of future shale. In one species known as the *neuropteris*, the nerves of the leaves are as clear and as apparent as in a newly-grown fern, the name being derived from two Greek words meaning "nerve-fern." It is interesting to consider the history of such a leaf, throughout the ages that have elapsed since it was part of a living fern. First it grew up as a new frond, then gradually unfolded itself, and developed into the perfect fern. Then it became cut off by the rising waters, and buried beneath an accumulation of sediment, and while momentous changes have gone on in connection with the surface of the earth, it has lain dormant in its hiding-place exactly as we see it, until now excavated, with its contemporaneous vegetation, to form fuel for our winter fires.

[Illustration: FIG. 3.—*Rhacopteris inaequilatera.* Carboniferous limestone.]

Although many of the ferns greatly resembled existing species, yet there were others in these ancient days utterly unlike anything indigenous to England now. There were undoubted tree-ferns, similar to those which thrive now so luxuriously in the tropics, and which throw out their graceful crowns of ferns at the head of a naked stem, whilst on the bark are the marks at different levels of the points of attachment of former leaves. These have left in their places cicatrices or scars, showing the places from which they formerly grew. Amongst the tree-ferns found are *megaphyton*, *paloeopteris*, and *caulopteris*, all of which have these marks upon them, thus proving that at one time even tree-ferns had a habitat in England.

[Illustration: Fig. 4.—Frond of *Pecopteris.* Coal-shale.]

One form of tree-fern is known by the name of *Psaronius*, and this was peculiar in the possession of masses of aerial roots grouped round the stem. Some of the smaller species exhibit forms of leaves which are utterly unknown in the nomenclature of living ferns. Most have had names assigned to them in accordance with certain characteristics which they possess. This was the more possible since the fossilised impressions had been retained in so distinct

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a manner. Here before us is a specimen in a shale of *pecopteris*, as it is called, (*pekos*, a comb). The leaf in some species is not altogether unlike the well-known living fern *osmunda*. The position of the pinnules on both sides of the central stalk are seen in the fossil to be shaped something like a comb, or a saw, whilst up the centre of each pinnule the vein is as prominent and noticeable as if the fern were but yesterday waving gracefully in the air, and but to-day imbedded in its shaly bed.

[Illustration: FIG. 5.—*Pecopteris Serlii*. Coal-shale.]

Sphenopteris, or “wedge-fern,” is the name applied to another coal-fern; *glossopteris*, or “tongue-leaf”; *cyclopteris*, or “round-leaf”; *odonlopteris,* or “tooth-leaf,” and many others, show their chief characteristics in the names which they individually bear. *Alethopteris* appears to have been the common brake of the coal-period, and in some respects resembles *pecopteris*.

[Illustration: Fig. 6.—*Sphenopteris Affinis.* Coal-shale.]

In some species of ferns so exact are the representations which they have impressed on the shale which contains them, that not only are the veins and nerves distinctly visible, but even the fructification still remains in the shape of the marks left by the so-called seeds on the backs of the leaves. Something more than a passing look at the coal specimens in a good museum will well repay the time so spent.

What are known as septarian nodules, or snake-stones, are, at certain places, common in the carboniferous strata. They are composed of layers of ironstone and sandstone which have segregated around some central object, such as a fern-leaf or a shell. When the leaf of a fern has been found to be the central object, it has been noticed that the leaf can sometimes be separated from the stone in the form of a carbonaceous film.

Experiments were made many years ago by M. Goppert to illustrate the process of fossilisation of ferns. Having placed some living ferns in a mass of clay and dried them, he exposed them to a red heat, and obtained thereby striking resemblances to fossil plants. According to the degree of heat to which they were subjected, the plants were found to be either brown, a shining black, or entirely lost. In the last mentioned case, only the impression remained, but the carbonaceous matter had gone to stain the surrounding clay black, thus indicating that the dark colour of the coal-shales is due to the carbon derived from the plants which they included.

Another very prominent member of the vegetation of the coal period, was that order of plants known as the *Calamites*. The generic distinctions between fossil and living ferns were so slight in many cases as to be almost indistinguishable. This resemblance between the ancient and the modern is not found so apparent in other plants. The

Calamites of the coal-measures bore indeed a very striking resemblance, and were closely related, to our modern horse-tails, as the *equiseta* are popularly called; but in some respects they differed considerably.

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Most people are acquainted with the horse-tail (*equisetum fluviatile)* of our marshes and ditches. It is a somewhat graceful plant, and stands erect with a jointed stem. The foliage is arranged in whorls around the joints, and, unlike its fossil representatives, its joints are protected by striated sheaths. The stem of the largest living species rarely exceeds half-an-inch in diameter, whilst that of the calamite attained a thickness of five inches. But the great point which is noticeable in the fossil calamites and *equisetites* is that they grew to a far greater height than any similar plant now living, sometimes being as much as eight feet high. In the nature of their stems, too, they exhibited a more highly organised arrangement than their living representatives, having, according to Dr Williamson, a “fistular pith, an exogenous woody stem, and a thick smooth bark.” The bark having almost al ways disappeared has left the fluted stem known to us as the calamite. The foliage consisted of whorls of long narrow leaves, which differed only from the fern *asterophyllites* in the fact that they were single-nerved. Sir William Dawson assigns the calamites to four sub-types: *calamite* proper, *calamopitus, calamodendron*, and *eucalamodendron*.

[Image: FIG. 7.—Root of *Catamites Suckowii*. Coal-shale.]

[Image: FIG 8.—*Calamocladus grandis*. Carboniferous sandstone.]

Having used the word “exogenous,” it might be as well to pay a little attention, in passing, to the nomenclature and broad classification of the various kinds of plants. We shall then doubtless find it far easier thoroughly to understand the position in the scale of organisation to which the coal plants are referable.

[Illustration: FIG. 9.—*Asterophyllites foliosa*. Coal-measures.]

The plants which are lowest in organisation are known as *Cellular*. They are almost entirely composed of numerous cells built up one above the other, and possess none of the higher forms of tissue and organisation which are met with elsewhere. This division includes the lichens, sea-weeds, confervae (green aquatic scum), fungi (mushrooms, dry-rot), &c.

The division of *Vascular* plants includes the far larger proportion of vegetation, both living and fossil, and these plants are built up of vessels and tissues of various shapes and character.

All plants are divided into (1) Cryptogams, or Flowerless, such as mosses, ferns, equisetums, and (2) Phanerogams, or Flowering. Flowering plants are again divided into those with naked seeds, as the conifers and cycads (gymnosperms), and those whose seeds are enclosed in vessels, or ovaries (angiosperms).

Angiosperms are again divided into the monocotyledons, as the palms, and dicotyledons, which include most European trees.

Thus:—

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(M.A. Brongniart).		(Lindley).
CELLULAR		
Cryptogams (Flowerless)	Fungi, seaweeds, lichens	Thallogens
VASCULAR		
Cryptogams (Flowerless)	Ferns, equisetums, mosses, lycopodiums	Acrogens
Phanerogams (Flowering)		
Gymnosperms (having naked seeds)	Conifers and cycads	Gymnogens
Two or more Cotyledons		
Angiosperms (having enclosed seeds)		
Monocotyledons	Palms, lilies, grasses	Endogens
Dicotyledons	Most European trees and shrubs	Exogens

Adolphe Brongniart termed the coal era the “Age of Acrogens,” because, as we shall see, of the great predominance in those times of vascular cryptogamic plants, known in Dr Lindley’s nomenclature as “Acrogens.”

[Illustration: FIG. 10.—*Spenophyllum cuneifolium.* Coal-shale.]

Two of these families have already been dealt with, *viz*., the ferns (*felices*), and the equisetums, (*calamites* and *equisetites*), and we now have to pass on to another family. This is that which includes the fossil representatives of the Lycopodiums, or Club-mosses, and which goes to make up in some coals as much as two-thirds of the whole mass. Everyone is more or less familiar with some of the living Lycopodiums, those delicate little fern-like mosses which are to be found in many a home. They are but lowly members of our British flora, and it may seem somewhat astounding at first sight that their remote ancestors occupied so important a position in the forests of the ancient period of which we are speaking. Some two hundred living species are known, most of them being confined to tropical climates. They are as a rule, low creeping plants, although some few stand erect. There is room for astonishment when we consider the fact that the fossil representatives of the family, known as *Lepidodendra*, attained a height of no less than fifty feet, and, there is good ground for believing, in many cases, a far greater magnitude. They consist of long straight stems, or trunks which branch considerably near the top. These stems are covered with scars or scales, which have been caused by the separation of the petioles or leaf-stalks, and this gives rise to the name which the genus bears. The scars are arranged in a spiral manner the whole of the way up the stem, and the stems often remain perfectly upright in the coal-mines, and reach into the strata which have accumulated above the coal-seam.

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[Illustration: FIG. 11.—Cast of *lepidodendron* in sandstone.]

Count Sternberg remarked that we are unacquainted with any existing species of plant, which like the *Lepidodendron*, preserves at all ages, and throughout the whole extent of the trunk, the scars formed by the attachment of the petioles, or leaf-stalks, or the markings of the leaves themselves. The yucca, dracaena, and palm, entirely shed their scales when they are dried up, and there only remain circles, or rings, arranged round the trunk in different directions. The flabelliform palms preserve their scales at the inferior extremity of the trunk only, but lose them as they increase in age; and the stem is entirely bare, from the middle to the superior extremity. In the ancient *Lepidodendron*, on the other hand, the more ancient the scale of the leaf-stalk, the more apparent it still remains. Portions of stems have been discovered which contain leaf-scars far larger than those referred to above, and we deduce from these fragments the fact that those individuals which have been found whole, are not by any means the largest of those which went to form so large a proportion of the ancient coal-forests. The *lepidodendra* bore linear one-nerved leaves, and the stems always branched dichotomously and possessed a central pith. Specimens variously named *knorria, lepidophloios, halonia*, and *ulodendron* are all referable to this family.

[Illustration: FIG. 12.—*Lepidodendron longifolium.* Coal-shale.]

[Illustration: FIG. 13.—*Lepidodendron aculeatum* in sandstone.]

In some strata, as for instance that of the Shropshire coalfield, quantities of elongated cylindrical bodies known as *lepidostrobi* have been found, which, it was early conjectured, were the fruit of the giant club-mosses about which we have just been speaking. Their appearance can be called to mind by imagining the cylindrical fruit of the maize or Indian corn to be reduced to some three or four inches in length. The sporangia or cases which contained the microscopic spores or seeds were arranged around a central axis in a somewhat similar manner to that in which maize is found. These bodies have since been found actually situated at the end of branches of *lepidodendron*, thus placing their true nature beyond a doubt. The fossil seeds (spores) do not appear to have exceeded in volume those of recent club-mosses, and this although the actual trees themselves grew to a size very many times greater than the living species. This minuteness of the seed-germs goes to explain the reason why, as Sir Charles Lyell remarked, the same species of *lepidodendra* are so widely distributed in the coal measures of Europe and America, their spores being capable of an easy transportation by the wind.

[Illustration: FIG. 14.—*Lepidostrobus.* Coal-shale.]

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One striking feature in connection with the fruit of the *lepidodendron* and other ancient representatives of the club-moss tribe, is that the bituminous coals in many, if not in most, instances, are made up almost entirely of their spores and spore-cases. Under a microscope, a piece of such coal is seen to be thronged with the minute rounded bodies of the spores interlacing one another and forming almost the whole mass, whilst larger than these, and often indeed enclosing them, are flattened bag-like bodies which are none other than the compressed sporangia which contained the former.

[Illustration: FIG. 15.—*Lycopodites*. Coal sandstone.]

Now, the little Scottish or Alpine club-moss which is so familiar, produces its own little cones, each with its series of outside scales or leaves; these are attached to the bags or spore-cases, which are crowded with spores. Although in miniature, yet it produces its fruit in just the same way, at the terminations of its little branches, and the spores, the actual germs of life, when examined microscopically, are scarcely distinguishable from those which are contained in certain bituminous coals. And, although ancient club-mosses have been found in a fossilised condition at least forty-nine feet high, the spores are no larger than those of our miniature club-mosses of the present day.

The spores are more or less composed of pure bitumen, and the bituminous nature of the coal depends largely on the presence or absence of these microscopic bodies in it. The spores of the living club-mosses contain so much resinous matter that they are now largely used in the making of fireworks, and upon the presence of this altered resinous matter in coal depends its capability of providing a good blazing coal.

At first sight it seems almost impossible that such a minute cause should result in the formation of huge masses of coal, such an inconceivable number of spores being necessary to make even the smallest fragment of coal. But if we look at the cloud of spores that can be shaken from a single spike of a club-moss, then imagine this to be repeated a thousand times from each branch of a fairly tall tree, and then finally picture a whole forest of such trees shedding in due season their copious showers of spores to earth, we shall perhaps be less amazed than we were at first thought, at the stupendous result wrought out by so minute an object.

Another well-known form of carboniferous vegetation is that known as the *Sigillaria*, and, connected with this form is one, which was long familiar under the name of *Stigmaria*, but which has since been satisfactorily proved to have formed the branching root of the sigillaria. The older geologists were in the habit of placing these plants among the tree-ferns, principally on account of the cicatrices which were left at the junctions of the leaf-stalks with the stem, after the former had fallen off.

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No foliage had, however, been met with which was actually attached to the plants, and hence, when it was discovered that some of them had long attenuated leaves not at all like those possessed by ferns, geologists were compelled to abandon this classification of them, and even now no satisfactory reference to existing orders of them has been made, owing to their anomalous structure. The stems are fluted from base to stem, although this is not so apparent near the base, whilst the raised prominences which now form the cicatrices, are arranged at regular distances within the vertical grooves.

When they have remained standing for some length of time, and the strata have been allowed quietly to accumulate around the trunks, they have escaped compression. They were evidently, to a great extent, hollow like a reed, so that in those trees which still remain vertical, the interior has become filled up by a coat of sandstone, whilst the bark has become transformed into an envelope of an inch, or half an inch of coal. But many are found lying in the strata in a horizontal plane. These have been cast down and covered up by an ever-increasing load of strata, so that the weight has, in the course of time, compressed the tree into simply the thickness of the double bark, that is, of the two opposite sides of the envelope which covered it when living.

Sigillarae grew to a very great height without branching, some specimens having measured from 60 to 70 feet long. In accordance with their outside markings, certain types are known as *syringodendron*, *favularia*, and *clathraria*. *Diploxylon* is a term applied to an interior stem referable to this family.

[Illustration: FIG. 16.—*Stigmaria ficoides*. Coal-shale.]

But the most interesting point about the *sigillariae* is the root. This was for a long time regarded as an entirely distinct individual, and the older geologists explained it in their writings as a species of succulent aquatic plant, giving it the name of *stigmaria*. They realized the fact that it was almost universally found in those beds which occur immediately beneath the coal seams, but for a long time it did not strike them that it might possibly be the root of a tree. In an old edition of Lyell's "Elements of Geology," utterly unlike existing editions in quality, quantity, or comprehensiveness, after describing it as an extinct species of water-plant, the author hazarded the conjecture that it might ultimately be found to have a connection with some other well-known plant or tree. It was noticed that above the coal, in the roof, stigmariae were absent, and that the stems of trees which occurred there, had become flattened by the weight of the overlying strata. The stigmariae on the other hand, abounded in the *underclay*, as it is called, and were not in any way compressed but retained what appeared to be their natural shape and position. Hence to explain their appearance,

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it was thought that they were water-plants, ramifying the mud in every direction, and finally becoming overwhelmed and covered by the mud itself. On botanical grounds, Brongniart and Lyell conjectured that they formed the roots of other trees, and this became the more apparent as it came to be acknowledged that the underclays were really ancient soils. All doubt was, however, finally dispelled by the discovery by Mr Binney, of a sigillaria and a stigmaria in actual connection with each other, in the Lancashire coal-field.

Stigmariae have since been found in the Cape Breton coal-field, attached to Lepidodendra, about which we have already spoken, and a similar discovery has since been made in the British coal-fields. This, therefore, would seem to shew the affinity of the sigillaria to the lepidodendron, and through it to the living lycopods, or club-mosses.

Some few species of stigmarian roots had been discovered, and various specific names had been given to them before their actual nature was made out. What for some time were thought to be long cylindrical leaves, have now been found to be simply rootlets, and in specimens where these have been removed, the surface of the stigmaria has been noticed to be covered with large numbers of protuberant tubercles, which have formed the bases of the rootlets. There appears to have also been some special kind of arrangement in their growth, since, unlike the roots of most living plants, the tubercles to which these rootlets were attached, were arranged spirally around the main root. Each of these tubercles was pitted in the centre, and into these the almost pointed ends of the rootlets fitted, as by a ball and socket joint.

[Illustration: FIG. 17—*Section of stigmaria*.]

“A single trunk of *sigillaria* in an erect forest presents an epitome of a coal-seam. Its roots represent the *stigmaria* underclay; its bark the compact coal; its woody axis, the mineral charcoal; its fallen leaves and fruits, with remains of herbaceous plants growing in its shade, mixed with a little earthy matter, the layers of coarse coal. The condition of the durable outer bark of erect trees, concurs with the chemical theory of coal, in showing the especial suitableness of this kind of tissue for the production of the purer compact coals.”—(Dawson, “Structures in Coal.”)

There is yet one other family of plants which must be mentioned, and which forms a very important portion of the constituent *flora* of the coal period. This is the great family of the *coniferae*, which although differing in many respects from the highly organised dicotyledons of the present day, yet resembled them in some respects, especially in the formation of an annual ring of woody growth.

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The conifers are those trees which, as the name would imply, bear their fruit in the form of cones, such as the fir, larch, cedar, and others. The order is one which is familiar to all, not only on account of the cones they bear, and their sheddings, which in the autumn strew the ground with a soft carpet of long needle-like leaves, but also because of the gum-like secretion of resin which is contained in their tissues. Only a few species have been found in the coal-beds, and these, on examination under the microscope, have been discovered to be closely related to the araucarian division of pines, rather than to any of our common firs. The living species of this tree is a native of Norfolk Island, in the Pacific, and here it attains a height of 200 feet, with a girth of 30 feet. From the peculiar arrangement of the ducts in the elongated cellular tissue of the tree, as seen under the microscope, the fossil conifers, which exhibit this structure, have been placed in the same division.

The familiar fossil known to geologists as *Sternbergia* has now been shown to be the cast of the central pith of these conifers, amongst which may be mentioned *cordaites, araucarites*, and *dadoxylon.*. The central cores had become replaced with inorganic matter after the pith had shrunk and left the space empty. This shrinkage of the pith is a process which takes place in many plants even when living, and instances will at once occur, in which the stems of various species of shrubs when broken open exhibit the remains of the shrunken pith, in the shape of thin discs across the interval cavity.

We might reasonably expect that where we find the remains of fossil coniferous trees, we should also meet with the cones or fruit which they bear. And such is the case. In some coal-districts fossil fruits, named *cardiocarpum* and *trigonocarpum*, have been found in great quantities, and these have now been decided by botanists to be the fruits of certain conifers, allied, not to those which bear hard cones, but to those which bear solitary fleshy fruits. Sir Charles Lyell referred them to a Chinese genus of the yew tribe called *salisburia*. Dawson states that they are very similar to both *taxus* and *salisburia.*. They are abundant in some coal-measures, and are contained, not only in the coal itself, but also in the sandstones and shales. The under-clays appear to be devoid of them, and this is, of course, exactly what might have been expected, since the seeds would remain upon the soil until covered up by vegetable matter, but would never form part of the clay soil itself.

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In connection with the varieties which have been distinguished in the families of the conifers, calamites, and sigillariae, Sir William Dawson makes the following observations: "I believe that there was a considerably wide range of organisation in *cordaitinae* as well as in *calamites* and *sigillariae*, and that it will eventually be found that there were three lines of connection between the higher cryptogams (flowerless) and the phaenogams (flowering), one leading from the lycopodes by the *sigillariae*, another leading by the *cordaites*, and the third leading from the *equisetums* by the *calamites*. Still further back the characters, afterwards separated in the club-mosses, mare's-tails, and ferns, were united in the *rhizocarps*, or, as some prefer to call them, the heterosporous *filicinae*."

In concluding this chapter dealing with the various kinds of plants which have been discovered as contributing to the formation of coal-measures, it would be as well to say a word or two concerning the climate which must have been necessary to permit of the growth of such an abundance of vegetation. It is at once admitted by all botanists that a moist, humid, and warm atmosphere was necessary to account for the existence of such an abundance of ferns. The gorgeous waving tree-ferns which were doubtless an important feature of the landscape, would have required a moist heat such as does not now exist in this country, although not necessarily a tropical heat. The magnificent giant lycopodiums cast into the shade all our living members of that class, the largest of which perhaps are those that flourish in New Zealand. In New Zealand, too, are found many species of ferns, both those which are arborescent and those which are of more humble stature. Add to these the numerous conifers which are there found, and we shall find that a forest in that country may represent to a certain extent the appearance presented by a forest of carboniferous vegetation. The ferns, lycopods, and pines, however, which appear there, it is but fair to add, are mixed with other types allied to more recent forms of vegetation.

There are many reasons for believing that the amount of carbonic acid gas then existing in the atmosphere was larger than the quantity which we now find, and Professor Tyndall has shown that the effect of this would be to prevent radiation of heat from the earth. The resulting forms of vegetation would be such as would be comparable with those which are now reared in the green-house or conservatory in these latitudes. The gas would, in fact, act as a glass roof, extending over the whole world.

CHAPTER II.

A GENERAL VIEW OF THE COAL-BEARING STRATA.

In considering the source whence coal is derived, we must be careful to remember that coal itself is but a minor portion of the whole formation in which it occurs. The presence of coal has indeed given the name to the formation, the word "carboniferous" meaning "coal-bearing," but in taking a comprehensive view of the position which it occupies in the bowels of the earth, it will be necessary to take into consideration the strata in which it is found, and the conditions, so far as are known, under which these were deposited.

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Geologically speaking, the Carboniferous formation occurs near the close of that group of systems which have been classed as “palaeozoic,” younger in point of age than the well known Devonian and Old Red Sandstone strata, but older by far than the Oolites, the Wealden, or the Cretaceous strata.

In South Wales the coal-bearing strata have been estimated at between 11,000 and 12,000 feet, yet amongst this enormous thickness of strata, the whole of the various coal-seams, if taken together, probably does not amount to more than 120 feet. This great disproportion between the total thickness and the thickness of coal itself shows itself in every coal-field that has been worked, and when a single seam of coal is discovered attaining a thickness of 9 or 10 feet, it is so unusual a thing in Great Britain as to cause it to be known as the “nine” or “ten-foot seam,” as the case may be. Although abroad many seams are found which are of greater thicknesses, yet similarly the other portions of the formation are proportionately greater.

It is not possible therefore to realise completely the significance of the coal-beds themselves unless there is also a knowledge of the remaining constituents of the whole formation. The strata found in the various coal-fields differ considerably amongst themselves in character. There are, however, certain well-defined characteristics which find representation in most of the principal coal-fields, whether British or European. Professor Hull classifies these carboniferous beds as follows:—

UPPER CARBONIFEROUS.
Upper coal-measures.
Reddish and purple sandstones, red and grey clays and shales,
thin bands of coal, ironstone and limestone, with *spirorbis*
and fish.

Middle coal-measures.
Yellow and gray sandstones, blue and black clays and shales,
bands of coal and ironstone, fossil plants, bivalves
and fish, occasional marine bands.

MIDDLE CARBONIFEROUS.
Gannister beds or *Lower coal-measures.*
Millstone grit. Flagstone series in Ireland.
Yoredale beds. Upper shale series of Ireland.

LOWER CARBONIFEROUS.
Mountain limestone.
Limestone shale.

Each of the three principal divisions has its representative in Scotland, Belgium, and Ireland, but, unfortunately for the last-named country, the whole of the upper coal-measures are there absent. It is from these measures that almost all our commercial coals are obtained.

This list of beds might be further curtailed for all practical purposes of the geologist, and the three great divisions of the system would thus stand:—

Upper Carboniferous, or Coal-measures proper.

Millstone grit.

Lower Carboniferous, or Mountain limestone.

In short, the formation consists of masses of sandstone, shale, limestone and coal, these also enclosing clays and ironstones, and, in the limestone, marbles and veins of the ores of lead, zinc, and antimony, and occasionally silver.

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[Illustration: FIG. 18.—Sigillarian trunks in current-bedded sandstone. St Etienne.]

As the most apparent of the rocks of the system are sandstone, shale, limestone, and coal, it will be necessary to consider how these were deposited in the waters of the carboniferous ages, and this we can best do by considering the laws under which strata of a similar nature are now being deposited as sedimentary beds.

A great proportion consists of sandstone. Now sandstone is the result of sand which has been deposited in large quantities, having become indurated or hardened by various processes brought to bear upon it. It is necessary, therefore, first to ascertain whence came the sand, and whether there are any peculiarities in its method of deposition which will explain its stratification. It will be noticed at once that it bears a considerable amount of evidence of what is called “current-bedding,” that is to say, that the strata, instead of being regularly deposited, exhibit series of wedge-shaped masses, which are constantly thinning out.

Sand and quartz are of the same chemical composition, and in all probability the sand of which every sandstone in existence is composed, appeared on this earth in its first solid form in the shape of quartz. Now quartz is a comparatively heavy mineral, so also, therefore, will sand be. It is also very hard, and in these two respects it differs entirely from another product of sedimentary deposition, namely, mud or clay, with which we shall have presently to deal when coming to the shales. Since quartz is a hard mineral it necessarily follows that it will suffer, without being greatly affected, a far greater amount of wearing and knocking about when being transported by the agency of currents and rivers, than will a softer substance, such as clay. An equal amount of this wearing action upon clay will reduce it to a fine impalpable silt. The grains of sand, however, will still remain of an appreciable average size, and where both sand and clay are being transported to the sea in one and the same stream, the clay will be transported to long distances, whilst the sand, being heavier, bulk for bulk, and also consisting of grains larger in size than grains of clay, will be rapidly deposited, and form beds of sand. Of course, if the current be a violent one, the sand is transported, not by being held in suspension, but rather by being pushed along the bed of the river; such an action will then tend to cause the sand to become powdered into still finer sand.

When a river enters the sea it soon loses its individuality; it becomes merged in the body of the ocean, where it loses its current, and where therefore it has no power to keep in suspension the sediment which it had brought down from the higher lands. When this is the case, the sand borne in suspension is the first to be deposited, and this accumulates in banks near the entrance of the river into the sea. We will

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suppose, for illustration, that a small river has become charged with a supply of sand. As it gradually approaches the sea, and the current loses its force, the sand is the more sluggishly carried along, until finally it falls to the bottom, and forms a layer of sand there. This layer increases in thickness until it causes the depth of water above it to become comparatively shallow. On the shallowing process taking place, the current will still have a certain, though slighter, hold on the sand in suspension, and will transport it yet a little further seaward, when it will be thrown down, at the edge of the bank or layer already formed, thus tending to extend the bank, and to shallow a wider space of river-bed.

As a result of this action, strata would be formed, shewing stratification diagonally as well as horizontally, represented in section as a number of banks which had seemingly been thrown down one above the other, ending in thin wedge-shaped terminations where the particular supply of sediment to which each owed its formation had failed.

The masses of sandstone which are found in the carboniferous formation, exhibit in a large degree these wedge-shaped strata, and we have therefore a clue at once, both as to their propinquity to sea and land, and also as to the manner in which they were formed.

[Illustration: FIG. 19.—*Productus*. Coal-measures.]

There is one thing more, too, about them. Just as, in the case we were considering, we could observe that the wedge-shaped strata always pointed away from the source of the material which formed them, so we can similarly judge that in the carboniferous strata the same deduction holds good, that the diagonally-pointing strata were formed in the same way, and that their thinning out was simply owing to temporary failure of sediment, made good, however, by a further deposition of strata when the next supply was borne down.

It is scarcely likely, however, that sand in a pure state was always carried down by the currents to the sea. Sometimes there would be some silt mixed with it. Just as in many parts large masses of almost pure sandstone have been formed, so in other places shales, or, as they are popularly known by miners, “bind,” have been formed. Shales are formed from the clays which have been carried down by the rivers in the shape of silt, but which have since become hardened, and now split up easily into thin parallel layers. The reader has no doubt often handled a piece of hard clay when fresh from the quarry, and has remembered how that, when he has been breaking it up, in order, perhaps, to excavate a partially-hidden fossil, it has readily split up in thin flakes or layers of shaly substance. This exhibits, on a small scale, the chief peculiarity of the coal shales.

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The formation of shales will now demand our attention. When a river is carrying down with it a quantity of mud or clay, it is transported as a fine, dusty silt, and when present in quantities, gives the muddy tint to the water which is so noticeable. We can very well see how that silt will be carried down in greater quantities than sand, since nearly all rivers in some part of their course will travel through a clayey district, and finely-divided clay, being of a very light nature, will be carried forward whenever a river passes over such a district. And a very slight current being sufficient to carry it in a state of suspension, it follows that it will have little opportunity of falling to the bottom, until, by some means or other, the current, which is the means of its conveyance, becomes stopped or hindered considerably in its flow.

When the river enters a large body of water, such as the ocean or a lake, in losing its individuality, it loses also the velocity of its current, and the silt tends to sink down to the bottom. But being less heavy than the sand, about which we have previously spoken, it does not sink all at once, but partly with the impetus it has gained, and partly on account of the very slight velocity which the current still retains, even after having entered the sea, it will be carried out some distance, and will the more gradually sink to the bottom. The deeper the water in which it falls the greater the possibility of its drifting farther still, since in sinking, it would fall, not vertically, but rather as the drops of rain in a shower when being driven before a gale of wind. Thus we should notice that clays and shales would exhibit a regularity and uniformity of deposition over a wide area. Currents and tides in the sea or lake would tend still further to retard deposition, whilst any stoppages in the supply of silt which took place would give the former layer time to consolidate and harden, and this would assist in giving it that bedded structure which is so noticeable in the shales, and which causes it to split up into fine laminae. This uniformity of structure in the shales over wide areas is a well ascertained characteristic of the coal-shales, and we may therefore regard the method of their deposition as given here with a degree of certainty.

There is a class of deposit found among the coal-beds, which is known as the “underclay,” and this is the most regular of all as to the position in which it is found. The underclays are found beneath every bed of coal. “Warrant,” “spavin,” and “gannister” are local names which are sometimes applied to it, the last being a term used when the clay contains such a large proportion of silicious matter as to become almost like a hard flinty rock. Sometimes, however, it is a soft clay, at others it is mixed with sand, but whatever the composition of the underclays may be, they always agree in being unstratified. They also agree in this respect that the peculiar

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fossils known as *stigmariae* abound in them, and in some cases to such an extent that the clay is one thickly-matted mass of the filamentous rootlets of these fossils. We have seen how these gradually came to be recognised as the roots of trees which grew in this age, and whose remains have subsequently become metamorphosed into coal, and it is but one step farther to come to the conclusion that these underclays are the ancient soils in which the plants grew.

No sketch of the various beds which go to form the coal-measures would be complete which did not take into account the enormous beds of mountain limestone which form the basis of the whole system, and which in thinner bands are intercalated amongst the upper portion of the system, or the true coal-measures.

Now, limestones are not formed in the same way in which we have seen that sandstones and shales are formed. The last two mentioned owe their origin to their deposition as sediment in seas, estuaries or lakes, but the masses of limestone which are found in the various geological formations owe their origin to causes other than that of sedimentary deposition.

In carboniferous times there lived numberless creatures which we know nowadays as *encrinites*. These, when growing, were fixed to the bed of the ocean, and extended upward in the shape of pliant stems composed of limestone joints or plates; the stem of each encrinite then expanded at the top in the shape of a gorgeous and graceful starfish, possessed of numberless and lengthy arms. These encrinites grew in such profusion that after death, when the plates of which their stems consisted, became loosened and scattered over the bed of the sea, they accumulated and formed solid beds of limestone. Besides the encrinites, there were of course other creatures which were able to create the hard parts of their structures by withdrawing lime from the sea, such as *foraminifera*, shell-fish, and especially corals, so that all these assisted after death in the accumulation of beds of limestone where they had grown and lived.

[Illustration: FIG. 20.—Encrinite.]

[Illustration: FIG. 21.—Encrinital limestone.]

There is one peculiarity in connection with the habitats of the encrinites and corals which goes some distance in supplying us with a useful clue as to the conditions under which this portion of the carboniferous formation was formed. These creatures find it a difficult matter, as a rule, to live and secrete their calcareous skeleton in any water but that which is clear, and free from muddy or sandy sediment. They are therefore not found, generally speaking, where the other deposits which we have considered, are forming, and, as these are always found near the coasts, it follows that the habitats of the creatures referred to must be far out at sea where no muddy sediments, borne by rivers, can reach them. We can therefore safely come to the conclusion that the large masses of encrinital

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limestone, which attain such an enormous thickness in some places, especially in Ireland, have been formed far away from the land of the period; we can at the same time draw the conclusion that if we find the encrinites broken and snapped asunder, and the limestone deposits becoming impure through being mingled with a proportion of clayey or sandy deposits, that we are approaching a coast-line where perhaps a river opened out, and where it destroyed the growth of encrinites, mixing with their dead remains the sedimentary debris of the land.

[Illustration: FIG. 22.—Encrinites: various. Mountain limestone.]

We have lightly glanced at the circumstances attending the deposition of each of the principal rocks which form the beds amongst which coal is found, and have now to deal with the formation of the coal itself. We have already considered the various kinds of plants and trees which have been discovered as contributing their remains to the formation of coal, and have now to attempt an explanation of how it came to be formed in so regular a manner over so wide an area.

Each of the British coal-fields is fairly extensive. The Yorkshire and Derbyshire coal-fields, together with the Lancashire coal-field, with which they were at one time in geological connection, give us an area of nearly 1000 square miles, and other British coal-fields show at least some hundreds of square miles. And yet, spread over them, we find a series of beds of coal which in many cases extend throughout the whole area with apparent regularity. If we take it, as there seems every reason to believe was the case, that almost all these coal-fields were not only being formed at the same time, but were in most instances in continuation with one another, this regularity of deposition of comparatively narrow beds of coal, appears all the more remarkable.

The question at once suggests itself, Which of two things is probable? Are we to believe that all this vegetable matter was brought down by some mighty river and deposited in its delta, or that the coal-plants grew just where we now find the coal?

Formerly it was supposed that coal was formed out of dead leaves and trees, the refuse of the vegetation of the land, which had been carried down by rivers into the sea and deposited at their mouths, in the same way that sand and mud, as we have seen, are swept down and deposited. If this were so, the extent of the deposits would require a river with an enormous embouchure, and we should be scarcely warranted in believing that such peaceful conditions would there prevail as to allow of the layers of coal to be laid down with so little disturbance and with such regularity over these wide areas. But the great objection to this theory is, that not only do the remains still retain their perfection of structure, but they are comparatively *pure,—i.e.,* unmixed with sedimentary depositions of clay or sand. Now, rivers would not bring down the dead vegetation

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alone; their usual burden of sediment would also be deposited at their mouths, and thus dead plants, sand, and clay would be mixed up together in one black shaly or sandy mass, a mixture which would be useless for purposes of combustion. The only theory which explained all the recognised phenomena of the coal-measures was that the plants forming the coal actually grew where the coal was formed, and where, indeed, we now find it. When the plants and trees died, their remains fell to the ground of the forest, and these soon turned to a black, pasty, vegetable mass, the layer thus formed being regularly increased year by year by the continual accumulation of fresh carbonaceous matter. By this means a bed would be formed with regularity over a wide area; the coal would be almost free from an admixture of sandy or clayey sediment, and probably the rate of formation would be no more rapid in one part of the forest than another. Thus there would be everywhere uniformity of thickness. The warm and humid atmosphere, which it is probable then existed, would not only have tended towards the production of an abnormal vegetation, but would have assisted in the decaying and disintegrating processes which went on amongst the shed leaves and trees.

When at last it was announced as a patent fact that every bed of coal possessed its underclay, and that trees had been discovered actually standing upon their own roots in the clay, there was no room at all for doubt that the correct theory had been hit upon—-viz., that coal is now found just where the trees composing it had grown in the past.

But we have more than one coal-seam to account for. We have to explain the existence of several layers of coal which have been formed over one another on the same spot at successive periods, divided by other periods when shale and sandstones only have been formed.

A careful estimate of the Lancashire coal-field has been made by Professor Hull for the Geological Survey. Of the 7000 feet of carboniferous strata here found, spread out over an area of 217 square miles, there are on the average eighteen seams of coal.

This is only an instance of what is to be found elsewhere. Eighteen coal-seams! what does this mean? It means that, during carboniferous times, on no less than eighteen occasions, separate and distinct forests have grown on this self-same spot, and that between each of these occasions changes have taken place which have brought it beneath the waters of the ocean, where the sandstones and shales have been formed which divide the coal-seams from each other. We are met here by a wonderful demonstration of the instability of the surface of the earth, and we have to do our best to show how the changes of level have been brought about, which have allowed of this game of geological see-saw to take place between sea and land. Changes of level! Many a hard geological nut has only been overcome by the application of the principle of changes of level in the surface of the earth, and in this we shall find a sure explanation of the phenomena of the coal-measures.

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Great changes of the level of the land are undoubtedly taking place even now on the earth’s surface, and in assuming that similar changes took place in carboniferous times, we shall not be assuming the former existence of an agent with which we are now unfamiliar. And when we consider the thicknesses of sandstone and shale which intervene beneath the coal-seams, we can realise to a certain extent the vast lapses of years which must have taken place between the existence of each forest; so that although now an individual passing up a coal-mine shaft may rapidly pass through the remains of one forest after another, the rise of the strata above each forest-bed then was tremendously slow, and the period between the growth of each forest must represent the passing away of countless ages. Perhaps it would not be too much to say that the strata between some of the coal-seams would represent a period not less than that between the formation of the few tertiary coals with which we are acquainted, and a time which is still to us in the far-away future.

The actual seams of coal themselves will not yield much information, from which it will be possible to judge of the contour of the landmasses at this ancient period. Of one thing we are sure, namely, that at the time each seam was formed, the spot where it accumulated was dry land. If, therefore, the seams which appear one above the other coincide fairly well as to their superficial extent, we can conclude that each time the land was raised above the sea and the forest again grew, the contour of the land was very similar. This conclusion will be very useful to go upon, since whatever decision may be come to as an explanation of one successive land-period and sea-period on the same spot, will be applicable to the eighteen or more periods necessary for the completion of some of the coal-fields.

We will therefore look at one of the sandstone masses which occur between the coal-seams, and learn what lessons these have to teach us. In considering the formation of strata of sand in the seas around our river-mouths, it was seen that, owing to the greater weight of the particles of the sand over those of clay, the former the more readily sank to the bottom, and formed banks not very far away from the land. It was seen, too, that each successive deposition of sand formed a wedge-shaped layer, with the point of the wedge pointing away from the source of origin of the sediment, and therefore of the current which conveyed the sediment. Therefore, if in the coal-measure sandstones the layers were found with their wedges all pointing in one direction, we should be able to judge that the currents were all from one direction, and that, therefore, they were formed by a single river. But this is just what we do not find, for instead of it the direction of the wedge-shaped strata varies in almost every layer, and the current-bedding has been brought about by currents travelling in every direction. Such diverse current-bedding could

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only result from the fact that the spot where the sand was laid down was subject to currents from every direction, and the inference is that it was well within the sphere of influence of numerous streams and rivers, which flowed from every direction. The only condition of things which would explain this is that the sandstone was originally formed in a closed sea or large lake, into which numerous rivers flowing from every direction poured their contents.

Now, in the sandstones, the remains of numerous plants have been found, but they do not present the perfect appearance that they do when found in the shales; in fact they appear to have suffered a certain amount of damage through having drifted some distance. This, together with the fact that sandstones are not formed far out at sea, justify the safe conclusion that the land could not have been far off. Wherever the current-bedding shows itself in this manner we may be sure we are examining a spot from which the land in every direction could not have been at a very great distance, and also that, since the heavy materials of which sandstone is composed could only be transported by being impelled along by currents at the bed of the sea, and that in deep water such currents could not exist, therefore we may safely decide that the sea into which the rivers fell was a comparatively shallow one.

Although the present coal-fields of England are divided from one another by patches of other beds, it is probable that some of them were formerly connected with others, and a very wide sheet of coal on each occasion was laid down. The question arises as to what was the extent of the inland sea or lake, and did it include the area covered by the coal basins of Scotland and Ireland, of France and Belgium? And if these, why not those of America and other parts? The deposition of the coal, according to the theory here advanced, may as well have been brought about in a series of large inland seas and lakes, as by one large comprehensive sea, and probably the former is the more satisfactory explanation of the two. But the astonishing part of it is that the changes in the level of the land must have been taking place simultaneously over these large areas, although, of course, while one quarter may have been depressed beneath the sea, another may have been raised above it.

In connection with the question of the contour of the land during the existence of the large lakes or inland seas, Professor Hull has prepared, in his series of maps illustrative of the Palaeo-Geography of the British Islands, a map showing on incontestible grounds the existence during the coal-ages of a great central barrier or ridge of high land stretching across from Anglesea, south of Flint, Staffordshire, and Shropshire coal-fields, to the eastern coast of Norfolk. He regards the British coal-measures as having been laid down in two, or at most three, areas of deposition—one south of this ridge, the remainder to the north of

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it. In regard to the extent of the former deposits of coal in Ireland, there is every probability that the sister island was just as favourably treated in this respect as Great Britain. Most unfortunately, Ireland has since suffered extreme denudation, notably from the great convulsions of nature at the close of the very period of their deposition, as well as in more recent times, resulting in the removal of nearly all the valuable upper carboniferous beds, and leaving only the few unimportant coal-beds to which reference has been made.

[Illustration: FIG. 23.—*Cyathophyllum*. Coral in encrinital limestone.]

We are unable to believe in the continuity of our coal-beds with those of America, for the great source of sediment in those times was a continent situated on the site of the Atlantic Ocean, and it is owing to this extensive continent that the forms of *flora* found in the coal-beds in each country bear so close a resemblance to one another, and also that the encrinital limestone which was formed in the purer depths of the ocean on the east, became mixed with silt, and formed masses of shaly impure limestone in the south-western parts of Ireland.

It must be noted that, although we may attribute to upheaval from beneath the fact that the bed of the sea became temporarily raised at each period into dry land, the deposits of sand or shale would at the same time be tending to shallow the bed, and this alone would assist the process of upheaval by bringing the land at least very near to the surface of the water.

Each upheaval, however, could have been but a temporary arrest of the great movement of crust subsidence which was going on throughout the coal period, so that, at its close, when the last coal forest grew upon the surface of the land, there had disappeared, in the case of South Wales, a thickness of 11,000 feet of material.

Of the many remarkable things in connection with coal-beds, not the least is the state of purity in which coal is found. On the floor of each forest there would be many a streamlet or even small river which would wend its way to meet the not very distant sea, and it is surprising at first that so little sediment found its way into the coal itself. But this was cleverly explained by Sir Charles Lyell, who noticed, on one of his visits to America, that the water of the Mississippi, around the rank growths of cypress which form the “cypress swamps” at the mouths of that river, was highly charged with sediment, but that, having passed through the close undergrowth of the swamps, it issued in almost a pure state, the sediment which it bore having been filtered out of it and precipitated. This very satisfactorily explained how in some places carbonaceous matter might be deposited in a perfectly pure state, whilst in others, where sandstone or shale was actually forming, it might be impregnated by coaly matter in such a way as to cause it to be stained black. In times

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of flood sediment would be brought in, even where pure coal had been forming, and then we should have a thin “parting” of sandstone or shale, which was formed when the flood was at its height. Or a slight sinking of the land might occur, in which case also the formation of coal would temporarily cease, and a parting of foreign matter would be formed, which, on further upheaval taking place, would again give way to another forest growth. Some of the thicker beds have been found presenting this aspect, such as the South Staffordshire ten-yard coal, which in some parts splits up into a dozen or so smaller beds, with partings of sediment between them.

In the face of the stupendous movements which must have happened in order to bring about the successive growth of forests one above another on the same spot, the question at once arises as to how these movements of the solid earth came about, and what was the cause which operated in such a manner. We can only judge that, in some way or other, heat, or the withdrawal of heat, has been the prime motive power. We can perceive, from what is now going on in some parts of the earth, how great an influence it has had in shaping the land, for volcanoes owe their activity to the hidden heat in the earth’s interior, and afford us an idea of the power of which heat is capable in the matter of building up and destroying continents. No less certain is it that heat is the prime factor in those more gradual vertical movements of the land to which we have referred elsewhere, but in regard to the exact manner in which it acts we are very much in the dark. Everybody knows that, in the majority of instances, material substances of all kinds expand under the influence of heat, and contract when the source of heat is withdrawn. If we can imagine movements in the quantity of heat contained in the solid crust, the explanation is easy, for if a certain tract of land receive an accession of heat beneath it, it is certain that the principal effect will be an elevation of the land, consequent on the expansion of its materials, with a subsequent depression when the heat beneath the tract in question becomes gradually lessened. Should the heat be retained for a long period, the strata would be so uplifted as to form an anticlinal, or saddle-back, and then, should subsequent denudation take place, more ancient strata would be brought to view. It was thus in the instance of the tract bounded by the North and South Downs, which were formerly entirely covered by chalk, and in the instance of the uprising of the carboniferous limestone between the coal-fields of Lancashire, Staffordshire, and Derbyshire.

How the heat-waves act, and the laws, if any, which they obey in their subterranean movements, we are unable to judge. From the properties which heat possesses we know that its presence or absence produces marked differences in the positions of the strata of the earth, and from observations made in connection with the closing of some volcanoes, and the opening up of fresh earth-vents, we have gone a long way towards establishing the probability that there are even now slow and ponderous movements taking place in the heat stored in the earth’s crust, whose effects are appreciably communicated to the outside of the thin rind of solid earth upon which we live.

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Owing to the great igneous and volcanic activity at the close of the deposition of the carboniferous system of strata, the coal-measures exhibit what are known as *faults* in abundance. The mountain limestone, where it outcrops at the surface, is observed to be much jointed, so much so that the work of quarrying the limestone is greatly assisted by the jointed structure of the rock. Faults differ from joints in that, whilst the strata in the latter are still in relative position on each side of the joint, they have in the former slipped out of place. In such a case the continuation of a stratum on the opposite side of a fault will be found to be depressed, perhaps a thousand feet or more. It will be seen at once how that, in sinking a new shaft into a coal-seam, the possibility of an unknown fault has to be brought into consideration, since the position of the seam may prove to have been depressed to such an extent as to cause it to be beyond workable depth. Many seams, on the other hand, which would have remained altogether out of reach of mining operations, have been brought within workable depth by a series of *step-faults*, this being a term applied to a series of parallel faults, in none of which the amount of down-throw is great.

The amount of the down-throw, or the slipping-down of the beds, is measured, vertically, from the point of disappearance of a layer to an imaginary continuation of the same layer from where it again appears beyond the fault. The plane of a fault is usually more or less inclined, the amount of the inclination being known as the *hade* of the fault, and it is a remarkable characteristic of faults that, as a general rule, they hade to the down-throw. This will be more clearly understood when it is explained that, by its action, a seam of coal, which is subject to numerous faults, can never be pierced more than once by one and the same boring. In mountainous districts, however, there are occasions when the hade is to the up-throw, and this kind of fault is known as an *inverted fault*.

Lines of faults extend sometimes for hundreds of miles. The great Pennine Fault of England is 130 miles long, and others extend for much greater distances. The surfaces on both sides of a fault are often smooth and highly polished by the movement which has taken place in the strata. They then show the phenomenon known as *slicken-sides*. Many faults have become filled with crystalline minerals in the form of veins of ore, deposited by infiltrating waters percolating through the natural fissures.

In considering the formation and structure of the better-known coal-bearing beds of the carboniferous age, we must not lose sight of the fact that important beds of coal also occur in strata of much more recent date. There are important coal-beds in India of Permian age. There are coal-beds of Liassic age in South Hungary and in Texas, and of Jurassic age in Virginia, as well as at Brora in Sutherlandshire; there are coals of Cretaceous age in Moravia, and valuable Miocene Tertiary coals in Hungary and the Austrian Alps.

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Again, older than the true carboniferous age, are the Silurian anthracites of Co. Cavan, and certain Norwegian coals, whilst in New South Wales we are confronted with an assemblage of coal-bearing strata which extend apparently from the Devonian into Mesozoic times.

Still, the age we have considered more closely has an unrivalled right to the title, coal appearing there not merely as an occasional bed, but as a marked characteristic of the formation.

The types of animal life which are found in this formation are varied, and although naturally enough they do not excel in number, there are yet sufficient varieties to show probabilities of the existence of many with which we are unfamiliar. The highest forms yet found, show an advance as compared with those from earlier formations, and exhibit amphibian characteristics intermediate between the two great classes of fishes and reptiles. Numerous specimens proper to the extinct order of *labyrinthodontia* have been arranged into at least a score of genera, these having been drawn from the coal-measures of Newcastle, Edinburgh, Kilkenny, Saaerbruck, Bavaria, Pennsylvania, and elsewhere. The *Archegosaurus,* which we have figured, and the *Anthracosaurus,* are forms which appear to have existed in great numbers in the swamps and lakes of the age. The fish of the period belong almost entirely to the ancient orders of the ganoids and placoids. Of the ganoids, the great *megalichthys Hibberti* ranges throughout the whole of the system. Wonderful accumulations of fish remains are found at the base of the system, in the bone-bed of the Bristol coal-field, as well as in a similar bed at Armagh. Many fishes were armed with powerful conical teeth, but the majority, like the existing Port Jackson shark, were possessed of massive palates, suited in some cases for crushing, and in others for cutting.

[Illustration: FIG. 24.—*Archegosaurus minor*. Coal-measures.]

[Illustration: FIG. 25.—*Psammodus porosus*. Crushing palate of a fish.]

[Illustration: FIG. 26.—*Orthoceras*. Mountain limestone.]

In the mountain limestone we see, of course, the predominance of marine types, encrinital remains forming the greater proportion of the mass. There are occasional plant remains which bear evidence of having drifted for some distance from the shore. But next to the *encrinites*, the corals are the most important and persistent. Corals of most beautiful forms and capable of giving polished marble-like sections, are in abundance. *Polyzoa* are well represented, of which the lace-coral (*fenestella*) and screw-coral (*archimedopora*) are instances. *Cephalopoda* are represented by the *orthoceras*, sometimes five or six feet long, and *goniatites*, the forerunner of the familiar *ammonite*. Many species of brachiopods and lammellibranchs are met with. *Lingula*, most persistent throughout all geological time, is abundant in the coal-shales, but not in the limestones. *Aviculopecten* is there abundant also. In the mountain limestone the last of the trilobites (*Phillipsia*) is found.

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[Illustration: FIG. 27.—*Fenestella retipora*. Mountain limestone.]

[Illustration: FIG. 28.—*Goniatites*. Mountain limestone.]

We have evidence of the existence in the forests of a variety of *centipede*, specimens having been found in the erect stump of a hollow tree, although the fossil is an extremely rare one. The same may be said of the only two species of land-snail which have been found connected with the coal forests, *viz*., *pupa vetusta* and *zonites priscus*, both discovered in the cliffs of Nova Scotia. These are sufficient to demonstrate that the fauna of the period had already reached a high stage of development. In the estuaries of the day, masses of a species of freshwater mussel (*anthracosia*) were in existence, and these have left their remains in the shape of extensive beds of shells. They are familiar to the miner as *mussel-binds*, and are as noticeable a feature of this long ago period, as are the aggregations of mussels on every coast at the present day.

[Illustration: FIG. 29.—*Aviculopecten papyraceus*. Coal-shale.]

CHAPTER III.

VARIOUS FORMS OF COAL AND CARBON.

In considering the various forms and combinations into which coal enters, it is necessary that we should obtain a clear conception of what the substance called “carbon” is, and its nature and properties generally, since this it is which forms such a large percentage of all kinds of coal, and which indeed forms the actual basis of it. In the shape of coke, of course, we have a fairly pure form of carbon, and this being produced, as we shall see presently, by the driving off of the volatile or vaporous constituents of coal, we are able to perceive by the residue how great a proportion of coal consists of carbon. In fact, the two have almost an identical meaning in the popular mind, and the fact that the great masses of strata, in which are contained our principal and most valuable seams of coal, are termed “carboniferous,” from the Latin *carbo*, coal, and *fero*, I bear, tends to perpetuate the existence of the idea.

There is always a certain, though slight, quantity of carbon in the air, and this remains fairly constant in the open country. Small though it may be in proportion to the quantity of pure air in which it is found, it is yet sufficient to provide the carbon which is necessary to the growth of vegetable life. Just as some of the animals known popularly as the *zoophytes*, which are attached during life to rocks beneath the sea, are fed by means of currents of water which bring their food to them, so the leaves, which inhale carbon-food during the day through their under-surfaces, are provided with it by means of the currents of air which are always circulating around them; and while the fuel is being taken in beneath, the heat and light are being received from above, and the sun supplies the motive power to digestion.

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It is assumed that it is, within the knowledge of all that, for the origin of the various seams and beds of coaly combinations which exist in the earth's crust, we must look to the vegetable world. If, however, we could go so far back in the world's history as the period when our incandescent orb had only just severed connection with a gradually-diminishing sun, we should probably find the carbon there, but locked up in the bonds of chemical affinities with other elements, and existing therewith in a gaseous condition. But, as the solidifying process went on, and as the vegetable world afterwards made its appearance, the carbon became, so to speak, wrenched from its combinations, and being absorbed by trees and plants, finally became deposited amongst the ruins of a former vegetable world, and is now presented to us in the form of coal.

We are able to trace the gradual changes through which the pasty mass of decaying vegetation passed, in consequence of the fact that we have this material locked up in various stages of carbonisation, in the strata beneath our feet. These we propose to deal with individually, in as unscientific and untechnical a manner as possible.

First of all, when a mass of vegetable matter commences to decay, it soon loses its colour. There is no more noticeable proof of this, than that when vitality is withdrawn from the leaves of autumn, they at once commence to assume a rusty or an ashen colour. Let the leaves but fall to the ground, and be exposed to the early frosts of October, the damp mists and rains of November, and the rapid change of colour is at once apparent. Trodden under foot, they soon assume a dirty blackish hue, and even when removed they leave a carbonaceous trace of themselves behind them, where they had rested. Another proof of the rapid acquisition of their coaly hue is noticeable in the spring of the year. When the trees have burst forth and the buds are rapidly opening, the cases in which the buds of such trees as the horse-chestnut have been enclosed will be found cast off, and strewing the path beneath. Moistened by the rains and the damp night-mists, and trodden under foot, these cases assume a jet black hue, and are to all appearance like coal in the very first stages of formation.

But of course coal is not made up wholly and only of leaves. The branches of trees, twigs of all sizes, and sometimes whole trunks of trees are found, the last often remaining in their upright position, and piercing the strata which have been formed above them. At other times they lie horizontally on the bed of coal, having been thrown down previously to the formation of the shale or sandstone, which now rests upon them. They are often petrified into solid sandstone themselves, whilst leaving a rind of coal where formerly was the bark. Although the trunk of a tree looks so very different to the leaves which it bears upon its branches, it is only naturally to be supposed that, as they are both built

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up after the same manner from the juices of the earth and the nourishment in the atmosphere, they would have a similar chemical composition. One very palpable proof of the carbonaceous character of tree-trunks suggests itself. Take in your hand a few dead twigs or sticks from which the leaves have long since dropped; pull away the dead parts of the ivy which has been creeping over the summer-house; or clasp a gnarled old monster of the forest in your arms, and you will quickly find your hand covered with a black smut, which is nothing but the result of the first stage which the living plant has made, in its progress towards its condition as dead coal. But an easy, though rough, chemical proof of the constituents of wood, can be made by placing a few pieces of wood in a medium-sized test-tube, and holding it over a flame. In a short time a certain quantity of steam will be driven off, next the gaseous constituents of wood, and finally nothing will be left but a few pieces of black brittle charcoal. The process is of course the same in a fire-grate, only that here more complete combustion of the wood takes place, owing to its being intimately exposed to the action of the flames. If we adopt the same experiment with some pieces of coal, the action is similar, only that in this case the quantity of gases given off is not so great, coal containing a greater proportion of carbon than wood, owing to the fact that, during its long burial in the bowels of the earth, it has been acted upon in such a way as to lose a great part of its volatile constituents.

From processes, therefore, which are to be seen going on around us, it is easily possible to satisfy ourselves that vegetation will in the long run undergo such changes as will result in the formation of coal.

There are certain parts in most countries, and particularly in Ireland, where masses of vegetation have undergone a still further stage in metamorphism, namely, in the well-known and famous peat-bogs. Ireland is *par excellence* the land of bogs, some three millions of acres being said to be covered by them, and they yield an almost inexhaustible supply of peat. One of the peat-bogs near the Shannon is between two and three miles in breadth and no less than fifty in length, whilst its depth varies from 13 feet to as much as 47 feet. Peat-bogs have in no way ceased to be formed, for at their surfaces the peat-moss grows afresh every year; and rushes, horse-tails, and reeds of all descriptions grow and thrive each year upon the ruins of their ancestors. The formation of such accumulations of decaying vegetation would only be possible where the physical conditions of the country allowed of an abundant rainfall, and depressions in the surface of the land to retain the moisture. Where extensive deforesting operations have taken place, peat-bogs have often been formed, and many of those in existence in Europe undoubtedly owe their formation to that destruction of forests which went on under the sway of the Romans. Natural drainage would soon be obstructed by fallen trees, and the formation of marsh-land would follow; then with the growth of marsh-plants and their successive annual decay, a peaty mass would collect, which would quickly grow in thickness without let or hindrance.

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In considering the existence of inland peat-bogs, we must not lose sight of the fact that there are subterranean forest-beds on various parts of our coasts, which also rest upon their own beds of peaty matter, and very possibly, when in the future they are covered up by marine deposits, they will have fairly started on their way towards becoming coal.

Peat-bogs do not wholly consist of peat, and nothing else. The trunks of such trees as the oak, yew, and fir, are often found mingled with the remains of mosses and reeds, and these often assume a decidedly coaly aspect. From the famous Bog of Allen in Ireland, pieces of oak, generally known as “bog-oak,” which have been buried for generations in peat, have been excavated. These are as black as any coal can well be, and are sufficiently hard to allow of their being used in the manufacture of brooches and other ornamental objects. Another use to which peat of some kinds has been put is in the manufacture of yarn, the result being a material which is said to resemble brown worsted. On digging a ditch to drain a part of a bog in Maine, U.S., in which peat to a depth of twenty feet had accumulated, a substance similar to cannel coal itself was found. As we shall see presently, cannel coal is one of the earliest stages of true coal, and the discovery proved that under certain conditions as to heat and pressure, which in this case happened to be present, the materials which form peat may also be metamorphosed into true coal.

Darwin, in his well-known “Voyage in the *Beagle*” gives a peculiarly interesting description of the condition of the peat-beds in the Chonos Archipelago, off the Chilian coast, and of their mode of formation. “In these islands,” he says, “cryptogamic plants find a most congenial climate, and within the forest the number of species and great abundance of mosses, lichens, and small ferns, is quite extraordinary. In Tierra del Fuego every level piece of land is invariably covered by a thick bed of peat. In the Chonos Archipelago where the nature of the climate more closely approaches that of Tierra del Fuego, every patch of level ground is covered by two species of plants (*Astelia pumila* and *Donatia megellanica*), which by their joint decay compose a thick bed of elastic peat.

“In Tierra del Fuego, above the region of wood-land, the former of these eminently sociable plants is the chief agent in the production of peat. Fresh leaves are always succeeding one to the other round the central tap-root; the lower ones soon decay, and in tracing a root downwards in the peat, the leaves, yet holding their places, can be observed passing through every stage of decomposition, till the whole becomes blended in one confused mass. The Astelia is assisted by a few other plants,—here and there a small creeping Myrtus (*M. nummularia*), with a woody stem like our cranberry and with a sweet berry,—an Empetrum (*E. rubrum*),

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like our heath,—a rush (*Juncus grandiflorus*), are nearly the only ones that grow on the swampy surface. These plants, though possessing a very close general resemblance to the English species of the same genera, are different. In the more level parts of the country the surface of the peat is broken up into little pools of water, which stand at different heights, and appear as if artificially excavated. Small streams of water, flowing underground, complete the disorganisation of the vegetable matter, and consolidate the whole.

“The climate of the southern part of America appears particularly favourable to the production of peat. In the Falkland Islands almost every kind of plant, even the coarse grass which covers the whole surface of the land, becomes converted into this substance: scarcely any situation checks its growth; some of the beds are as much as twelve feet thick, and the lower part becomes so solid when dry that it will hardly burn. Although every plant lends its aid, yet in most parts the Astelia is the most efficient.

“It is rather a singular circumstance, as being so very different from what occurs in Europe, that I nowhere saw moss forming by its decay any portion of the peat in South America. With respect to the northern limit at which the climate allows of that peculiar kind of slow decomposition which is necessary for its production, I believe that in Chiloe (lat. 41 deg. to 42 deg.), although there is much swampy ground, no well characterised peat occurs; but in the Chonos Islands, three degrees farther southward, we have seen that it is abundant. On the eastern coast in La Plata (lat. 35 deg.) I was told by a Spanish resident, who had visited Ireland, that he had often sought for this substance, but had never been able to find any. He showed me, as the nearest approach to it which he had discovered, a black peaty soil, so penetrated with roots as to allow of an extremely slow and imperfect combustion.”

The next stage in the making of coal is one in which the change has proceeded a long way from the starting-point. *Lignite* is the name which has been applied to a form of impure coal, which sometimes goes under the name of “brown coal.” It is not a true coal, and is a very long way from that final stage to which it must attain ere it takes rank with the most valuable of earth’s products. From the very commencement, an action has being going on which has caused the amount of the gaseous constituents to become less and less, and which has consequently caused the carbon remaining behind to occupy an increasingly large proportion of the whole mass. So, when we arrive at the lignite stage, we find that a considerable quantity of volatile matter has already been parted with, and that the carbon, which in ordinary living wood is about 50 per cent. of the whole, has already increased to about 67 per cent. In most lignites there is, as a rule, a comparatively large proportion of sulphur, and in such cases it is rendered useless

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as a domestic fuel. It has been used as a fuel in various processes of manufacture, and the lignite of the well-known Bovey Tracey beds has been utilised in this way at the neighbouring potteries. As compared with true coal, it is distinguished by the abundance of smoke which it produces and the choking sulphurous fumes which also accompany its combustion, but it is largely used in Germany as a useful source of paraffin and illuminating oils. In Silesia, Saxony, and in the district about Bonn, large quantities of lignite are mined, and used as fuel. Large stores of lignite are known to exist in the Weald of the south-east of England, and although the mining operations which were carried on at one time at Heathfield, Bexhill, and other places, were failures so far as the actual discovery of true coal was concerned, yet there can be no doubt as to the future value of the lignite in these parts, when England's supplies of coal approach exhaustion, and attention is turned to other directions for the future source of her gas and paraffin oils.

Beside the Bovey Tracey lignitic beds to which we have above referred, other tertiary clays are found to contain this early promise of coal. The *eocene* beds of Brighton are an important instance of a tertiary lignite, the seam of *surturbrand*, as it is locally called, being a somewhat extensive deposit.

We have now closely approached to true coal, and the next step which we shall take will be to consider the varieties in which the black mineral itself is found. The principal of these varieties are as follows, against each being placed the average proportion of pure carbon which it contains:—

Splint or Hard Coal, 83 per cent.;
Cannel, Candle or Parrott Coal, 84 per cent.;
Cherry or Soft Coal, 85 per cent.;
Common Bituminous, or Caking Coal, 88 per cent.;
Anthracite, Blind Coal, Culm, Glance, or Stone Coal, from South Wales, 93 per cent.

As far as the gas-making properties of the first three are concerned, the relative proportions of carbon and volatile products are much the same. Everybody knows a piece of cannel coal when it is seen, how it appears almost to have been once in a molten condition, and how it breaks with a conchoidal fracture, as opposed to the cleavage of bituminous coal into thin layers; and, most apparent and most noticeable of all, how it does not soil the hands after the manner of ordinary coal. It is at times so dense and compact that it has been fashioned into ornaments, and is capable of receiving a polish like jet. From the large percentage of volatile products which it contains, it is greatly used in gasworks.

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Caking coal and the varieties of coal which exist between it and anthracite, are familiar to every householder; the more it approaches the composition of the latter the more difficult it is to get it to burn, but when at last fairly alight it gives out great heat, and what is more important, a less quantity of volatile constituents in the shape of gas, smoke, ammonia, ash and sulphurous acid. For this reason it has been proposed to compel consumers to adopt anthracite as *the* domestic coal by Act of Parliament. Certainly by this means the amount of impurities in the air might be appreciably lessened, but as it would involve the reconstruction of some millions of fire-places, and an increase in price in consequence of the general demand for it, it is not likely that a government would be so rash as to attempt to pass such a measure; even if passed, it would probably soon become as dead and obsolete and impotent as those many laws with which our ancestors attempted, first to arrest, and then to curb the growth in the use of coal of any sort. Anthracite is not a “homely” coal. If we use it alone it will not give us that bright and cheerful blaze which English-speaking people like to obtain from their fires.

It is a significant fact, and one which proves that the various kinds of coal which are found are nothing but stages begotten by different degrees of disentanglement of the contained gases, that where, as in some parts, a mass of basalt has come into contact with ordinary bituminous coal, the coal has assumed the character of anthracite, whilst the change has in some instances gone so far as to convert the anthracite into graphite. The basalt, which is one of the igneous rocks, has been erupted into the coal-seam in a state of fusion, and the heat contained in it has been sufficient to cause the disentanglement of the gases, the extraction of which from the coal brings about the condition of anthracite and graphite.

The mention of graphite brings us to the next stage. Graphite, plumbago, or, as it is more commonly called, black-lead, which, we may say in passing, has nothing of lead about it at all, is best known in the shape of that very useful and cosmopolitan article, the black-lead pencil. This is even purer carbon than anthracite, not more than 5 per cent. of ash and other impurities being present. It is well-known by its grey metallic lustre; the chemist uses it mixed with fire-clay to make his crucibles; the engineer uses it, finely powdered, to lubricate his machinery; the house-keeper uses it to “black-lead” her stoves to prevent them from rusting. An imperfect graphite is found inside some of the hottest retorts from which gas is distilled, and this is used as the negative element in zinc and carbon electricity-making cells, whilst its use as the electrodes or carbons of the arc-lamp is becoming more and more widely adopted, as installations of electric light become more general.

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One great source of true graphite for many years was the famous mine at Borrowdale, in Cumberland, but this is now almost exhausted. The vein lay between strata of slate, and was from eight to nine feet thick. As much as L100,000 is said to have been realised from it in one year. Extensive supplies of graphite are found in rocks of the Laurentian age in Canada. In this formation nothing which can undoubtedly be classed as organic has yet been discovered. Life at this early period must have found its home in low and humble forms, and if the *eozooen* of Dawson, which has been thought to represent the earliest type of life, turns out after all not to be organic, but only a deceptive appearance assumed by certain of the strata, we at least know that it must have been in similarly humble forms that life, if it existed at all, did then exist. We can scarcely, therefore, expect that the vegetable world had made any great advance in complexity of organism at this time, otherwise the supplies of graphite or plumbago which are found in the formation, would be attributed to dense forest growths, acted upon, after death, in a similar manner to that which awaited the vegetation which, ages after, went to form beds of coal. At present we know of no source of carbon except through the intervention and the chemical action of plants. Like iron, carbon is seldom found on the earth except in combination. If there were no growth of vegetation at this far-away period to give rise to these deposits of graphite, we are compelled to ask ourselves whether, perchance, there did not then exist conditions of which we are not now cognisant on the earth, and which allowed graphite to be formed without assistance from the vegetable kingdom. At present, however, science is in the dark as to any other process of its formation, and we are left to assume that the vegetable growth of the time was enormous in quantity, although there is nothing to show the kind of vegetation, whether humble mosses or tall forest trees, which went to constitute the masses of graphite. Geologists will agree that this is no small assumption to make, since, if true, it may show that there was an abundance of vegetation at a time when animal life was hidden in one or more very obscure forms, one only of which has so far been detected, and whose very identity is strongly doubted by nearly all competent judges. At the same time there *may* have been an abundance of both animal and vegetable life at the time. We must not forget that it is a well-ascertained fact that in later ages, the minute seed-spores of forest trees were in such abundance as to form important seams of coal in the true carboniferous era, the trees which gave birth to them being now classed amongst the humble *cryptogams*, the ferns, and club-mosses, &c. The graphite of Laurentian age may not improbably have been caused by deposits of minute portions of similar lowly specimens of vegetable life, and if the *eozooen* the “dawn-animalcule,” does represent the animal life of the time, life whose types were too minute to leave undoubted traces of their existence, both animal life and vegetable life may be looked upon as existing side by side in extremely humble forms, neither as yet having taken an undoubted step forward in advance of the other in respect to complexity of organism.

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[Illustration: FIG 30.—*Lepidodendron*. Portion of Sandstone stem after removal of bark of a giant club-moss]

There is but one more form of carbon with which we have to deal in running through the series. We have seen that coal is not the *summum bonum* of the series. Other transformations take place after the stage of coal is reached, which, by the continued disentanglement of gases, finally bring about the plumbago stage.

What the action is which transforms plumbago or some other form of carbon into the condition of a diamond cannot be stated. Diamond is the purest form of carbon found in nature. It is a beautiful object, alike from the results of its powers of refraction, as also from the form into which its carbon has been crystallised. How Nature, in her wonderful laboratory, has precipitated the diamond, with its wonderful powers of spectrum analysis, we cannot say with certainty. Certain chemists have, at a great expense, produced crystals which, in every respect, stand the tests of true diamonds; but the process of their production at a great expense has in no way diminished the value of the natural product.

The process by which artificial diamonds have been produced is so interesting, and the subject may prove to be of so great importance, that a few remarks upon the process may not be unacceptable.

The experiments of the great French chemist, Dumas, and others, satisfactorily proved the fact, which has ever since been considered thoroughly established, that the diamond is nothing but carbon crystallised in nearly a pure state, and many chemists have since been engaged in the hitherto futile endeavour to turn ordinary carbon into the true diamond.

Despretz at one time considered that he had discovered the process, which consisted in his case of submitting a piece of charcoal to the action of an electric battery, having in his mind the similar process of electrolysis, by which water is divided up into the two gases, hydrogen and oxygen. He obtained a microscopic deposit on the poles of the battery, which he pronounced to be diamond dust, but which, a long time after, was proved to be nothing but graphite in a crystallised state. This was, however, certainly a step in the right direction.

The honour of first accomplishing the task fell to Mr Hannay, of Glasgow, who succeeded in producing very small but comparatively soft diamonds, by heating lampblack under great pressure, in company with one or two other ingredients. The process was a costly one, and beyond being a great scientific feat, the discovery led to little result.

A young French chemist, M. Henri Moissau, has since come to the front, and the diamonds which he has produced have stood every test for the true diamond to which they could be subjected; above all, the density of the product is 3.5, *i.e.*, that of the diamond, that of graphite reaching 2 only.

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He recognised that in all diamonds which he had consumed—and he consumed some L150 worth in order to assure himself of the fact—there were always traces of iron in their composition. He saw that iron in fusion, like other metals, always dissolves a certain quantity of carbon. Might it not be that molten iron, cooling in the presence of carbon, deep in volcanic depths where there was little scope for the iron to expand in assuming the solid form, would exert such tremendous pressure upon the particles of carbon which it absorbed, that these would assume the crystalline state?

He packed a cylinder of soft iron with the carbon of sugar, and placed the whole in a crucible filled with molten iron, which was raised to a temperature of 3000 deg. by means of an electric furnace. The soft cylinder melted, and dissolved a large portion of the carbon. The crucible was thrown into water, and a mass of solid iron was formed. It was allowed further to cool in the open air, but the expansion which the iron would have undergone on cooling, was checked by the crucible which contained it. The result was a tremendous pressure, during which the carbon, which was still dissolved, was crystallised into minute diamonds.

These showed themselves as minute points which were easily separable from the mass by the action of acids. Thus the wonderful transformation from sugar to the diamond was accomplished.

It should be mentioned that iron, silver, and water, alone possess the peculiar property of expanding when passing from the liquid to the solid state.

The diamonds so obtained were of both kinds. The particles of white diamond resembled in every respect the true brilliant. But there was also an appreciable quantity of the variety known as the “black diamond.” These diamonds seem to approximate more closely to carbon as we are most familiar with it. They are not considered as of such value as the transparent form, but they are still of considerable commercial value. The *carbonado*, as this kind is called, possesses so great a degree of hardness that by means of it it is possible to bore through the hardest rocks. The diamond drill, used for boring purposes, is furnished around the outer edge of the cylinder of the “boring bit,” as it is called, with perhaps a dozen black diamonds, together with another row of Brazilian diamonds on the inside. By the rotation of the boring tool the sharp edges of the diamonds cut their way through rocks of all degrees of hardness, leaving a core of the rock cut through, in the centre of the cylindrical drill. It is found that the durability of the natural edge of the diamond is far greater than that of the edge caused by *artificial* cutting and trimming. The cutting of a pane of glass by means of a ring set with an artificially-cut diamond, cannot therefore be done without injuring to a slight extent the edge of the stone.

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The diamond is the hardest of all known substances, leaving a scratch on any substance across which it may be drawn. Yet it is one whose form can be changed, and whose hardness can be completely destroyed, by the simple process of combustion. It can be deprived of its high lustre, and of its power of breaking up by refraction the light of the sun into the various tints of the solar spectrum, simply by heating it to a red heat, and then plunging it into a jar of oxygen gas. It immediately expands, changes into a coky mass, and burns away. The product left behind is a mixture of carbon and oxygen, in the proportions in which it is met with in carbonic-anhydride, or, carbonic acid gas deprived of its water. This is indeed a strange transformation, from the most valuable of all our precious stones to a compound which is the same in chemical constituents as the poisonous gas which we and all animals exhale. But there is this to be said. Probably in the far-away days when the diamond began to be formed, the tree or other vegetable product which was its far-removed ancestor abstracted carbonic acid gas from the atmosphere, just as do our plants in the present day. By this means it obtained the carbon wherewith to build up its tissues. Thus the combustion of the diamond into carbonic-anhydride now is, after all, only a return to the same compound out of which it was originally formed. How it was formed is a secret: probably the time occupied in the formation of the diamond may be counted by centuries, but the time of its re-transformation into a mass of coky matter is but the work of seconds!

There is another form of carbon which was formerly of much greater importance than it is now, and which, although not a natural product, is yet deserving of some notice here. Charcoal is the substance referred to.

In early days the word “coal,” or, as it was also spelt, “cole,” was applied to any substance which was used as fuel; hence we have a reference in the Bible to a “fire of coals,” so translated when the meaning to be conveyed was probably not coal as we know it. Wood was formerly known as coal, whilst charred wood received the name of charred-coal, which was soon corrupted into charcoal. The charcoal-burners of years gone by were a far more flourishing community than they are now. When the old baronial halls and country-seats depended on them for the basis of their fuel, and the log was a more frequent occupant of the fire-grate than now, these occupiers of midforest were a people of some importance.

We must not overlook the fact that there is another form of charcoal, namely, animal charcoal or bone-black. This can be obtained by heating bones to redness in closed iron vessels. In the refining of raw sugar the discoloration of the syrup is brought about by filtering it through animal-charcoal; by this means the syrup is rendered colourless.

When properly prepared, charcoal exhibits very distinctly the rings of annual growth which may have characterised the wood from which it was formed. It is very light in consequence of its porous nature, and it is wonderfully indestructible.

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But its greatest, because it is its most useful property, is undoubtedly the power which it has of absorbing great quantities of gas into itself. It is in fact what may be termed an all-round purifier. It is a deodoriser, a disinfectant, and a decoloriser. It is an absorbent of bad odours, and partially removes the smell from tainted meat. It has been used when offensive manures have been spread over soils, with the same object in view, and its use for the purification of water is well known to all users of filters. Some idea of its power as a disinfectant may be gained by the fact that one volume of wood-charcoal will absorb no less than 90 volumes of ammonia, 35 volumes of carbonic anhydride, and 65 volumes of sulphurous anhydride.

Other forms of carbon which are well-known are (1) coke, the residue left when coal has been subjected to a great heat in a closed retort, but from which all the bye-products of coal have been allowed to escape; (2) soot and lamp-black, the former of which is useful as a manure in consequence of ammonia being present in it, whilst the latter is a specially prepared soot, and is used in the manufacture of Indian ink and printers' ink.

CHAPTER IV.

THE COAL-MINE AND ITS DANGERS.

It is somewhat strange to think that where once existed the solitudes of an ancient carboniferous forest now is the site of a busy underground town. For a town it really is. The various roads and passages which are cut through the solid coal as excavation of a coal-mine proceeds, represent to a stranger all the intricacies of a well-planned town. Nor is the extent of these underground towns a thing to be despised. There is an old pit near Newcastle which contains not less than fifty miles of passages. Other pits there are whose main thoroughfares in a direct line are not less than four or five miles in length, and this, it must be borne in mind, is the result of excavation wrought by human hands and human labour.

So great an extent of passages necessarily requires some special means of keeping the air within it in a pure state, such as will render it fit for the workers to breathe. The further one would go from the main thoroughfare in such a mine, the less likely one would be to find air of sufficient purity for the purpose. It is as a consequence necessary to take some special steps to provide an efficient system of ventilation throughout the mine. This is effectually done by two shafts, called respectively the downcast and the upcast shaft. A shaft is in reality a very deep well, and may be circular, rectangular or oval in form. In order to keep out water which may be struck in passing through the various strata, it is protected by plank or wood tubbing, or the shaft is bricked over, or sometimes even cast-iron segments are sunk. In many shafts which, owing to their great depth, pass through strata of every degree of looseness or viscosity, all three methods

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are utilised in turn. In Westphalia, where coal is worked beneath strata of more recent geological age, narrow shafts have been, in many cases, sunk by means of boring apparatus, in preference to the usual process of excavation, and the practice has since been adopted in South Wales. In England the usual form of the pit is circular, but elliptical and rectangular pits are also in use. On the Continent polygonal-shaped shafts are not uncommon, all of them, of whatever shape, being constructed with a view to resist the great pressure exerted by the rock around.

[Illustration: FIG. 31.—Engine-House and Buildings at head of a Coal-Pit.]

If there be one of these shafts at one end of the mine, and another at a remote distance from it, a movement of the air will at once begin, and a rough kind of ventilation will ensue. This is, however, quite insufficient to provide the necessary quantity of air for inhalation by the army of workers in the coal-mine, for the current thus set up does not even provide sufficient force to remove the effete air and impurities which accumulate from hundreds of perspiring human bodies.

It is therefore necessary to introduce some artificial means, by which a strong and regular current shall pass down one shaft, through the mine in all its workings, and out at the other shaft. This is accomplished in various ways. It took many years before those interested in mines came thoroughly to understand how properly to secure ventilation, and in bygone days the system was so thoroughly bad that a tremendous amount of sickness prevailed amongst the miners, owing to the poisonous effects of breathing the same air over and over again, charged, as it was, with more or less of the gases given off by the coal itself. Now, those miners who do so great a part in furnishing the means of warming our houses in winter, have the best contrivances which can be devised to furnish them with an ever-flowing current of fresh air.

Amongst the various mechanical appliances which have been used to ensure ventilation may be mentioned pumps, fans, and pneumatic screws. There is, as we have said, a certain, though slight, movement of the air in the two columns which constitute the upcast and the downcast shafts, but in order that a current may flow which shall be equal to the necessities of the miners, some means are necessary, by which this condition of almost equilibrium shall be considerably disturbed, and a current created which shall sweep all foul gases before it. One plan was to force fresh air into the downcast, which should in a sense push the foetid air away by the upcast. Another was to exhaust the upcast, and so draw the gases in the train of the exhausted air. In other cases the plan was adopted of providing a continual falling of water down the downcast shaft.

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These various plans have almost all given way to that which is the most serviceable of all, namely, the plan of having an immense furnace constantly burning in a specially-constructed chamber at the bottom of the upcast. By this means the column of air above it becomes rarefied under the heat, and ascends, whilst the cooler air from the downcast rushes in and spreads itself in all directions whence the bad air has already been drawn. On the other hand, to so great a state of perfection have ventilating fans been brought, that one was recently erected which would be capable of changing the air of Westminster Hall thirty times in one hour.

Having procured a current of sufficient power, it will be at once understood that, if left to its own will, it would take the nearest path which might lie between its entrance and its exit, and, in this way, ventilating the principal street only, would leave all the many off-shoots from it undisturbed. It is consequently manipulated by means of barriers and tight-fitting doors, in such a way that the current is bound in turn to traverse every portion of the mine. A large number of boys, known as trappers, are employed in opening the doors to all comers, and in carefully closing the doors immediately after they have passed, in order that the current may not circulate through passages along which it is not intended that it should pass.

The greatest dangers which await the miners are those which result, in the form of terrible explosions, from the presence of inflammable gases in the mines. The great walls of coal which bound the passages in mines are constantly exuding supplies of gas into the air. When a bank of coal is brought down by an artificial explosion, by dynamite, by lime cartridges, or by some other agency, large quantities of gas are sometimes disengaged, and not only is this highly detrimental to the health of the miners, if not carried away by proper ventilation, but it constitutes a constant danger which may at any time cause an explosion when a naked light is brought into contact with it. Fire-damp may be sometimes heard issuing from fiery seams with a peculiar hissing sound. If the volume be great, the gas forms what is called a *blower*, and this often happens in the neighbourhood of a fault. When coal is brought down in any large volume, the blowers which commence may be exhausted in a few moments. Others, however, have been known to last for years, this being the case at Wallsend, where the blower gave off 120 feet of gas per minute. In such cases the gas is usually conveyed in pipes to a place where it can be burned in safety.

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In the early days of coal-mining the explosions caused by this gas soon received the serious attention of the scientific men of the age. In the *Philosophical Transactions of the Royal Society* we find a record of a gas explosion in 1677. The amusing part of such records was that the explosions were ascribed by the miners to supernatural agencies. Little attention seemed to have been paid to the fact, which has since so thoroughly been established, that the explosions were caused by accumulations of gas, mixed in certain proportions with air. As a consequence, tallow candles with an exposed flame were freely used, especially in Britain. These were placed in niches in the workings, where they would give to the pitman the greatest amount of light. Previous to the introduction of the safety-lamp, workings were tested before the men entered them, by “trying the candle”. Owing to the specific gravity of fire-damp (.555) being less than that of air, it always finds a lodgement at the roofs of the workings, so that, to test the condition of the air, it was necessary to steadily raise the candle to the roof at certain places in the passages, and watch carefully the action of the flame. The presence of fire-damp would be shown by the flame assuming a blue colour, and by its elongation; the presence of other gases could be detected by an experienced man by certain peculiarities in the tint of the flame. This testing with the open flame has almost entirely ceased since the introduction of the perfected Davy lamp.

The use of candles for illumination soon gave place in most of the large collieries to the introduction of small oil-lamps. In the less fiery mines on the Continent, oil-lamps of the well-known Etruscan pattern are still in use, whilst small metal lamps, which can conveniently be attached to the cap of the worker, occasionally find favour in the shallower Scotch mines. These lamps are very useful in getting the coal from the thinner seams, where progress has to be made on the hands and feet. At the close of the last century, as workings began to be carried deeper, and coal was obtained from places more and more infested with fire-damp, it soon came to be realised that the old methods of illumination would have to be replaced by others of a safer nature.

It is noteworthy that mere red heat is insufficient in itself to ignite fire-damp, actual contact with flame being necessary for this purpose. Bearing this in mind, Spedding, the discoverer of the fact, invented what is known as the “steel-mill” for illuminating purposes. In this a toothed wheel was made to play upon a piece of steel, the sparks thus caused being sufficient to give a moderate amount of illumination. It was found, however, that this method was not always trustworthy, and lamps were introduced by Humboldt in 1796, and by Clanny in 1806. In these lamps the air which fed the flame was isolated from the air of the mine by having to bubble through a liquid. Many miners were not, however, provided with these lamps, and the risks attending naked lights went on as merrily as ever.

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In order to avoid explosions in mines which were known to give off large quantities of gas, “fiery” pits as they are called, Sir Humphrey Davy in 1815 invented his safety lamp, the principle of which can be stated in a few words.

If a piece of fine wire gauze be held over a gas-jet before it is lit, and the gas be then turned on, it can be lit above the gauze, but the flame will not pass downwards towards the source of the gas; at least, not until the gauze has become over-heated. The metallic gauze so rapidly conducts away the heat, that the temperature of the gas beneath the gauze is unable to arrive at the point of ignition. In the safety-lamp the little oil-lamp is placed in a circular funnel of fine gauze, which prevents the flame from passing through it to any explosive gas that may be floating about outside, but at the same time allows the rays of light to pass through readily. Sir Humphrey Davy, in introducing his lamp, cautioned the miners against exposing it to a rapid current of air, which would operate in such a way as to force the flame through the gauze, and also against allowing the gauze to become red-hot. In order to minimise, as far as possible, the necessity of such caution the lamp has been considerably modified since first invented, the speed of the ventilating currents not now allowing of the use of the simple Davy lamp, but the principle is the same.

During the progress of Sir Humphrey Davy’s experiments, he found that when fire-damp was diluted with 85 per cent. of air, and any less proportion, it simply ignited without explosion. With between 85 per cent. and 89 per cent. of air, fire-damp assumed its most explosive form, but afterwards decreased in explosiveness, until with 94-1/4 per cent. of air it again simply ignited without explosion. With between 11 and 12 per cent. of fire-damp the mixture was most dangerous. Pure fire-damp itself, therefore, is not dangerous, so that when a small quantity enters the gauze which surrounds the Davy lamp, it simply burns with its characteristic blue flame, but at the same time gives the miner due notice of the danger which he was running.

[Illustration: FIG. 32.—Gas Jet and Davy Lamp.]

With the complicated improvements which have since been made in the Davy lamp, a state of almost absolute safety can be guaranteed, but still from time to time explosions are reported. Of the cause of many we are absolutely ignorant, but occasionally a light is thrown upon their origin by a paragraph appearing in a daily paper. Two men are charged before the magistrates with being in the possession of keys used exclusively for unlocking their miners’ safety-lamps. There is no defence. These men know that they carry their lives in their hands, yet will risk their own and those of hundreds of others, in order that they may be able to light their pipes by means of their safety-lamps. Sometimes in an unexpected moment there is a great dislodgement of coal, and a

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tremendous quantity of gas is set free, which may be sufficient to foul the passages for some distance around. The introduction or exposure of a naked light for even so much as a second is sufficient to cause explosion of the mass; doors are blown down, props and tubbing are charred up, and the volume of smoke, rushing up by the nearest shaft and overthrowing the engine-house and other structures at the mouth, conveys its own sad message to those at the surface, of the dreadful catastrophe that has happened below. Perhaps all that remains of some of the workers consists of charred and scorched bodies, scarcely recognisable as human beings. Others escape with scorched arms or legs, and singed hair, to tell the terrible tale to those who were more fortunately absent; to speak of their own sufferings when, after having escaped the worst effects of the explosion, they encountered the asphyxiating rush of the after-damp or choke-damp, which had been caused by the combustion of the fire-damp. “Choke-damp” in very truth it is, for it is principally composed of our old acquaintance carbonic acid gas (carbon dioxide), which is well known as a non-supporter of combustion and as an asphyxiator of animal life.

It seems a terrible thing that on occasions the workings and walls themselves of a coal-mine catch fire and burn incessantly. Yet such is the case. Years ago this happened in the case of an old colliery near Dudley, at the surface of which, by means of the heat and steam thus afforded, early potatoes for the London market, we are told, were grown; and it was no unusual thing to see the smoke emerging from cracks and crevices in the rocks in the vicinity of the town.

From fire on the one hand, we pass, on the other, to the danger which awaits miners from a sudden inrush of water. During the great coal strike of 1893, certain mines became unworkable in consequence of the quantity of water which flooded the mines, and which, continually passing along the natural fractures in the earth’s crust, is always ready to find a storage reservoir in the workings of a coal-mine. This is a difficulty which is always experienced in the sinking of shafts, and the shutting off of water engages the best efforts of mining engineers.

Added to these various dangers which exist in the coal-mine, we must not omit to notice those accidents that are continually being caused by the falling-in of roofs or of walls, from the falling of insecure timber, or of what are known as “coal-pipes” or “bell-moulds.” Then, again, every man that enters the mine trusts his life to the cage by which he descends to his labour, and shaft accidents are not infrequent.

The following table shows the number of deaths from colliery accidents for a period of ten years, compiled by a Government inspector, and from this it will be seen that those resulting from falling roofs number considerably more than one-third of the whole.

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Causes of Death.	No. of Deaths.	Proportion per cent.
Deaths resulting from fire-damp explosions	2019	20.36
Deaths resulting from falling roofs and coals	3953	39.87
Deaths resulting from shaft accidents	1710	17.24
Deaths resulting from miscellaneous causes and above ground	2234	22.53
	9916	100.00

Every reader of the daily papers is familiar with the harrowing accounts which are there given of coal-mine explosions.

This kind of accident is one, which is, above all, associated in the public mind with the dangers of the coal-pit. Yet the accidents arising from this cause number but 20 per cent. of those recorded, and granted there be proper inspection, and the use of naked lights be absolutely abolished, this low percentage might still be considerably reduced.

A terrific explosion occurred at Whitwick Colliery, Leicestershire, in 1893, when two lads were killed, whilst a third was rescued after a very narrow escape. The lads, it is stated, *were working with naked lights*, when a sudden fall of coal released a quantity of gas, and an immediate explosion was the natural result. Accidents had been so rare at this pit that it was regarded as particularly safe, and it was alleged that the use of naked lights was not uncommon.

This is an instance of that large number of accidents which are undoubtedly preventable.

An interesting commentary on the careless manner in which miners risk their lives was shown in the discoveries made after an explosion at a colliery near Wrexham in 1889.

Near the scene of the explosion an unsecured safety lamp was found, and the general opinion at the time was that the disaster was caused by the inexcusable carelessness of one of the twenty victims. Besides this, when the clothing of the bodies recovered was searched, the contents, taken, it should be noted, with the pitmen into the mines, consisted of pipes, tobacco, matches, and even keys for unlocking the lamps. It is a strange reflection on the manner in which this mine had been examined previous to the men entering upon their work, that the under-looker, but half an hour previously, had reported the pit to be free from gas.

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Another instance of the same foolhardiness on the part of the miners is contained in the report issued in regard to an explosion which occurred at Denny, in Stirlingshire, on April 26th, 1895. By this accident thirteen men lost their lives, and upon the bodies of eight of the number the following articles were found; upon Patrick Carr, tin matchbox half full of matches and a contrivance for opening lamps; John Comrie, split nail for opening lamps; Peter Conway, seven matches and split key for opening lamps; Patrick Dunton, split nail for opening lamps; John Herron, clay pipe and piece of tobacco; Henry M'Govern, tin matchbox half full of matches; Robert Mitchell, clay pipe and piece of tobacco; John Nicol, wooden pipe, piece of tobacco, one match, and box half full of matches. The report stated that the immediate cause of the disaster was the ignition of fire-damp by naked light, the conditions of temperature being such as to exclude the possibility of spontaneous combustion. Henry M'Govern had previously been convicted of having a pipe in the mine. With regard to the question of sufficient ventilation it continued:—"And we are therefore led, on a consideration of the whole evidence, to the conclusion that the accident cannot be attributed to the absence of ventilation, which the mine owners were bound under the Mines Regulation Act and the special rules to provide." The report concluded as follows:— "On the whole matter we have to report that, in our opinion, the explosion at Quarter Pit on April 26th, 1895, resulting in the loss of thirteen lives, was caused by the ignition of an accumulation or an outburst of gas coming in contact with a naked light, 'other than an open safety-lamp,' which had been unlawfully kindled by one of the miners who were killed. In our opinion, the intensity of the explosion was aggravated, and its area extended, by the ignition of coal-dust."

We have mentioned that accidents have frequently occurred from the falling of "coal-pipes," or, as they are also called, "bell-moulds." We must explain what is meant by this term. They are simply what appear to be solid trunks of trees metamorphosed into coal. If we go into a tropical forest we find that the woody fibre of dead trees almost invariably decays faster than the bark. The result is that what may appear to be a sound tree is nothing but an empty cylinder of bark. This appears to have been the case with many of the trees in coal-mines, where they are seen to pierce the strata, and around which the miners are excavating the coal. As the coaly mass collected around the trunk when the coal was being formed, the interior was undergoing a process of decomposition, while the bark assumed the form of coal. The hollow interior then became filled with the shale or sandstone which forms the roof of the coal, and its sole support when the coal is removed from around it, is the thin rind of carbonised bark. When this falls to pieces, or loses its cohesion, the sandstone trunk falls of its own weight, often causing the death of the man that works beneath it. Sir Charles Lyell mentions that in a colliery near Newcastle, no less than thirty *sigillaria* trees were standing in their natural position in an area of fifty yards square, the interior in each case being sandstone, which was surrounded by a bark of friable coal.

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[Illustration: Fig. 33—Part of a trunk of *Sigillaria*, showing the thin outer carbonised bark, with leaf-scars, and the seal-like impressions where the bark is removed.]

The last great danger to which we have here to make reference, is the explosive action of a quantity of coal-dust in a dry condition. It is only now commencing to be fully recognised that this is really a most dangerous explosive. As we have seen, large quantities of coal are formed almost exclusively of *lepidodendron* spores, and such coal is productive of a great quantity of dust. Explosions which are always more or less attributable to the effects of coal-dust are generally considered, in the official statistics, to have been caused by fire-damp. The Act regulating mines in Great Britain is scarcely up to date in this respect. There is a regulation which provides for the watering of all dry and dusty places within twenty yards from the spot where a shot is fired, but the enforcement of this regulation in each and every pit necessarily devolves on the managers, many of whom in the absence of an inspector leave the requirement a dead letter. Every improvement which results in the better ventilation of a coal-mine tends to leave the dust in a more dangerous condition. The air, as it descends the shaft and permeates the workings, becomes more and more heated, and licks up every particle of moisture it can touch. Thorough ventilation results in more greatly freeing a mine of the dangerous fire-damp, but the remedy brings about another disease, *viz*., the drying-up of all moisture. The dust is thus left in a dangerously inflammable condition, acting like a train of gunpowder, to be started, it may be, by the slightest breath of an explosion. There is apparently little doubt that the presence of coal-dust in a dry state in a mine appreciably increases the liability of explosion in that mine.

So far as Great Britain is concerned, a Royal Commission was appointed by Lord Rosebery’s Government to inquire into and investigate the facts referring to coal-dust. Generally speaking, the conclusion arrived at was that fine coal-dust was inflammable under certain conditions. There was considerable difference of opinion as to what these conditions were. Some were of opinion that coal-dust and air alone were of an explosive nature, whilst others thought that alone they were not, but that the addition of a small quantity of fire-damp rendered the mixture explosive. An important conclusion was come to, that, with the combustion of coal-dust alone, there was little or no concussion, and that the flame was not of an explosive character.

Coal-dust was, however, admittedly dangerous, especially if in a dry condition. The effects of an explosion of gas might be considerably extended by its presence, and there seems every reason to believe that, with a suitable admixture of air and a very small proportion of gas, it forms a dangerous explosive. Legislation in the direction of the report of the Commission is urgently needed.

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We have seen elsewhere what it is in the dust which makes it dangerous, how that, for the most part, it consists of the dust-like spores of the *lepidodendron* tree, fine and impalpable as the spores on the backs of some of our living ferns, and the fact that this consists of a large proportion of resin makes it the easily inflammable substance it is. Nothing but an incessant watering of the workings in such cases will render the dust innocuous. The dust is extremely fine, and is easily carried into every nook and crevice, and when, as at Bridgend in 1892, it explodes, it is driven up and out of the shaft, enveloping everything temporarily in dust and darkness.

In some of the pits in South Wales a system of fine sprays of water is in use, by which the water is ejected from pin-holes pricked in a series of pipes which are carried through the workings. A fine mist is thus caused where necessary, which is carried forward by the force of the ventilating current.

A thorough system of inspection in coal-mines throughout the world is undoubtedly urgently called for, in order to ensure the proper carrying out of the various regulations framed for their safety. It is extremely unfortunate that so many of the accidents which happen are preventable, if only men of knowledge and of scientific attainments filled the responsible positions of the overlookers.

CHAPTER V.

EARLY HISTORY—ITS USE AND ITS ABUSE.

The extensive use of coal throughout the civilised world for purposes of heating and illumination, and for the carrying on of manufactures and industries, may be regarded as a well-marked characteristic of the age in which we live.

Coal must have been in centuries past a familiar object to many generations. People must have long been living in close proximity to its outcrops at the sides of the mountains and at the surface of the land, yet without being acquainted with its practical value, and it seems strange that so little use was made of it until about three centuries ago, and that its use did not spread earlier and more quickly throughout civilised countries.

A mineral fuel is mentioned by Theophrastus about 300 B.C., from which it is inferred that thus early it was dug from some of the more shallow depths. The Britons before the time of the Roman invasion are credited with some slight knowledge of its industrial value. Prehistoric excavations have been found in Monmouthshire, and at Stanley, in Derbyshire, and the flint axes there actually found imbedded in the layer of coal are reasonably held to indicate its excavation by neolithic or palaeolithic (stone-age) workmen.

The fact that coal cinders have been found on old Roman walls in conjunction with Roman tools and implements, goes to prove that its use, at least for heating purposes, was known in England prior to the Saxon invasion, whilst some polygonal chambers in the six-foot seam near the river Douglas, in Lancashire, are supposed also to be Roman.

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The Chinese were early acquainted with the existence of coal, and knew of its industrial value to the extent of using it for the baking of porcelain.

The fact of its extensive existence in Great Britain, and the valuable uses to which it might be put, did not, however, meet with much notice until the ninth century, when, owing to the decrease of the forest-area, and consequently of the supply of wood-charcoal therefrom, it began to attract attention as affording an excellent substitute for charcoal.

The coal-miner was, however, still a creation of the future, and even as peat is collected in Ireland at the present day for fuel, without the laborious process of mining for it, so those people living in coal-bearing districts found their needs satisfied by the quantity of coal, small as it was, which appeared ready to hand on the sides of the carboniferous mountains. Till then, and for a long time afterwards, the principal source of fuel consisted of vast forests, amidst which the charcoal-burners, or “colliers” as they were even then called, lived out their lonely existence in preparing charcoal and hewing wood, for the fires of the baronial halls and stately castles then swarming throughout the land. As the forests became used up, recourse was had more and more to coal, and in 1239 the first charter dealing with and recognising the importance of the supplies was granted to the freemen of Newcastle, according them permission to dig for coals in the Castle fields. About the same time a coal-pit at Preston, Haddingtonshire, was granted to the monks of Newbattle.

Specimens of Newcastle coal were sent to London, but the city was loth to adopt its use, objecting to the innovation as one prejudicial to the health of its citizens. By the end of the 16th century, two ships only were found sufficient to satisfy the demand for stone-coal in London. This slow progress may, perhaps, have been partially owing to the difficulties which were placed in the way of its universal use. Great opposition was experienced by those who imported it into the metropolis, and the increasing amount which was used by brewers and others about the year 1300, caused serious complaints to be made, the effect of which was to induce Parliament to obtain a proclamation from the King prohibiting its use, and empowering the justices to inflict a fine on those who persisted in burning it. The nuisance which coal has since proved itself, in the pollution of the atmosphere and in the denuding of wide tracts of country of all vegetation, was even thus early recognised, and had the efforts which were then made to stamp out its use, proved successful, those who live now in the great cities might never have become acquainted with that species of black winter fog which at times hangs like a pall over them, and transforms the brightness of day into a darkness little removed from that of night. At the same time, we must bear in mind that it is universally acknowledged that England owes her prosperity, and her pre-eminence in commerce, in great part, to her happy possession of wide and valuable coal-fields, and many authorities have not hesitated to say, that, in their opinion, the length of time during which England will continue to hold her prominent position as an industrial nation is limited by the time during which her coal will last.

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The attempt to prohibit the burning of coal was not, however, very successful, for in the reign of Edward III. a license was again granted to the freemen of Newcastle to dig for coals. Newcastle was thus the first town to become famous as the home of the coal-miner, and the fame which it early acquired, it has held unceasingly ever since.

Other attempts at prohibition of the article were made at various times subsequently, amongst them being one which was made in Elizabeth's reign. It was supposed that the health of the country squires, who came to town to attend the session of Parliament, suffered considerably during their sojourn in London, and, to remedy this serious state of affairs, the use of stone-coal during the time Parliament was sitting was once more prohibited.

Coal was, however, by this time beginning to be recognised as a most valuable and useful article of fuel, and had taken a position in the industrial life of the country from which it was difficult to remove it. Rather than attempt to have arrested the growing use of coal, Parliament would have been better employed had it framed laws compelling the manufacturers and other large burners to consume their own smoke, and instead of aiming at total prohibition, have encouraged an intelligent and more economical use of it.

In spite of all prohibition its use rapidly spread, and it was soon applied to the smelting of iron and to other purposes. Iron had been largely produced in the south of England from strata of the Wealden formation, during the existence of the great forest which at one time extended for miles throughout Surrey and Sussex. The discovery of coal, however, and the opening up of many mines in the north, gave an important impetus to the smelting of iron in those counties, and as the forests of the Weald became exhausted, the iron trade gradually declined. Furnace after furnace became extinguished, until in 1809 that at Ashburnham, which had lingered on for some years, was compelled to bow to the inevitable fate which had overtaken the rest of the iron blast-furnaces.

In referring to this subject, Sir James Picton says:—"Ironstone of excellent quality is found in various parts of the county, and was very early made use of. Even before the advent of the Romans, the Forest of Dean in the west, and the Forest of Anderida, in Sussex, in the east, were the two principal sources from which the metal was derived, and all through the mediaeval ages the manufacture was continued. After the discovery of the art of smelting and casting iron in the sixteenth century, the manufacture in Sussex received a great impulse from the abundance of wood for fuel, and from that time down to the middle of the last century it continued to flourish. One of the largest furnaces was at Lamberhurst, on the borders of Kent, where the noble balustrade surrounding St Paul's Cathedral was cast at a cost of about L11,000. It is stated by the historian Holinshed that the first

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cast-iron ordnance was manufactured at Buxted. Two specialities in the iron trade belonged to Sussex, the manufacture of chimney-backs, and cast-iron plates for grave-stones. At the time when wood constituted the fuel the backs of fire-places were frequently ornamented with neat designs. Specimens, both of the chimney-backs and of the monuments, are occasionally met with. These articles were exported from Rye. The iron manufacture, of course, met with considerable discouragement on the discovery of smelting with pit-coal, and the rapid progress of iron works in Staffordshire and the North, but it lingered on until the great forest was cut down and the fuel exhausted."

In his interesting work, "Sylvia," published in 1661, Evelyn, in speaking of the noxious vapours poured out into the air by the increasing number of coal fires, writes, "This is that pernicious smoke which sullies all her glory, superinducing a sooty crust or furr upon all that it lights, spoiling movables, tarnishing the plate, gildings and furniture, and corroding the very iron bars and hardest stones with those piercing and acrimonious spirits which accompany its sulphur, and executing more in one year than the pure air of the country could effect in some hundreds." The evils here mentioned are those which have grown and have become intensified a hundred-fold during the two centuries and a half which have since elapsed. When the many efforts which were made to limit its use in the years prior to 1600 are remembered; at which time, we are informed, two ships only were engaged in bringing coal to London, it at once appears how paltry are the efforts made now to moderate these same baneful influences on our atmosphere, at a time when the annual consumption of coal in the United Kingdom has reached the enormous total of 190 millions of tons. The various smoke-abatement associations which have started into existence during the last few years are doing a little, although very little, towards directing popular attention to the subject; but there is an enormous task before them, that of awakening every individual to an appreciation of the personal interest which he has in their success, and to realise how much might at once be done if each were to do his share, minute though it might be, towards mitigating the evils of the present mode of coal-consumption. Probably very few householders ever realise what important factories their chimneys constitute, in bringing about air pollution, and the more they do away with the use of bituminous coal for fuel, the nearer we shall be to the time when yellow fog will be a thing of the past.

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A large proportion of smoke consists of particles of pure unconsumed carbon, and this is accompanied in its passage up our chimneys by sulphurous acid, begotten by the sulphur which is contained in the coal to the amount of about eight pounds in every thousand; by sulphuretted hydrogen, by hydro-carbons, and by vapours of various kinds of oils, small quantities of ammonia, and other bodies not by any means contributing to a healthy condition of the atmosphere. A good deal of the heavier carbon is deposited along the walls of chimneys in the form of soot, together with a small percentage of sulphate of ammonia; this is as a consequence very generally used for manure. The remainder is poured out into the atmosphere, there to undergo fresh changes, and to become a fruitful cause of those thick black fogs with which town-dwellers are so familiar. Sulphuretted hydrogen (H_2S) is a gas well known to students of chemistry as a most powerful reagent, its most characteristic external property being the extremely offensive odour which it possesses, and which bears a strong resemblance to that of rotten eggs or decomposing fish. It tarnishes silver work and picture frames very rapidly. On combustion it changes to sulphurous acid (SO_2), and this in turn has the power of taking up from the air another atom of oxygen, forming sulphuric acid (SO_3 + water), or, as we more familiarly know it, oil of vitriol.

Yet the smoke itself, including as it does all the many impurities which exist in coal, is not only evil in itself, but is evil in its influences. Dr Siemens has said:—“It has been shown that the fine dust resulting from the imperfect combustion of coal was mainly instrumental in the formation of fog; each particle of solid matter attracting to itself aqueous vapour. These globules of fog were rendered particularly tenacious and disagreeable by the presence of tar vapour, another result of imperfect combustion of raw fuel, which might be turned to better account at the dyeworks. The hurtful influence of smoke upon public health, the great personal discomfort to which it gave rise, and the vast expense it indirectly caused through the destruction of our monuments, pictures, furniture, and apparel, were now being recognised.”

The most effectual remedy would result from a general recognition of the fact that wherever smoke was produced, fuel was being consumed wastefully, and that all our calorific effects, from the largest furnace to the domestic fire, could be realised as completely, and more economically, without allowing any of the fuel employed to reach the atmosphere unburnt. This most desirable result might be effected by the use of gas for all heating purposes, with or without the additional use of coke or anthracite. The success of the so-called smoke-consuming stoves is greatly open to question, whilst some of them have been reported upon by those appointed to inspect them as actually accentuating the incomplete combustion, the abolition of which they were invented to bring about.

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The smoke nuisance is one which cuts at the very basis of our business life. The cloud which, under certain atmospheric conditions, rests like a pall over our great cities, will not even permit at times of a single ray of sunshine permeating it. No one knows whence it rises, nor at what hour to expect it. It is like a giant spectre which, having lain dormant since the carboniferous age, has been raised into life and being at the call of restless humanity; it is now punishing us for our prodigal use of the wealth it left us, by clasping us in its deadly arms, cutting off our brilliant sunshine, and necessitating the use in the daytime of artificial light; inducing all kinds of bronchial and throat affections, corroding telegraph and telephone wires, and weathering away the masonry of public buildings.

The immense value to us of the coal-deposits which lie buried in such profusion in the earth beneath us, can only be appreciated when we consider the many uses to which coal has been put. We must remember, as we watch the ever-extending railway ramifying the country in every direction, that the first railway and the first locomotive ever built, were those which were brought into being in 1814 by George Stephenson, for the purpose of the carriage of coals from the Killingworth Colliery. To the importance of coal in our manufactures, therefore, we owe the subsequent development of steam locomotive power as the means of the introduction of passenger traffic, and by the use of coal we are enabled to travel from one end of the country to the other in a space of time inconceivably small as compared with that occupied on the same journey in the old coaching days. The increased rapidity with which our vessels cross the wide ocean we owe to the use of coal; our mines are carried to greater depths owing to the power our pumping-engines obtain from coal in clearing the mines of water and in ensuring ventilation; the enormous development of the iron trade only became possible with the increased blast power obtained from the consumption of coal, and the very hulls and engines of our steamships are made of this iron; our railroads and engines are mostly of iron, and when we think of the extensive use of iron utensils in every walk in life, we see how important becomes the power we possess of obtaining the necessary fuel to feed the smelting furnaces. Evaporation by the sun was at one time the sole means of obtaining salt from seawater; now coal is used to boil the salt pans and to purify the brine from the salt-mines in the triassic strata of Cheshire. The extent to which gas is used for illuminating purposes reminds us of another important product obtained from coal. Paraffin oil and petroleum we obtain from coal, whilst candles, oils, dyes, lubricants, and many other useful articles go to attest the importance of the underground stores of that mineral which has well and deservedly been termed the “black diamond.”

CHAPTER VI.

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HOW GAS IS MADE—ILLUMINATING OILS AND BYE-PRODUCTS.

Accustomed as we are at the present day to see street after street of well-lighted thoroughfares, brilliantly illuminated by gas-lamps maintained by public authority, we can scarcely appreciate the fact that the use of gas is, comparatively speaking, of but recent growth, and that, like the use of coal itself, it has not yet existed a century in public favour. Valuable as coal is in very many different ways, perhaps next in value to its actual use as fuel, ranks the use of the immediate product of its distillation—viz., gas; and although gas is in some respects waning before the march of the electric light in our day, yet, even as gas at no time has altogether superseded old-fashioned oil, so we need not anticipate a time when gas in turn will be likely to be superseded by the electric light, there being many uses to which the one may be put, to which the latter would be altogether inapplicable; for, in the words of Dr Siemens, assuming the cost of electric light to be practically the same as gas, the preference for one or other would in each application be decided upon grounds of relative convenience, but gas-lighting would hold its own as the poor man’s friend. Gas is an institution of the utmost value to the artisan; it requires hardly any attention, is supplied upon regulated terms, and gives, with what should be a cheerful light, a genial warmth, which often saves the lighting of a fire.

The revolution which gas has made in the appearance of the streets, where formerly the only illumination was that provided by each householder, who, according to his means, hung out a more or less efficient lantern, and consequently a more or less smoky one, cannot fail also to have brought about a revolution in the social aspects of the streets, and therefore is worthy to be ranked as a social reforming agent; and some slight knowledge of the process of its manufacture, such as it is here proposed to give, should be in the possession of every educated individual. Yet the subjects which must be dealt with in this chapter are so numerous and of such general interest, that we shall be unable to enter more than superficially into any one part of the whole, but shall strive to give a clear and comprehensive view, which shall satisfy the inquirer who is not a specialist.

The credit of the first attempt at utilising the gaseous product of coal for illumination appears to be due to Murdock, an engineer at Redruth, who, in 1792, introduced it into his house and offices, and who, ten years afterwards, as the result of numerous experiments which he made with a view to its utilisation, made a public display at Birmingham on the occasion of the Peace of Amiens, in 1802.

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More than a century before, however, the gas obtained from coal had been experimented upon by a Dr Clayton, who, about 1690, conceived the idea of heating coal until its gaseous constituents were forced out of it. He described how he obtained steam first of all, then a black oil, and finally a “spirit,” as our ancestors were wont to term the gas. This, to his surprise, ignited on a light being applied to it, and he considerably amused his friends with the wonders of this inflammatory spirit. For a century afterwards it remained in its early condition, a chemical wonder, a thing to be amused with; but it required the true genius and energy of Murdock to show the great things of which it was capable.

London received its first instalment of gas in 1807, and during the next few years its use became more and more extended, houses and streets rapidly receiving supplies in quick succession. It was not, however, till about the year 1820 that its use throughout the country became at all general, St James’ Park being gas-lit in the succeeding year. This is not yet eighty years ago, and amongst the many wonderful things which have sprung up during the present century, perhaps we may place in the foremost rank for actual utility, the gas extracted from coal, conveyed as it is through miles upon miles of underground pipes into the very homes of the people, and constituting now almost as much a necessity of a comfortable existence as water itself.

The use of gas thus rapidly extended for illuminating purposes, and to a very great extent superseded the old-fashioned means of illumination.

[Illustration: FIG. 34.—Inside a Gas-Holder.]

The gas companies which sprang up were not slow to notice that, seeing the gas was supplied by meter, it was to their pecuniary advantage “to give merely the prescribed illuminating power, and to discourage the invention of economical burners, in order that the consumption might reach a maximum. The application of gas for heating purposes had not been encouraged, and was still made difficult in consequence of the objectionable practice of reducing the pressure in the mains during daytime to the lowest possible point consistent with prevention of atmospheric indraught.”

The introduction of an important rival into the field in the shape of the electric light has now given a powerful impetus to the invention and introduction of effective gas-lamps, and amongst inventors of recent years no name is, perhaps, in this respect so well known as the name of Sugg. As long as gas retained almost the monopoly, there was no incentive to the gas companies to produce an effective light cheaply; but now that the question of the relative cheapness of gas and electricity is being actively discussed, the gas companies, true to the instinct of self-preservation, seem determined to show what can be done when gas is consumed in a scientific manner.

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In order to understand how best a burner should be constructed in order that the gas that is burnt should give the greatest possible amount of illumination, let us consider for a moment the composition of the gas flame. It consists of three parts, (1) an interior dark space, in which the elements of the gas are in an unconsumed state; (2) an inner ring around the former, whence the greatest amount of light is obtained, and in which are numerous particles of carbon at a white heat, each awaiting a supply of oxygen in order to bring about combustion; and (3) an outer ring of blue flame in which complete combustion has taken place, and from which the largest amount of heat is evolved.

The second of these portions of the flame corresponds with the “reducing” flame of the blow-pipe, since this part, if turned upon an oxide, will reduce it, *i.e.*, abstract its oxygen from it. This part also corresponds with the jet of the Bunsen burner, when the holes are closed by which otherwise air would mingle with the gas, or with the flame from a gas-stove when the gas ignites beneath the proper igniting-jets, and which gives consequently a white or yellow flame.

The third portion, on the other hand, corresponds with the “oxidising” flame of the blow-pipe, since it gives up oxygen to bodies that are thirsting for it. This also corresponds with the ordinary blue flame of the Bunsen burner, and with the blue flame of gas-stoves where heat, and not light, is required, the blue flame in both cases being caused by the admixture of air with the gas.

Thus, in order that gas may give the best illumination, we must increase the yellow or white space of carbon particles at a white heat, and a burner that will do this, and at the same time hold the balance so that unconsumed particles of carbon shall not escape in the way of smoke, will give the most successful illuminating results. With this end in view the addition of albo-carbon to a bulb in the gas-pipe has proved very successful, and the incandescent gas-jet is constructed on exactly the same chemical principle. The invention of burners which brought about this desirable end has doubtless not been without effect in acting as a powerful obstacle to the widespread introduction of the electric light.

Without entering into details of the manufacture of gas, it will be as well just to glance at the principal parts of the apparatus used.

The gasometer, as it has erroneously been called, is a familiar object to most people, not only to sight but unfortunately also to the organs of smell. It is in reality of course only the gas-holder, in which the final product of distillation of the coal is stored, and from which the gas immediately passes into the distributing mains.

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The first, and perhaps, most important portion of the apparatus used in gas-making is the series of *retorts* into which the coal is placed, and from which, by the application of heat, the various volatile products distil over. These retorts are huge cast-iron vessels, encased in strong brick-work, usually five in a group, and beneath which a large furnace is kept going until the process is complete. Each retort has an iron exit pipe affixed to it, through which the gases generated by the furnace are carried off. The exit pipes all empty themselves into what is known as the *hydraulic main*, a long horizontal cylinder, and in this the gas begins to deposit a portion of its impurities. The immediate products of distillation are, after steam and air, gas, tar, ammoniacal liquor, sulphur in various forms, and coke, the last being left behind in the retort. In the hydraulic main some of the tar and ammoniacal liquor already begin to be deposited. The gas passes on to the *condenser*, which consists of a number of U-shaped pipes. Here the impurities are still further condensed out, and are collected in the *tar-pit* whilst the gas proceeds, still further lightened of its impurities. It may be mentioned that the temperature of the gas in the condenser is reduced to about 60 deg. F., but below this some of the most valuable of the illuminants of coal-gas would commence to be deposited in liquid form, and care has to be taken to prevent a greater lowering of temperature. A mechanical contrivance known as the *exhauster* is next used, by which the gas is, amongst other things, helped forward in its onward movement through the apparatus. The gas then passes to the *washers* or *scrubbers*, a series of tall towers, from which water is allowed to fall as a fine spray, and by means of which large quantities of ammonia, sulphuretted hydrogen, carbonic acid and oxide, and cyanogen compounds, are removed. In the scrubber the water used in keeping the coke, with which it is filled, damp, absorbs these compounds, and the union of the ammonia with certain of them takes place, resulting in the formation of carbonate of ammonia (smelling salts), sulphide and sulphocyanide of ammonia.

[Illustration: FIG. 35.—Filling Retorts by Machinery.]

[Illustration: FIG. 36.—CONDENSERS.]

Hitherto the purification of the gas has been brought about by mechanical means, but the gas now enters the “*purifier*,” in which it undergoes a further cleansing, but this time by chemical means.

[Illustration: FIG. 37.]

The agent used is either lime or hydrated oxide of iron, and by their means the gas is robbed of its carbonic acid and the greater part of its sulphur compounds. The process is then considered complete, and the gas passes on into the water chamber over which the gas-holder is reared, and in which it rises through the water, forcing the huge cylinder upward according to the pressure it exerts.

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The gas-holder is poised between a number of upright pillars by a series of chains and pulleys, which allow of its easy ascent or descent according as the supply is greater or less than that drawn from it by the gas mains.

[Illustration: FIG. 38.]

When we see the process which is necessary in order to obtain pure gas, we begin to appreciate to what an extent the atmosphere is fouled when many of the products of distillation, which, as far as the production of gas is concerned, may be called impurities, are allowed to escape free without let or hindrance. In these days of strict sanitary inspection it seems strange that the air in the neighbourhood of gas-works is still allowed to become contaminated by the escape of impure compounds from the various portions of the gas-making apparatus. Go where one may, the presence of these compounds is at once apparent to the nostrils within a none too limited area around them, and yet their deleterious effects can be almost reduced to a minimum by the use of proper purifying agents, and by a scientific oversight of the whole apparatus. It certainly behoves all sanitary authorities to look well after any gas-works situated within their districts.

Now let us see what these first five products of distillation actually are.

Firstly, house-gas. Everybody knows what house-gas is. It cannot, however, be stated to be any one gas in particular, since it is a mechanical mixture of at least three different gases, and often contains small quantities of others.

A very large proportion consists of what is known as marsh-gas, or light carburetted hydrogen. This occurs occluded or locked up in the pores of the coal, and often oozes out into the galleries of coal-mines, where it is known as firedamp (German *dampf*, vapour). It is disengaged wherever vegetable matter has fallen and has become decayed. If it were thence collected, together with an admixture of ten times its volume of air, a miniature coal-mine explosion could be produced by the introduction of a match into the mixture. Alone, however, it burns with a feebly luminous flame, although to its presence our house-gas owes a great portion of its heating power. Marsh-gas is the first of the series of hydro-carbons known chemically as the *paraffins*, and is an extremely light substance, being little more than half the weight of an equal bulk of air. It is composed of four atoms of hydrogen to one of carbon (CH_{4}).

Marsh-gas, together with hydrogen and the monoxide of carbon, the last of which burns with the dull blue flame often seen at the surface of fires, particularly coke and charcoal fires, form about 87 per cent. of the whole volume of house-gas, and are none of them anything but poor illuminants.

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The illuminating power of house-gas depends on the presence therein of olefiant gas (*ethylene*), or, as it is sometimes termed, heavy carburetted hydrogen. This is the first of the series of hydro-carbons known as the *olefines*, and is composed of two atoms of carbon to every four atoms of hydrogen ($C_{2}H_{4}$). Others of the olefines are present in minute quantities. These assist in increasing the illuminosity, which is sometimes greatly enhanced, too, by the presence of a small quantity of benzene vapour. These illuminants, however, constitute but about 6 per cent. of the whole.

Added to these, there are four other usual constituents which in no way increase the value of gas, but which rather detract from it. They are consequently as far as possible removed as impurities in the process of gas-making. These are nitrogen, carbonic acid gas, and the destructive sulphur compounds, sulphuretted hydrogen and carbon bisulphide vapour. It is to the last two to which are to be attributed the injurious effects which the burning of gas has upon pictures, books, and also the tarnishing which metal fittings suffer where gas is burnt, since they give rise to the formation of oil of vitriol (sulphuric acid), which is being incessantly poured into the air. Of course the amount so given off is little as compared with that which escapes from a coal fire, but, fortunately for the inmates of the room, in this case the greater quantity goes up the chimney; this, however, is but a method of postponing the evil day, until the atmosphere becomes so laden with impurities that what proceeds at first up the chimney will finally again make its way back through the doors and windows. A recent official report tells us that, in the town, of St Helen’s alone, sufficient sulphur escapes annually into the atmosphere to finally produce 110,580 tons of sulphuric acid, and a computation has been made that every square mile of land in London is deluged annually with 180 tons of the same vegetation-denuding acid. It is a matter for wonder that any green thing continues to exist in such places at all.

The chief constituents of coal-gas are, therefore, briefly as follows:—

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/ (1)  Hydrogen,
| (2)  Marsh-gas (carburetted hydrogen or fire-damp),
| (3)  Carbon monoxide,
| (4)  Olefiant gas (ethylene, or heavy carburetted hydrogen), with
\      other olefines,
/ (5)  Nitrogen,
| (6)  Carbonic acid gas,
| (7)  Sulphuretted hydrogen,
\ (8) Carbon bisulphide (vapour),
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the last four being regarded as impurities, which are removed as far as possible in the manufacture.

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In the process of distillation of the coal, we have seen that various other important substances are brought into existence. The final residue of coke, which is impregnated with the sulphur which has not been volatilised in the form of sulphurous gases, we need scarcely more than mention here. But the gas-tar and the ammoniacal liquor are two important products which demand something more than our casual attention. At one time regarded by gas engineers as unfortunately necessary nuisances in the manufacture of gas, they have both become so valuable on account of materials which can be obtained from them, that they enable gas itself to be sold now at less than half its original price. The waste of former generations is being utilised in this, and an instance is recorded in which tar, which was known to have been lying useless at the bottom of a canal for years, has been purchased by a gas engineer for distilling purposes. It has been estimated that about 590,000 tons of coal-tar are distilled annually.

Tar in its primitive condition has been used, as every one is aware, for painting or tarring a variety of objects, such as barges and palings, in fact, as a kind of protection to the object covered from the ravages of insects or worms, or to prevent corrosion when applied to metal piers. But it is worthy of a better purpose, and is capable of yielding far more useful and interesting substances than even the most imaginative individual could have dreamed of fifty years ago.

In the process of distillation, the tar, after standing in tanks for some time, in order that any ammoniacal liquor which may be present may rise to the surface and be drawn off, is pumped into large stills, where a moderate amount of heat is applied to it. The result is that some of the more volatile products pass over and are collected in a receiver. These first products are known as *first light oils*, or *crude coal-naphtha*, and to this naphtha all the numerous natural naphthas which have been discovered in various portions of the world, and to which have been applied numerous local names, bear a very close resemblance. Such an one, for instance, was that small but famous spring at Biddings, in Derbyshire, from which the late Mr Young—Paraffin Young—obtained his well-known paraffin oil, which gave the initial impetus to what has since developed into a trade of immense proportions in every quarter of the globe.

After a time the crude coal-naphtha ceases to flow over, and the heat is increased. The result is that a fresh series of products, known as *medium oils*, passes over, and these oils are again collected and kept separate from the previous series. These in turn cease to flow, when, by a further increase of heat, what are known as the *heavy oils* finally pass over, and when the last of these, *green grease*, as it is called, distils over, pitch alone is left in the still. Pitch is used to a large extent in the preparation of artificial asphalte, and also of a fuel known as "briquettes."

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The products thus obtained at the various stages of the process are themselves subjected to further distillation, and by the exercise of great care, requiring the most delicate and accurate treatment, a large variety of oils is obtained, and these are retailed under many and various fanciful names.

One of the most important and best known products of the fractional distillation of crude coal-naphtha is that known as *benzene*, or benzole, (C_6H_6). This, in its unrefined condition, is a light spirit which distils over at a point somewhat below the boiling point of water, but a delicate process of rectification is necessary to produce the pure spirit. Other products of the same light oils are toluene and xylene.

Benzene of a certain quality is of course a very familiar and useful household supplement. It is sometimes known and sold as *benzene collas*, and is used for removing grease from clothing, cleaning kid gloves, &c. If pure it is in reality a most dangerous spirit, being very inflammable; it is also extremely volatile, so much so that, if an uncorked bottle be left in a warm room where there is a fire or other light near, its vapour will probably ignite. Should the vapour become mixed with air before ignition, it becomes a most dangerous explosive, and it will thus be seen how necessary it is to handle the article in household use in a most cautious manner. Being highly volatile, a considerable degree of cold is experienced if a drop be placed on the hand and allowed to evaporate.

Benzene, which is only a compound of carbon and hydrogen, was first discovered by Faraday in 1825; it is now obtained in large quantities from coal-tar, not so much for use as benzene; is for its conversion, in the first place, by the action of nitric acid, into *nitro-benzole,* a liquid having an odour like the oil of bitter almonds, and which is much used by perfumers under the name of *essence de mirbane*; and, in the second place, for the production from this nitro-benzole of the far-famed *aniline*. After the distillation of benzene from the crude coal-naphtha is completed, the chief impurities in the residue are charred and deposited by the action of strong sulphuric acid. By further distillation a lighter oil is given off, often known as *artificial turpentine oil*, which is used as a solvent for varnishes and lackers. This is very familiar to the costermonger fraternity as the oil which is burned in the flaring lamps which illuminate the New Cut or the Elephant and Castle on Saturday and other market nights.

By distillation of the *heavy oils*, carbolic acid and commercial *anthracene* are produced, and by a treatment of the residue, a white and crystalline substance known as *naphthalin* ($C_{10}H_8$) is finally obtained.

Thus, by the continued operation of the chemical process known as fractional distillation of the immediate products of coal-tar, these various series of useful oils are prepared.

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The treatment is much the same which has resulted in the production of paraffin oil, to which we have previously referred, and an account of the production of coal-oils would be very far from satisfactory, which made no mention of the production of similar commodities by the direct distillation of shale. Oil-shales, or bituminous shales, exist in all parts of the world, and may be regarded as mineral matter largely impregnated by the products of decaying vegetation. They therefore greatly resemble some coals, and really only differ therefrom in degree, in the quantity of vegetable matter which they contain. Into the subject of the various native petroleums which have been found—for these rock-oils are better known as petroleums—in South America, in Burmah (Rangoon Oil), at Baku, and the shores of the Caspian, or in the United States of America, we need not enter, except to note that in all probability the action of heat on underground bituminous strata of enormous extent has been the cause of their production, just as on a smaller scale the action of artificial heat has forced the reluctant shale to give up its own burden of mineral oil. However, previous to 1847, although native mineral oil had been for some years a recognised article of commerce, the causes which gave rise to the oil-wells, and the source, probably a deep-seated one, of the supply of oil, does not appear to have been well known, or at least was not enquired after. But in that year Mr Young, a chemist at Manchester, discovered that by distilling some petroleum, which he obtained from a spring at Riddings in Derbyshire, he was able to procure a light oil, which he used for burning in lamps, whilst the heavier product which he also obtained proved a most useful lubricant for machinery. This naturally distilled oil was soon found to be similar to that oil which was noticed dripping from the roof of a coal-mine. Judging that the coal, being under the influence of heat, was the cause of the production of the oil, Mr Young tested this conclusion by distilling the coal itself. Success attended his endeavour thus to procure the oil, and indelibly Young stamped his name upon the roll of famous men, whose industrial inventions have done so much towards the accomplishment of the marvellous progress of the present century. From the distillation he obtained the well-known Young's Paraffin Oil, and the astonishing developments of the process which have taken place since he obtained his patent in 1850, for the manufacture of oils and solid paraffin, must have been a source of great satisfaction to him before his death, which occurred in 1883.

Cannel coal, Boghead or Bathgate coal, and bituminous shales of various qualities, have all been requisitioned for the production of oils, and from these various sources the crude naphthas, which bear a variety of names according to some peculiarity in their origin, or place of occurrence, are obtained. Boghead coal, also known as "Torebanehill mineral," gives Boghead naphtha, while the crude naphtha obtained from shales is often quoted as shale-oil. In chemical composition these naphthas are closely related to one another, and by fractional distillation of them similar series of products are obtained as those we have already seen as obtained from the crude coal-naphtha of coal-tar.

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In the direct distillation of cannel-coal for the production of paraffin, it is necessary that the perpendicular tubes or retorts into which the coal is placed be heated only to a certain temperature, which is considerably lower than that applied when the object is the production of coal-gas. By this means nearly all the volatile matters pass over in the form of condensible vapours, and the crude oils are at once formed, from whence are obtained at different temperatures various volatile ethers, benzene, and artificial turpentine oil or petroleum spirit. After these, the well-known safety-burning paraffin oil follows, but it is essential that the previous three volatile products be completely cleared first, since, mixed with air, they form highly dangerous explosives. To the fact that the operation is carried on in the manufactories with great care and accuracy can only be attributed the comparative rareness of explosions of the oil used in households.

After paraffin, the heavy lubricating oils are next given off, still increasing the temperature, and, the residue being in turn subjected to a very low temperature, the white solid substance known as paraffin, so much used for making candles, is the result. By a different treatment of the same residue is produced that wonderful salve for tender skins, cuts, and burns, known popularly as *vaseline*. Probably no such widely-advertised remedial substance has so deserved its success as this universally-used waste product of petroleum.

We have noticed the fact that in order to procure safety-burning oils, it is absolutely necessary that the more volatile portions be completely distilled over first. By Act of Parliament a test is applied to all oils which are intended for purposes of illumination, and the test used consists of what is known as the flashing-point. Many of the more volatile ethers, which are highly inflammable, are given off even at ordinary temperatures, and the application of a light to the oil will cause the volatile portion to “flash,” as it is called. A safety-burning oil, according to the Act, must not flash under 100 deg. Fahrenheit open test, and all those portions which flash at a less temperature must be volatilised off before the residue can be deemed a safe oil. It seems probable that the flashing-point will sooner or later be raised.

One instance may be cited to show how necessary it is that the native mineral oils which have been discovered should have this effectual test applied to them.

When the oil-wells were first discovered in America, the oil was obtained simply by a process of boring, and the fountain of oil which was bored into at times was so prolific, that it rushed out with a force which carried all obstacles before it, and defied all control. In one instance a column of oil shot into the air to a height of forty feet, and defied all attempts to keep it under. In order to prevent further accident, all lights in the immediate neighbourhood

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were extinguished, the nearest remaining being at a distance of four hundred feet. But in this crude naphtha there was, as usual, a quantity of volatile spirit which was being given off even at the temperature of the surrounding atmosphere. This soon became ignited, and with an explosion the column of oil was suddenly converted into a roaring column of fire. The owner of the property was thrown a distance of twenty feet by the explosion, and soon afterwards died from the burns which he had received from it. Such an accident could not now, however, happen. The tapping, stopping, and regulating of gushing wells can now be more effectually dealt with, and in the process of refining; the most inflammable portions are separated, with a result that, as no oil is used in the country which flashes under 100 deg. F. open test, and as our normal temperature is considerably less than this, there is little to be feared in the way of explosion if the Act be complied with.

When the results of Mr Young's labours became publicly known, a number of companies were started with the object of working on the lines laid down in his patent, and these not only in Great Britain but also in the United States, whither quantities of cannel coal were shipped from England and other parts to feed the retorts. In 1860, according to the statistics furnished, some seventy factories were established in the United States alone with the object of extracting oil from coal and other mineral sources, such as bituminous shale, *etc*. When Young's patent finally expired, a still greater impetus was given to its production, and the manufacture would probably have continued to develop were it not that attention had, two years previously, been forcibly turned to those discoveries of great stores of natural oil in existence beneath a comparatively thin crust of earth, and which, when bored into, spouted out to tremendous heights.

The discovery of these oil-fountains checked for a time the development of the industry, but with the great production there has apparently been a greatly increased demand for it, and the British industry once again appears to thrive, until even bituminous shales have been brought under requisition for their contribution to the national wealth.

Were it not for the nuisance and difficulty experienced in the proper cleaning and trimming of lamps, there seems no other reason why mineral oil should not in turn have superseded the use of gas, even as gas had, years before, superseded the expensive animal and vegetable oils which had formerly been in use.

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Although this great development in the use of mineral oils has taken place only within the last thirty years, it must not be thought that their use is altogether of modern invention. That they were not altogether unknown in the fifth century before Christ is a matter of certainty, and at the time when the Persian Empire was at the zenith of its glory, the fires in the temples of the fire-worshippers were undoubtedly kept fed by the natural petroleum which the districts around afforded. It is thought by some that the legend which speaks of the fire which came down from heaven, and which lit the altars of the Zoroastrians, may have had its origin in the discovery of a hitherto unknown petroleum spring. More recently, the remarks of Marco Polo in his account of his travels in A.D. 1260 and following years, are particularly interesting as showing that, even then, the use of mineral oil for various purposes was not altogether unknown. He says that on the north of Armenia the Greater is “Zorzania, in the confines of which a fountain is found, from which a liquor like oil flows, and though unprofitable for the seasoning of meat, yet is very fit for the supplying of lamps, and to anoint other things; and this natural oil flows constantly, and that in plenty enough to lade camels.”

From this we can infer that the nature of the oil was entirely unknown, for it was a “liquor like oil,” and was also, strange to say, “unprofitable for the seasoning of meat”! In another place in Armenia, Marco Polo states that there was a fountain “whence rises oil in such abundance that a hundred ships might be at once loaded with it. It is not good for eating, but very fit for fuel, for anointing the camels in maladies of the skin, and for other purposes; for which reason people come from a great distance for it, and nothing else is burned in all this country.”

The remedial effects of the oil, when used as an ointment, were thus early recognised, and the far-famed vaseline of the present day may be regarded as the lineal descendent, so to speak, of the crude medicinal agent to which Marco Polo refers.

The term asphalt has been applied to so many and various mixtures, that one scarcely associates it with natural mineral pitch which is found in some parts of the world. From time immemorial this compact, bituminous, resinous mineral has been discovered in masses on the shores of the Dead Sea, which has in consequence received the well-known title of Lake Asphaltites. Like the naphthas and petroleums which have been noticed, this has had its origin in the decomposition of vegetable matter, and appears to be thrown up in a liquid form by the volcanic energies which, are still believed to be active in the centre of the lake, and which may be existent beneath a stratum, or bed, of oil-producing bitumen.

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In connection with the formation of this substance, the remarks of Sir Charles Lyell, the great geologist, may well be quoted, as showing the transformation of vegetable matter into petroleum, and afterwards into solid-looking asphalt. At Trinidad is a lake of bitumen which is a mile and a half in circumference. “The Orinoco has for ages been rolling down great quantities of woody and vegetable bodies into the surrounding sea, where, by the influence of currents and eddies, they may be arrested, and accumulated in particular places. The frequent occurrence of earthquakes and other indications of volcanic action in those parts, lend countenance to the opinion that these vegetable substances may have undergone, by the agency of subterranean fire, those transformations or chemical changes which produce petroleum; and this may, by the same causes, be forced up to the surface, where, by exposure to the air, it becomes inspissated, and forms those different varieties of earth-pitch or asphaltum so abundant in the island.”

It is interesting to note also that it was obtained, at an ancient period, from the oil-fountains of Is, and that it was put to considerable use in the embalming of the bodies of the Egyptians. It appears, too, to have been employed in the construction of the walls of Babylon, and thus from very early times these wonderful products and results of decayed vegetation have been brought into use for the service of man.

Aniline has been previously referred (p. 135) to as having been prepared from nitro-benzole, or *essence de mirbane*, and its preparation, by treating this substance with iron-filings and acetic acid, was one of the early triumphs of the chemists who undertook the search after the unknown contained in gas-tar. It had previously been obtained from oils distilled from bones. The importance of the substance lies in the fact that, by the action of various chemical reagents, a series of colouring matters of very great richness are formed, and these are the well-known *aniline dyes*.

As early as 1836, it was discovered that aniline, when heated with chloride of lime, acquired a beautiful blue tint. This discovery led to no immediate practical result, and it was not until twenty-one years after that a further discovery was made, which may indeed be said to have achieved a world-wide reputation. It was found that, by adding bichromate of potash to a solution of aniline and sulphuric acid, a powder was obtained from which the dye was afterwards extracted, which is known as *mauve*. Since that time dyes in all shades and colours have been obtained from the same source. *Magenta* was the next dye to make its appearance, and in the fickle history of fashion, probably no colours have had such extraordinary runs of popularity as those of mauve and magenta. Every conceivable colour was obtained in due course from the same source, and chemists began to suspect that, in the course of time, the colouring matter

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of dyer's madder, which was known as *alizarin*, would also be obtained therefrom. Hitherto this had been obtained from the root of the madder-plant, but by dint of careful and well-reasoned research, it was obtained by Dr Groebe, from a solid crystalline coal-tar product, known as *anthracene*, ($C_{12}H_{14}$). This artificial alizarin yields colours which are purer than those of natural madder, and being derived from what was originally regarded as a waste product, its cost of production is considerably cheaper.

We have endeavoured thus far to deal with (1) gas, and (2) tar, the two principal products in the distillation of coal. We have yet to say a few words concerning the useful ammoniacal liquor, and the final residue in the retorts, *i.e.*, coke.

The ammoniacal liquor which has been passing over during distillation of the coal, and which has been collecting in the hydraulic main and in other parts of the gas-making apparatus, is set aside to be treated to a variety of chemical reactions, in order to wrench from it its useful constituents. Amongst these, of course, *ammonia* stands in the first rank, the others being comparatively unimportant. In order to obtain this, the liquor is first of all neutralised by being treated with a quantity of acid, which converts the principal constituent of the liquor, *viz*., carbonate of ammonia (smelling salts), into either sulphate of ammonia, or chloride of ammonia, familiarly known as sal-ammoniac, according as sulphuric acid or hydrochloric acid is the acid used. Thus carbonate of ammonia with sulphuric acid will give sulphate of ammonia, but carbonate of ammonia with hydrochloric acid will give sal-ammoniac (chloride of ammonia). By a further treatment of these with lime, or, as it is chemically known, oxide of calcium, ammonia is set free, whilst chloride of lime (the well-known disinfectant), or sulphate of lime (gypsum, or "plaster of Paris"), is the result.

Thus:

Sulphate of ammonia + lime = plaster of Paris + ammonia.

or,

Sal-ammoniac + lime = chloride of lime + ammonia.

Ammonia itself is a most powerful gas, and acts rapidly upon the eyes. It has a stimulating effect upon the nerves. It is not a chemical element, being composed of three parts of hydrogen by weight to one of nitrogen, both of which elements alone are very harmless, and, the latter indeed, very necessary to human life. Ammonia is fatal to life, producing great irritation of the lungs.

It has also been called "hartshorn," being obtained by destructive distillation of horn and bone. The name "ammonia" is said to have been derived from the fact that it was first obtained by the Arabs near the temple of Jupiter Ammon, in Lybia, North Africa, from the excrement of camels, in the form of sal-ammoniac. There are always traces of it in the atmosphere, especially in the vicinity of large towns and manufactories where large quantities of coal are burned.

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Coke, if properly prepared, should consist of pure carbon. Good coal should yield as much as 80 per cent. of coke, but owing to the unsatisfactory manner of its production, this proportion is seldom yielded, whilst the coke which is familiar to householders, being the residue left in the retorts after gas-making, usually contains so large a proportion of sulphur as to make its combustion almost offensive. No doubt the result of its unsatisfactory preparation has been that it has failed to make its way into households as it should have done, but there is also another objection to its use, namely, the fact that, owing to the quantity of oxygen required in its combustion, it gives rise to feelings of suffocation where insufficient ventilation of the room is provided.

Large quantities of coke are, however, consumed in the feeding of furnace fires, and in the heating of boilers of locomotives, as well as in metallurgical operations; and in order to supply the demand, large quantities of coal are “coked,” a process by which the volatile products are completely combusted, pure coke remaining behind. This process is therefore the direct opposite to that of “distillation,” by which the volatile products are carefully collected and re-distilled.

The sulphurous impurities which are always present in the coal, and which are, to a certain extent, retained in coke made at the gas-works, themselves have a value, which in these utilitarian days is not long likely to escape the attention of capitalists. In coal, bands of bright shining iron pyrites are constantly seen, even in the homely scuttle, and when coal is washed, as it is in some places, the removal of the pyrites increases the value of the coal, whilst it has a value of its own.

The conversion of the sulphur which escapes from our chimneys into sulphuretted hydrogen, and then into sulphuric acid, or oil of vitriol, has already been referred to, and we can only hope that in these days when every available source of wealth is being looked up, and when there threatens to remain nothing which shall in the future be known as “waste,” that the atmosphere will be spared being longer the receptacle for the unowned and execrated brimstone of millions of fires and furnaces.

CHAPTER VII.

THE COAL SUPPLIES OF THE WORLD.

As compared with some of the American coal-fields, those of Britain are but small, both in extent and thickness. They can be regarded as falling naturally into three principal areas.

The northern coal-field, including those of Fife, Stirling, and Ayr
in Scotland; Cumberland, Newcastle, and Durham in England; Tyrone
in Ireland.

The middle coal-field, all geologically in union, including those of Yorkshire, Derbyshire, Shropshire, Staffordshire, Flint, and Denbigh.

The southern coal-field, including South Wales, Forest of Dean, Bristol, Dover, with an offshoot at Leinster, &c., and Millstreet, Cork.

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Thus it will be seen that while England and Scotland are, in comparison with their extent of surface, bountifully supplied with coal-areas, in the sister island of Ireland coal-producing areas are almost absent. The isolated beds in Cork and Tipperary, in Tyrone and Antrim, are but the remnants left of what were formerly beds of coal extending the whole breadth and length of Ireland. Such beds as there remain undoubtedly belong to the base of the coal-measures, and observations all go to show that the surface suffered such extreme denudation subsequent to the growth of the coal-forests, that the wealth which once lay there, has been swept away from the surface which formerly boasted of it.

On the continent of Europe the coal-fields, though not occupying so large a proportion of the surface of the country as in England, are very far from being slight or to be disregarded. The extent of forest-lands still remaining in Germany and Austria are sufficing for the immediate needs of the districts where some of the best seams occur. It is only where there is a dearth of handy fuel, ready to be had, perhaps, by the simple felling of a few trees, that man commences to dig into the earth for his fuel. But although on the continent not yet occupying so prominent a position in public estimation as do coal-fields in Great Britain, those of the former have one conspicuous characteristic, *viz*., the great thickness of some of the individual seams.

In the coal-field of Midlothian the seams of coal vary from 2 feet to 5 feet in thickness. One of them is known as the “great seam,” and in spite of its name attains a thickness only of from 8 to 10 feet thick. There are altogether about thirty seams of coal. When, however, we pass to the continent, we find many instances, such as that of the coal-field of Central France, in which the seams attain vast thicknesses, many of them actually reaching 40 and 60 feet, and sometimes even 80 feet. One of the seams in the district of St. Etienne varies from 30 to 70 feet thick, whilst the fifteen to eighteen workable seams give a thickness of 112 feet, although the total area of the field is not great. Again, in the remarkable basin of the Saone-et-Loire, although there are but ten beds of coal, two of them run from 30 to 60 feet each, whilst at Creusot the main seam actually runs locally to a thickness varying between 40 and 130 feet.

The Belgian coal-field stretches in the form of a narrow strip from 7 to 9 miles wide by about 100 miles long, and is divided into three principal basins. In that stretching from Liege to Verviers there are eighty-three seams of coal, none of which are less than 3 feet thick. In the basin of the Sambre, stretching from Namur to Charleroi, there are seventy-three seams which are workable, whilst in that between Mons and Thulin there are no less than one hundred and fifty-seven seams. The measures here are so folded in zigzag fashion, that in boring in the neighbourhood of Mons to a depth of 350 yards vertical, a single seam was passed through no less than six times.

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Germany, on the west side of the Rhine, is exceptionally fortunate in the possession of the famous Pfalz-Saarbruecken coal-field, measuring about 60 miles long by 20 miles wide, and covering about 175 square miles. Much of the coal which lies deep in these coal-measures will always remain unattainable, owing to the enormous thickness of the strata, but a careful computation made of the coal which can be worked, gives an estimate of no less than 2750 millions of tons. There is a grand total of two hundred and forty-four seams, although about half of them are unworkable.

Beside other smaller coal-producing areas in Germany, the coal-fields of Silesia in the southeastern corner of Prussia are a possession unrivalled both on account of their extent and thickness. It is stated that there exist 333 feet of coal, all the seams of which exceed 2-1/2 feet, and that in the aggregate there is here, within a workable depth, the scarcely conceivable quantity of 50,000 million tons of coal.

The coal-field of Upper Silesia, occupying an area about 20 miles long by 15 miles broad, is estimated to contain some 10,000 feet of strata, with 333 feet of good coal. This is about three times the thickness contained in the South Wales coal-field, in a similar thickness of coal-measures. There are single seams up to 60 feet thick, but much of the coal is covered by more recent rocks of New Red and Cretaceous age. In Lower Silesia there are numerous seams 3-1/2 feet to 5 feet thick, but owing to their liability to change in character even in the same seam, their value is inferior to the coals of Upper Silesia.

When British supplies are at length exhausted, we may anticipate that some of the earliest coals to be imported, should coal then be needed, will reach Britain from the upper waters of the Oder.

The coal-field of Westphalia has lately come into prominence in connection with the search which has been made for coal in Kent and Surrey, the strata which are mined at Dortmund being thought to be continuous from the Bristol coal-field. Borings have been made through the chalk of the district north of the Westphalian coal-field, and these have shown the existence of further coal-measures. The coal-field extends between Essen and Dortmund a distance of 30 miles east and west, and exhibits a series of about one hundred and thirty seams, with an aggregate of 300 feet of coal.

It is estimated that this coal-field alone contains no less than 39,200 millions of tons of coal.

Russia possesses supplies of coal whose influence has scarcely yet been felt, owing to the sparseness of the population and the abundance of forest. Carboniferous rocks abut against the flanks of the Ural Mountains, along the sides of which they extend for a length of about a thousand miles, with inter-stratifications of coal. Their actual contents have not yet been gauged, but there is every reason to believe that those coal-beds which have been seen are but samples of many others which will, when properly worked, satisfy the needs of a much larger population than the country now possesses.

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Like the lower coals of Scotland, the Russian coals are found in the carboniferous limestone. This may also be said of the coal-fields in the governments of Tula and Kaluga, and of those important coal-bearing strata near the river Donetz, stretching to the northern corner of the Sea of Azov. In the last-named, the seams are spread over an area of 11,000 square miles, in which there are forty-four workable seams containing 114 feet of coal. The thickest of known Russian coals occur at Lithwinsk, where three seams are worked, each measuring 30 feet to 40 feet thick.

An extension of the Upper Silesian coal-field appears in Russian Poland. This is of upper Carboniferous age, and contains an aggregate of 60 feet of coal.

At Ostrau, in Upper Silesia (Austria), there is a remarkable coal-field. Of its 370 seams there are no less than 117 workable ones, and these contain 350 feet of coal. The coals here are very full of gas, which even percolates to the cellars of houses in the town. A bore hole which was sunk in 1852 to a depth of 150 feet, gave off a stream of gas, which ignited, and burnt for many years with a flame some feet long.

The Zwickau coal-field in Saxony is one of the most important in Europe. It contains a remarkable seam of coal, known as Russokohle or soot-coal, running at times 25 feet thick. It was separated by Geinitz and others into four zones, according to their vegetable contents, *viz*.:—

1. Zone of Ferns.

2. Zone of Annularia and Calamites.

3. Zone of Sigillaria.

4. Zone of Sagenaria (in Silesia), equivalent to the culm-measures of Devonshire.

Coals belonging to other than true Carboniferous age are found in Europe at Steyerdorf on the Danube, where there are a few seams of good coal in strata of Liassic age, and in Hungary and Styria, where there are tertiary coals which approach closely to those of true Carboniferous age in composition and quality.

In Spain there are a few small scattered basins. Coal is found overlying the carboniferous limestone of the Cantabrian chain, the seams being from 5 feet to 8 feet thick. In the Satero valley, near Sotillo, is a single seam measuring from 60 feet to 100 feet thick. Coal of Neocomian age appears at Montalban.

When we look outside the continent of Europe, we may well be astonished at the bountiful manner in which nature has laid out beds of coal upon these ancient surfaces of our globe.

Professor Rogers estimated that, in the United States of America, the coal-fields occupy an area of no less than 196,850 square miles.

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Here, again, it is extremely probable that the coal-fields which remain, in spite of their gigantic existing areas, are but the remnants of one tremendous area of deposit, bounded only on the east by the Atlantic, and on the west by a line running from the great lakes to the frontiers of Mexico. The whole area has been subjected to forces which have produced foldings and flexures in the Carboniferous strata after deposition. These undulations are greatest near the Alleghanies, and between these mountains and the Atlantic, whilst the flexures gradually dying out westward, cause the strata there to remain fairly horizontal. In the troughs of the foldings thus formed the coal-measures rest, those portions which had been thrown up as anticlines having suffered loss by denudation. Where the foldings are greatest there the coal has been naturally most altered; bituminous and caking-coals are characteristic of the broad flat areas west of the mountains, whilst, where the contortions are greatest, the coal becomes a pure anthracite.

It must not be thought that in this huge area the coal is all uniformly good. It varies greatly in quality, and in some districts it occurs in such thin seams as to be worthless, except as fuel for consumption by the actual coal-getters. There are, too, areas of many square miles in extent, where there are now no coals at all, the formation having been denuded right down to the palaeozoic back-bone of the country.

Amongst the actual coal-fields, that of Pennsylvania stands pre-eminent. The anthracite here is in inexhaustible quantity, its output exceeding that of the ordinary bituminous coal. The great field of which this is a portion, extends in an unbroken length for 875 miles N.E. and S.W., and includes the basins of Ohio, Maryland, Virginia, Kentucky, and Tennessee. The workable seams of anthracite about Pottsville measure in the aggregate from 70 to 207 feet. Some of the lower seams individually attain an exceptional thickness, that at Lehigh Summit mine containing a seam, or rather a bed, of 30 feet of good coal.

A remarkable seam of coal has given the town of Pittsburg its name. This is 8 feet thick at its outcrop near the town, and although its thickness varies considerably, Professor Rogers estimates that the sheet of coal measures superficially about 14,000 square miles. What a forest there must have existed to produce so widespread a bed! Even as it is, it has at a former epoch suffered great denudation, if certain detached basins should be considered as indicating its former extent.

The principal seam in the anthracite district of central Pennsylvania, which extends for about 650 miles along the left bank of the Susquehanna, is known as the “Mammoth” vein, and is 29-1/2 feet thick at Wilkesbarre, whilst at other places it attains to, and even exceeds, 60 feet.

On the west of the chain of mountains the foldings become gentler, and the coal assumes an almost horizontal position. In passing through Ohio we find a saddle-back ridge or anticline of more ancient strata than the coal, and in consequence of this, we have a physical boundary placed upon the coal-fields on each side.

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Passing across this older ridge of denuded Silurian and other rocks, we reach the famous Illinois and Indiana coal-field, whose coal-measures lie in a broad trough, bounded on the west by the uprising of the carboniferous limestone of the upper Mississippi. This limestone formation appears here for the first time, having been absent on the eastern side of the Ohio anticline. The area of the coal-field is estimated at 51,000 square miles.

In connection with the coal-fields of the United States, it is interesting to notice that a wide area in Texas, estimated at 3000 square miles, produces a large amount of coal annually from strata of the Liassic age. Another important area of production in eastern Virginia contains coal referable to the Jurassic age, and is similar in fossil contents to the Jurassic of Whitby and Brora. The main seam in eastern Virginia boasts a thickness of from 30 to 40 feet of good coal.

Very serviceable lignites of Cretaceous age are found on the Pacific slope, to which age those of Vancouver's Island and Saskatchewan River are referable.

Other coal-fields of less importance are found between Lakes Huron and Erie, where the measures cover an area of 5000 square miles, and also in Rhode Island.

In British North America we find extensive deposits of valuable coal-measures. Large developments occur in New Brunswick and Nova Scotia. At South Joggins there is a thickness of 14,750 feet of strata, in which are found seventy-six coal-seams of 45 feet in total thickness. At Picton there are six seams with a total of 80 feet of coal. In the lower carboniferous group is found the peculiar asphaltic coal of the Albert mine in New Brunswick. Extensive deposits of lignite are met with both in the Dominion and in the United States, whilst true coal-measures flank both sides of the Rocky Mountains. Coal-seams are often encountered in the Arctic archipelago.

The principal areas of deposit in South America are in Brazil, Uruguay, and Peru. The largest is the Candiota coal-field, in Brazil, where sections in the valley of the Candiota River show five good seams with a total of 65 feet of coal. It is, however, worked but little, the principal workings being at San Jeronimo on the Jacahahay River.

In Peru the true carboniferous coal-seams are found on the higher ground of the Andes, whilst coal of secondary age is found in considerable quantities on the rise towards the mountains. At Porton, east of Truxillo, the same metamorphism which has changed the ridge of sandstone to a hard quartzite has also changed the ordinary bituminous coal into an anthracite, which is here vertical in position. The coals of Peru usually rise to more than 10,000 feet above the sea, and they are practically inaccessible.

Cretaceous coals have been found at Lota in Chili, and at Sandy Point, Straits of Magellan.

Turning to Asia, we find that coal has been worked from time to time at Heraclea in Asia Minor. Lignites are met with at Smyrna and Lebanon.

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The coal-fields of Hindoostan are small but numerous, being found in all parts of the peninsula. There is an important coal-field at Raniganj, near the Hooghly, 140 miles north of Calcutta. It has an area of 500 square miles. In the Raniganj district there are occasional seams 20 feet to 80 feet in thickness, but the coals are of somewhat inferior quality.

The best quality amongst Indian coals has come from a small coal-field of about 11 square miles in extent, situated at Kurhurbali on the East Indian Railway. Other coal-fields are found at Jherria and on the Sone River, in Bengal, and at Mopani on the Nerbudda. Much is expected in future from the large coal-field of the Wardha and Chanda districts, in the Central Provinces, the coal of which may eventually prove to be of Permian age.

The coal-deposits of China are undoubtedly of tremendous extent, although from want of exploration it is difficult to form any satisfactory estimate of them. Near Pekin there are beds of coal 95 feet thick, which afford ample provision for the needs of the city. In the mountainous districts of western China the area over which carboniferous strata are exposed has been estimated at 100,000 square miles. The coal-measures extend westward to the Mongolian frontier, where coal-seams 30 feet thick are known to lie in horizontal plane for 200 miles. Most of the Chinese coal-deposits are rendered of small value, either owing to the mountainous nature of the valleys in which they outcrop, or to their inaccessibility from the sea. Japan is not lacking in good supplies of coal. A colliery is worked by the government on the island of Takasima, near Nagasaki, for the supply of coals for the use of the navy.

The British possession of Labuan, off the island of Borneo, is rich in a coal of tertiary age, remarkable for the quantity of fossil resin which, it contains. Coal is also found in Sumatra, and in the Malayan Archipelago.

In Cape Colony and Natal the coal-bearing Karoo beds are probably of New Red age. The coal is reported to be excellent in quantity.

In Abyssinia lignites are frequently met with in the high lands of the interior.

Coal is very extensively developed throughout Australasia. In New South Wales, coal-measures occur in large detached portions between 29 deg. and 35 deg. S. latitude. The Newcastle district, at the mouth of the Hunter river, is the chief seat of the coal trade, and the seams are here found up to 30 feet thick. Coal-bearing strata are found at Bowen River, in Queensland, covering an area of 24,000 square miles, whilst important mines of Cretaceous age are worked at Ipswich, near Brisbane. In New Zealand quantities of lignite, described as a hydrous coal, are found and utilised; also an anhydrous coal which may prove to be either of Cretaceous or Jurassic age.

We have thus briefly sketched the supplies of coal, so far as they are known, which are to be found in various countries. But England has of late years been concerned as to the possible failure of her home supplies in the not very distant future, and the effects which such failure would be likely to produce on the commercial prosperity of the country.

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Great Britain has long been the centre of the universe in the supply of the world's coal, and as a matter of fact, has been for many years raising considerably more than one half of the total amount of coal raised throughout the whole world. There is, as we have seen, an abundance of coal elsewhere, which will, in the course of time, compete with her when properly worked, but Britain seems to have early taken the lead in the production of coal, and to have become the great universal coal distributor. Those who have misgivings as to what will happen when her coal is exhausted, receive little comfort from the fact that in North America, in Prussia, in China and elsewhere, there are tremendous supplies of coal as yet untouched, although a certain sense of relief is experienced when that fact becomes generally known.

If by the time of exhaustion of the home mines Britain is still dependent upon coal for fuel, which, in this age of electricity, scarcely seems probable, her trade and commerce will feel with tremendous effect the blow which her prestige will experience when the first vessel, laden with foreign coal, weighs anchor in a British harbour. In the great coal lock-out of 1893, when, for the greater part of sixteen weeks scarcely a ton of coal reached the surface in some of her principal coal-fields, it was rumoured, falsely as it appeared, that a collier from America had indeed reached those shores, and the importance which attached to the supposed event was shown by the anxious references to it in the public press, where the truth or otherwise of the alarm was actively discussed. Should such a thing at any time actually come to pass, it will indeed be a retribution to those who have for years been squandering their inheritance in many a wasteful manner of coal-consumption.

Thirty years ago, when so much small coal was wasted and wantonly consumed in order to dispose of it in the easiest manner possible at the pitmouths, and when only the best and largest coal was deemed to be of any value, louder and louder did scientific men speak in protest against this great and increasing prodigality. Wild estimates were set on foot showing how that, sooner or later, there would be in Britain no native supply of coal at all, and finally a Royal Commission was appointed in 1866, to collect evidence and report upon the probable time during which the supplies of Great Britain would last.

This Commission reported in 1871, and the outcome of it was that a period of twelve hundred and seventy-three years was assigned as the period during which the coal would last, at the then-existing rate of consumption. The quantity of workable coal within a depth of 4000 feet was estimated to be 90,207 millions of tons, or, including that at greater depths, 146,480 millions of tons. Since that date, however, there has been a steady annual increase in the amount of coal consumed, and subsequent estimates go to show that the supplies cannot last for more than 250 years, or, taking into consideration a possible decrease in consumption, 350 years. Most of the coal-mines will, indeed, have been worked out in less than a hundred years hence, and then, perhaps, the competition brought about by the demand for, and the scarcity of, coal from the remaining mines, will have resulted in the dreaded importation of coal from abroad.

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In referring to the outcome of the Royal Commission of 1866, although the Commissioners fixed so comparatively short a period as the probable duration of the coal supplies, it is but fair that it should be stated that other estimates have been made which have materially differed from their estimate. Whereas one estimate more than doubled that of the Royal Commission, that of Sir William Armstrong in 1863 gave it as 212 years, and Professor Jevons, speaking in 1875 concerning Armstrong's estimate, observed that the annual increase in the amount used, which was allowed for in the estimate, had so greatly itself increased, that the 212 years must be considerably reduced.

One can scarcely thoroughly appreciate the enormous quantity of coal that is brought to the surface annually, and the only wonder is that there are any supplies left at all. The Great Pyramid which is said by Herodotus to have been twenty years in building, and which took 100,000 men to build, contains 3,394,307 cubic yards of stone. The coal raised in 1892 would make a pyramid which would contain 181,500,000 cubic yards, at the low estimate that one ton could be squeezed into one cubic yard.

The increase in the quantity of coal which has been raised in succeeding years can well be seen from the following facts.

In 1820 there were raised in Great Britain about 20 millions of tons. By 1855 this amount had increased to 64-1/2 millions. In 1865 this again had increased to 98 millions, whilst twenty years after, *viz*., in 1885, this had increased to no less than 159 millions, such were the giant strides which the increase in consumption made.

In the return for 1892, this amount had farther increased to 181-1/2 millions of tons, an advance in eight years of a quantity more than equal to the total raised in 1820, and in 1894 the total reached 199-1/2 millions; this was produced by 795,240 persons, employed in and about the mines.

CHAPTER VIII.

THE COAL-TAR COLOURS.

In a former chapter some slight reference has been made to those bye-products of coal-tar which have proved so valuable in the production of the aniline dyes. It is thought that the subject is of so interesting a nature as to deserve more notice than it was possible to bestow upon it in that place. With abstruse chemical formulae and complex chemical equations it is proposed to have as little as possible to do, but even the most unscientific treatment of the subject must occasionally necessitate a scientific method of elucidation.

The dyeing industry has been radically changed during the last half century by the introduction of what are known as the *artificial* dyes, whilst the *natural* colouring matters which had previously been the sole basis of the industry, and which had been obtained by very simple chemical methods from some of the constituents of the animal kingdom, or which were found in a natural state in the vegetable kingdom, have very largely given place to those which have been obtained from coal-tar, a product of the mineralised vegetation of the carboniferous age.

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The development and discovery of the aniline colouring matters were not, of course, possible until after the extensive adoption of house-gas for illuminating purposes, and even then it was many years before the waste products from the gas-works came to have an appreciable value of their own. This, however, came with the increased utilitarianism of the commerce of the present century, but although aniline was first discovered in 1826 by Unverdorben, in the materials produced by the dry distillation of indigo (Portuguese, *anil*, indigo), it was not until thirty years afterwards, namely, in 1856, that the discovery of the method of manufacture of the first aniline dye, mauveine, was announced, the discovery being due to the persistent efforts of Perkin, to whom, together with other chemists working in the same field, is due the great advance which has been made in the chemical knowledge of the carbon, hydrogen, and oxygen compounds. Scientists appeared to work along two planes; there were those who discovered certain chemical compounds in the resulting products of reactions in the treatment of *existing* vegetation, and there were those who, studying the wonderful constituents in coal-tar, the product of a *past* age, immediately set to work to find therein those compounds which their contemporaries had already discovered. Generally, too, with signal success.

The discovery of benzene in 1825 by Faraday was followed in the course of a few years by its discovery in coal-tar by Hofmann. Toluene, which was discovered in 1837 by Pelletier, was recognised in the fractional distillation of crude naphtha by Mansfield in 1848. Although the method of production of mauveine on a large scale was not accomplished until 1856, yet it had been noticed in 1834, the actual year of its recognition as a constituent of coal-tar, that, when brought into contact with chloride of lime, it gave brilliant colours, but it required a considerable cheapening of the process of aniline manufacture before the dyes commenced to enter into competition with the old natural dyes.

The isolation of aniline from coal-tar is expensive, in consequence of the small quantities in which it is there found, but it was discovered by Mitscherlich that by acting upon benzene, one of the early distillates of coal-tar, for the production of nitro-benzole, a compound was produced from which aniline could be obtained in large quantities. There were thus two methods of obtaining aniline from tar, the experimental and the practical.

In producing nitrobenzole (nitrobenzene), chemically represented as ($C_6H_5NO_2$), the nitric acid used as the reagent with benzene, is mixed with a quantity of sulphuric acid, with the object of absorbing water which is formed during the reaction, as this would tend to dilute the efficiency of the nitric acid. The proportions are 100 parts of purified benzene, with a mixture of 115 parts of concentrated nitric acid (HNO_3) and 160 parts of concentrated

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sulphuric acid. The mixture is gradually introduced into the large cast-iron cylinder into which the benzene has been poured. The outside of the cylinder is supplied with an arrangement by which fine jets of water can be made to play upon it in the early stages of the reaction which follows, and at the end of from eight to ten hours the contents are allowed to run off into a storage reservoir. Here they arrange themselves into two layers, the top of which consists of the nitrobenzene which has been produced, together with some benzene which is still unacted upon. The mixture is then freed from the latter by treatment with a current of steam. Nitrobenzene presents itself as a yellowish oily liquid, with a peculiar taste as of bitter almonds. It was formerly in great demand by perfumers, but its poisonous properties render it a dangerous substance to deal with. In practice a given quantity of benzene will yield about 150 per cent of nitrobenzene. Stated chemically, the reaction is shown by the following equation:—

C_6H_6 + HNO_3 = $C_6H_5NO_2$, + H_2O
(Benzene) (Nitric acid) (Nitrobenzene) (Water).

The water which is thus formed in the process, by the freeing of one of the atoms of hydrogen in the benzene, is absorbed by the sulphuric acid present, although the latter takes no actual part in the reaction.

From the nitrobenzene thus obtained, the aniline which is now used so extensively is prepared. The component atoms of a molecule of aniline are shown in the formula $C_6H_5NH_2$. It is also known as phenylamine or amido-benzole, or commercially as aniline oil. There are various methods of reducing nitrobenzene for aniline, the object being to replace the oxygen of the former by an equivalent number of atoms of hydrogen. The process generally used is that known as Bechamp’s, with slight modifications. Equal volumes of nitrobenzene and acetic acid, together with a quantity of iron-filings rather in excess of the weight of the nitrobenzene, are placed in a capacious retort. A brisk effervescence ensues, and to moderate the increase of temperature which is caused by the reaction, it is found necessary to cool the retort. Instead of acetic acid hydrochloric acid has been a good deal used, with, it is said, certain advantageous results. From 60 to 65 per cent. of aniline on the quantity of nitrobenzene used, is yielded by Bechamp’s process.

Stated in a few words, the above is the process adopted on all hands for the production of commercial aniline, or aniline oil. The details of the distillation and rectification of the oil are, however, as varied as they can well be, no two manufacturers adopting the same process. Many of the aniline dyes depend entirely for their superiority, on the quality of the oil used, and for this reason it is subject to one or more processes of rectification. This is performed by distilling, the distillates at the various temperatures being separately collected.

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When pure, aniline is a colourless oily liquid, but on exposure rapidly turns brown. It has strong refracting powers and an agreeable aromatic smell. It is very poisonous when taken internally; its sulphate is, however, sometimes used medicinally. It is by the action upon aniline of certain oxidising agents, that the various colouring matters so well known as aniline dyes are obtained.

Commercial aniline oil is not, as we have seen, the purest form of rectified aniline. The aniline oils of commerce are very variable in character, the principal constituents being pure aniline, para- and meta-toluidine, xylidines, and cumidines. They are best known to the colour manufacturer in four qualities—

(*a*) Aniline oil for blue and black.

(*b*) Aniline oil for magenta.

(*c*) Aniline oil for safranine.

(*d*) *Liquid toluidine.*

From the first of these, which is almost pure aniline, aniline black is derived, and a number of organic compounds which are further used for the production of dyes. The hydrochloride of aniline is important and is known commercially as “aniline salt.”

The distillation and rectification of aniline oil is practised on a similar principle to the fractional distillation which we have noticed as being used for the distillation of the naphthas. First, light aniline oils pass over, followed by others, and finally by the heavy oils, or “aniline-tailings.” It is a matter of great necessity to those engaged in colour manufacture to apply that quality oil which is best for the production of the colour required. This is not always an easy matter, and there is great divergence of opinion and in practice on these points.

The so-called aniline colours are not all derived from aniline, such colouring matters being in some cases derived from other coal-tar products, such as benzene and toluene, phenol, naphthalene, and anthracene, and it is remarkable that although the earlier dyes were produced from the lighter and more easily distilled products of coal-tar, yet now some of the heaviest and most stubborn of the distillates are brought under requisition for colouring matters, those which not many years ago were regarded as fit only to be used as lubricants or to be regarded as waste.

It is scarcely necessary or advisable in a work of this kind to pursue the many chemical reactions, which, from the various acids and bases, result ultimately in the many shades and gradations of colour which are to be seen in dress and other fabrics. Many of them, beautiful in the extreme, are the outcome of much careful and well-planned study, and to print here the complicated chemical formulae which show the great changes taking place in compounds of complex molecules, or to mention even the names of these many-syllabled compounds, would be to destroy the purpose of this little book. The Rosanilines, the Indulines, and Safranines; the Oxazines, the Thionines: the

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Phenol and Azo dyes are all substances which are of greater interest to the chemical students and to the colour manufacturer than to the ordinary reader. Many of the names of the bases of various dyes are unknown outside the chemical dyeworks, although each and all have complicated; reactions of their own. In the reds are rosanilines, toluidine xylidine, &c.; in the blues—phenyl-rosanilines, diphenylamine, toluidine, aldehyde, &c.; violets—rosaniline, mauve, phenyl, ethyl, methyl, &c.; greens—iodine, aniline, leucaniline, chrysotoluidine, aldehyde, toluidine, methyl-anilinine, &c.; yellows and orange—leucaniline, phenylamine, &c.; browns—chrysotoluidine, &c.; blacks—aniline, toluidine, &c.

To take the rosanilines as an instance of the rest.

Aniline red, magenta, azaleine, rubine, solferino, fuchsine, chryaline, roseine, erythrobenzine, and others, are colouring matters in this group which are salts of rosaniline, and which are all recognised in commerce.

The base rosaniline is known chemically by the formula $C_{20}H_{l9}N_{3}$, and is prepared by heating a mixture of magenta aniline, toluidine, and pseudotoluidine, with arsenic acid and other oxidising agents. It is important that water should be used in such quantities as to prevent the solution of arsenic acid from depositing crystals on cooling. Unless carefully crystallised rosaniline will contain a slight proportion of the arseniate, and when articles of clothing are dyed with the salt, it is likely to produce an inflammatory condition of skin, when worn. Some years ago there was a great outcry against hose and other articles dyed with aniline dyes, owing to the bad effects which were produced, and this has no doubt proved very prejudicial to aniline dyes as a whole.

Again, the base known as mauve, or mauveine, has a composition shown by the formula $C_{27}H_{24}N_{4}$. It is produced from the sulphate of aniline by mixing it with a cold saturated solution of bichromate of potash, and allowing the mixture to stand for ten or twelve hours. A blue-black precipitate is then formed, which, after undergoing a process of purification, is dissolved in alcohol and evaporated to dryness. A metallic-looking powder is then obtained, which constitutes this all-important base. Mauve forms with acids a series of well-defined salts and is capable of expelling ammonia from its combinations. Mauve was the first aniline dye which was produced on a large scale, this being accomplished by Perkin in 1856.

The substance known as carbolic acid is so useful a product of a piece of coal that a description of the method of its production must necessarily have a place here. It is one of the most powerful antiseptic agents with which we are acquainted, and has strong anaesthetic qualities. Some useful dyes are also obtained from it. It is obtained in quantities from coal-tar, that portion of the distillate known as the light oils being its immediate source.

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The tar oil is mixed with a solution of caustic soda, and the mixture is violently agitated. This results in the caustic soda dissolving out the carbolic acid, whilst the undissolved oils collect upon the surface, allowing the alkaline solution to be drawn from beneath. The soda in the solution is then neutralised by the addition of a suitable quantity of sulphuric acid, and the salt so formed sinks while the carbolic acid rises to the surface.

Purification of the product is afterwards carried out by a process of fractional distillation. There are various other methods of preparing carbolic acid.

Carbolic acid is known chemically as $C_{6}H_{5}(HO)$. When pure it appears as colourless needle-like crystals, and is exceedingly poisonous. It has been used with marked success in staying the course of disease, such as cholera and cattle plague. It is of a very volatile nature, and its efficacy lies in its power of destroying germs as they float in the atmosphere. Modern science tells us that all diseases have their origin in certain germs which are everywhere present and which seek only a suitable *nidus* in which to propagate and flourish. Unlike mere deodorisers which simply remove noxious gases or odours; unlike disinfectants which prevent the spread of infection, carbolic acid strikes at the very root and origin of disease by oxidising and consuming the germs which breed it. So powerful is it that one part in five thousand parts of flour paste, blood, &c., will for months prevent fermentation and putrefaction, whilst a little of its vapour in the atmosphere will preserve meat, as well as prevent it from becoming fly-blown. Although it has, in certain impure states, a slightly disagreeable odour, this is never such as to be in any way harmful, whilst on the other hand it is said to act as a tonic to those connected with its preparation and use.

The new artificial colouring matters which are continually being brought into the market, testify to the fact that, even with the many beautiful tints and hues which have been discovered, finality and perfection have not yet been reached. A good deal of popular prejudice has arisen against certain aniline dyes on account of their inferiority to many of the old dye-stuffs in respect to their fastness, but in recent years the manufacture of many which were under this disadvantage of looseness of dye, has entirely ceased, whilst others have been introduced which are quite as fast, and sometimes even faster than the natural dyes.

It is convenient to express the constituents of coal-tar, and the distillates of those constituents, in the form of a genealogical chart, and thus, by way of conclusion, summarise the results which we have noticed.

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```
COAL.
|
.----------+----------+----+-----------------+-------+--
--.
|         |          |                     |        |    |
Water   House-gas   Coal-tar             Ammoniacal  Coke  |
|                  liquor          |
.---------+-------+---------+---------.    |          Sulphur
|        |       |        |         |    |       (sulphurreted
First    Second   Heavy  Anthracene  Pitch |        hydrogen:
light     light   oils    (green           |          sulphurous
oils      oils  (creosote   oils)          |          acid:  oil
|      (crude   oils)      |             |          of vitriol)
.----+----.  naphtha)  |     Anthracene          |
|        |     |      |         |              |
Ammoniacal Benzene |      |     Alizarin or        |
liquor   toluene,|      |    dyer's madder       |
&c.   |      |                    |
|      |                    |
|      | Sulphuric acid=Carbonate of=Hydrochloric
|      |              |  ammonia        acid
|      |              | (smelling
|      |              |   salts)
|      |              |
|      |   Lime=Sulphate of   Lime=Chloride of
|      |        | ammonia           | ammonia (sal
|      |        |                | ammoniac)
|      |        |                |
|      |   .----+----.          .----+----.
|      |   |         |          |         |
|      | Ammonia  Sulphate   Ammonia  Chloride
|      |          of lime            of lime.
|      |     (Plaster of Paris)
|      |
|   .--+-----+----------.
|   |       |         |
|  Crude    Carbolic  Naphthalin
|  Creosote   acid
|
.-------------+---+--+-------+--------+----------.
|                  |      |       |          |
Benzene=Nitric Acid  Toluene  Nylene  Artificial   Burning
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```
|                        turpentine   oils
Nitrobenzene= } Iron filings       oil (solvent
(Essence de | } and acetic acid      naphtha)
mirbane)  |
|
Aniline=Various reagents
|
Aniline dyes
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