SOME ECONOMICAL PROCESSES CONNECTED WITH THE CLOTHWORKING INDUSTRY*.

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IN this present age of scientific and technical activity, there is one branch which has, I think, been the subject of an article in the *Quarterly Journal of Science*. It is one which deserves attention. It was there termed "The Investigation of Residual Phenomena," and I can conceive no better title to express the idea. The investigator who first explores an unknown region is content if he can in some measure delineate its grand features—its rivers, its mountain chains, its plains; if he be a geologist, he attempts no more than broadly to observe its most important rock formations; if a botanist, its more striking forms of vegetation. So with the scientific investigator. The chemist or physicist who discovers a new law seldom succeeds in doing more than testing its general accuracy by experiments; it is reserved for his successors to note the divergence between his broad and sweeping generalization and particular instances which do not quite accord with it. So it was with Boyle's law that the volume of a gas varies in inverse ratio to the pressure to which it is exposed; so it is with the Darwinian theory, inasmuch as deterioration and degeneration play a part which was, perhaps, at first overlooked; and similar instances may be found in almost all pure sciences.

I conceive that the parallel from the technical point of view is a double one. For just as every technical process cannot be considered to be beyond improvement, there is always scope for technical investigation; but the true residual phenomena of which I would speak to-night are waste products. There is, I imagine, no manufacture in which every substance produced meets with a market. Some products are always allowed to run to waste, yet it is evident that every effort consistent with economy should be made to prevent such waste; and it has been frequently found that an attempt in this direction, though at first unsuccessful, has finally been worked into such a form as to remunerate the manufacturer.

It is my purpose to-night to bring under your notice methods by which saving can be effected in the cloth industry. I am aware that these methods have not much claim to novelty; but I also know that there are, unfortunately, few works where they are practiced.

The first of these relates to the saving and utilization of the soap used in wool scouring and milling. It is, perhaps, hardly necessary to explain that woolen goods are scoured by being run between rollers, after passing through a bath of soap, and this is continued for several hours, the cloth being repeatedly moistened with the lye, and repeatedly wrung out by the rollers. The process is analogous to ordinary washing; the soap dissolves the greasy film adhering to the fibers, and the "dirt" mechanically retained is thus loosened, and washed away. Now, in order to dissolve this greasy matter, a considerable amount of soap must be employed; and in the course of purification of the fabric, not merely what may be characterized as "dirt" is removed, but also short fibers, and various dye-stuffs with which the fabric has been dyed, many of which are partially soluble in alkaline water; moreover, it invariably happens that some dye does not combine with the fiber and mordant, thus becoming fixed, but merely incrusts the fiber; hence this portion is washed off when the retaining film of grease is removed from the fiber. The suds, therefore, after fulfilling this purpose, are no longer a pure solution of soap, but contain many foreign matters; and the problem is so to treat these suds as to recover the fat in some condition available for re-conversion into soap.

For this purpose wooden runnels are placed beneath the rollers, through which the cloth passes in the scouring machine, so as to collect the suds after they have been spent. These runnels lead to a wooden pipe or runnel, which receives the spent suds from all the scouring machines, and the whole of the waste, instead of being let off into the stream, polluting it, delivers into a tank or trough, which may also be constructed of wood, but, as it has to withstand the action of acid, is better lined with lead. This tank is necessarily proportioned in size to the number of scouring machines and the quantity of spent suds to be treated. When a sufficient quantity has collected, oil of vitriol, diluted with twice its bulk of water, is added, one workman pouring it in gradually while another stirs the contents of the tank vigorously. At short intervals, the liquid is tested by means of litmus paper, and when it shows a faint acid reaction, by turning the blue paper red, the addition of acid is stopped. The acid has then combined with the alkali of the soap, while the fatty acids formerly in combination with the alkali are liberated, and float to the surface of the liquid, carrying with them the impurities in the shape of short fibers and dye stuffs; the sand and heavier impurity, should any be present, sinks to the bottom.

After standing for some hours, the separation is complete. In order to separate the two layers, the tank is provided with an exit in the side, near the bottom, closed by a sluice or valve. This valve is opened, and the watery portion is allowed to escape into a sand filter bed.

The filter serves to retain any solid impurities which may still remain suspended in the water; but it will be found that the escaping water is nearly pure.

The dark brown fatty acid is mixed with a large amount of impurity, such as short wool fibers, burrs, sand, and dye stuffs washed from the wool. To remove water more completely, the semi-fluid mass is pumped from the tank, and delivered into hair-cloth filters; the liquid which drains from these bags finds its ways to the sand filters joining the drainage which formerly passed out from the tank through the sluice. After being turned over in the filter several times, the residue is transferred to canvas sacks. These sacks are placed in a filter press, where they are exposed to pressure while heated to a temperature sufficient to melt the fat. The solid impurities remain in the bags, while the fatty acids escape, and are received in a barrel or tank for the purpose. The fatty acids, when cold, are of a deep brown color, and of the consistency of butter. The residue is kept, and the method of treating it for the recovery of indigo will afterward be described.

The fatty acids are now ready for conversion into soap. It may here be remarked that, on distillation, they yield a nearly white fatty mass, which, when treated with soda-lye, is capable of yielding a perfectly white soap. But, for the clothworker's purpose, this purification is unnecessary.

The conversion into soap is a very simple matter. As the fats are acids—a mixture of palmitic, oleic, and stearic acids—and not the glycerine salts of these acids, like ordinary fats, soap is made by causing them directly to unite with caustic soda. The fats are melted in a copper, by means of a steam-jacket, or coil of steam-pipe in the copper, and the soda-lye is run in until complete union has taken place. The exact point of neutralization can easily be found by taking out a small sample after stirring, and dissolving it in some methylated spirits. A few drops of alcoholic tincture of phenol-phthalein are then added, and as soon as a faint red color appears, addition of soda is stopped. This shows that the fatty acids have been oversaturated. Addition of a little more fat renders them perfectly neutral, and the soap is then ladled out into wooden moulds, lined with loose sheets of zinc.

The resulting soap is of a brown color, but is perfectly adapted for the purpose of wool-scouring. It should here be mentioned that, in practice, the soap is always made somewhat alkaline; in point of fact, it contains about 2 per cent. of free alkali. This is found to assist in scouring; I presume that the free alkali forms a soap with the oil added to the wool during spinning, and if no free alkali be present, this oil would not be so thoroughly removed.

It will be noticed that in this simple method of soap-making, there is no salting out to separate the true soap from the watery solution of glycerine, for no glycerine is present. The apparatus may be of the simplest nature, and on any required scale, proportionate to the size of the mill. It is a process which requires no specially skilled labor; in any works some hand may be told off to conduct the process as occasion requires; and as a very large proportion of the fatty matter is recovered, the soap-bill is reduced to a very small fraction of the amount which would be paid were recovery not practiced. And lastly, the streams are not polluted; the only waste is a little sulphate of soda, which can hardly be regarded as a nuisance, inasmuch as it is a not unfrequent constituent of many natural waters.

Let us now return to the solid matter from which the fatty acids have been removed by pressure. This brown, earthly-looking cake consists of vegetable impurity washed off from the cloth, of short fibers, and of various dye stuffs. It is divided into two lots: That which contains indigo, and that which contains none, or which contains too small a quantity for profitable extraction. And it may here be remarked, that it is advisable to collect the suds from cloth dyed with indigo separate from that to dye which no indigo has been employed. The residue from indigo-dyed cloth has always a more or less blue shade, and if much indigo is present, the well-known copper-color is evident. Of course, the amount of indigo must greatly vary, but it may rise to 8 or 10 per cent. of the total weight of the refuse.

To recover the indigo from this refuse, the somewhat hard cakes are broken up, placed in a tank, and allowed to steep in water. When quite disintegrated, they are transferred to another tank—a barrel may be used for small quantities—and thus this refuse is exposed to the reducing action of copperas and lime. The indigo is converted into indigo-white, and is rendered soluble, and it oxidizes on the surface, forming a layer of blue froth on the top of the liquid, while the remainder of the impurities sinks. This process of reduction may last for twenty-four hours, and is helped by frequent stirring.

The indigo scum is preserved, and placed in filter cloths, where it is thoroughly washed with water two or three times. The residue which has sunk to the bottom is removed, dried, and forms a valuable manure, owing to the amount of the nitrogen which it contains. Its value may be increased by addition of weak vitriol, which exercises a decomposing action on the nitrogenous matter, forming with it sulphate of ammonia. The original residue from the filter-press, if it does not contain indigo, may be at once put to similar use.

In large works, which dye their own goods, it is well known that the "fermentation vat" is in general use for indigo-dyeing. But this vat requires constant superintendence, and must be kept in continual action; besides, it is successful only on a comparatively large scale. And, moreover, it requires skilled labor. Small works, or works in which dyeing is only occasionally practiced, find it more convenient to use Schützenberger and Lalande's process. Although this process is well known, a short description of it may not here be out of place.

The process depends on the reduction of indigo to indigo-white, or soluble indigo, by means of hyposulphite, or, as it is generally termed to avoid confusion with antichlore, rightly named thiosulphate of soda, hydrosulphite of soda. The formula of this substance is $NaHSO_2$, as distinguished from what is commonly known as hyposulphite of soda, $Na_2S_2O_3$. It is produced by the action of zinc-dust on the acid sulphite of soda. The zinc may be supposed to remove oxygen from the acid sulphite, $NaHSO_3$, giving hyposulphite, $NaHSO_2$. The reduction of the acid sulphite is best performed in a cask, which can be closed at the top, so as to avoid entrance of air. The acid sulphite of soda, at a strength of 50 or 60 Twaddell (specific gravity 1·26 to 1·3), is placed in the cask, and zinc-dust is added, with frequent stirring. The liquid is then mixed with milk of lime, and after again thoroughly stirring, the liquid is allowed to settle, and the clear is decanted into the dyeing-copper. The indigo, in the frothy state in which it is skimmed from the purifying barrels or tanks, is then added, with sufficient lime to dissolve it when it has been reduced. It is heated gently by a steam coil, to about 90° Fahr., and the goods are dyed in it. The colors obtained by means of this indigo are light in shade, and the goods must be dipped several times if dark shades are required. But it is found better in practice not to attempt to dye dark shades by this process; the ordinary indigo-vat is better adapted for such work. The object of not wasting indigo is sufficiently attained by employing it for the purpose to which it is best adapted. Of course the recovered indigo may be used in the ordinary manner. I merely mention the most convenient way of disposing of it in works where only a small quantity is recovered, and which do not practice dyeing on an extensive scale.

I have now to ask you to turn to a different subject, namely, the scouring of wool, not by the usual agent, water, but by a liquid, bisulphide of carbon, made by the action of sulphur vapor on red hot coke or charcoal.

This, again, is not wholly a new process, for various attempts have been made to dissolve out the yolk, or *suint*, or greasy matter from unwashed wool, as it comes from the back of the sheep. Fusel oil has been patented for this purpose. Carbon disulphide has also been patented, but, as will afterward be shown, the old method of removing it from the wool injured the color and quality of the fiber, so as to make the application of this scouring agent a failure.

Wool in its unwashed state contains a considerable proportion of what is termed *suint*. This consists of the fatty matter exuded as perspiration from the sheep, along with, or in some form of combination with, potash derived from the grass on which the sheep feed. *Suint* was first investigated by Vauquelin. He obtained it by evaporating, after filtration, the water in which raw fleeces had been washed. The residue is of a brown color, and has a saline, bitter taste. On addition of an acid to its solution in water, it coagulates, and a fatty matter rises to the surface. It is, in fact, a potash soap, to a great extent containing carbonate and acetate of potash, along with chloride of potassium and lime, probably in combination also with fatty acids. It is usually mixed with sand and carbonate of lime.

In 1828, M. Chevreul, who is still alive in Paris, although nearly a century old, published an analysis of merino wool. It consisted of:

	Per cent.
Pure wool	31·23
Soluble *suint*	32·74
Insoluble	8·57
Earthy matter	27·46
	100·00

It is easily seen that *suint* forms a very important constituent of raw wool. Its proportion varies, of course, according to the nature of the pasture on which the sheep are fed, the climate, etc. Wool from Buenos Ayres, for example, contains much less than that analyzed by M. Chevreul; its amount is only 12 per cent. of the weight of the raw wool.

This *suint* contains always about 52 per cent. of residue when ignited. The composition of this residue is:

	Per cent.
Carbonate of potash	86·78
Chloride of potassium	6·18
Sulphate of potash	2·83
Silica, alumina, etc	4·21
	100·00

In 1859, MM. Maumene and Rogelet patented the use of the water in which wool has been washed as a source of potash, and at present the extraction of potash from *suint* is practiced in France on a large scale. The wool is washed in a systematic manner, in casks, with cold water, which runs out of the last cask with specific gravity 1·1. These washings are evaporated to dryness, and the residue is calcined in iron retorts, the gas evolved being used for illuminating purposes. The remaining cinder, consisting of a

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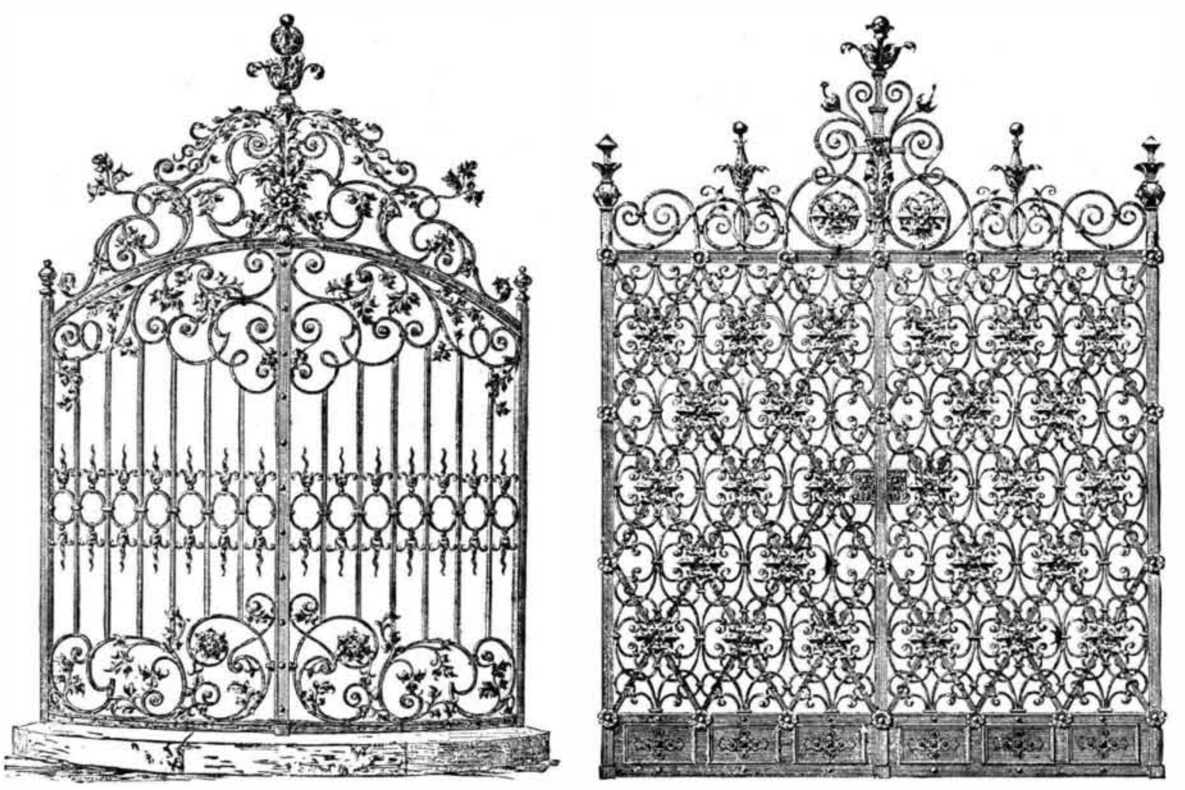

SUGGESTIONS IN DECORATIVE ART.—DESIGNS FOR IRON GATES.

mixture of charcoal and carbonate of potash, is treated with water, whereby the latter is dissolved out. The residue left on evaporation of this water consists largely—almost entirely—of white carbonate of potash. At present there are works at Rheims, Elbœuf, Fourmier, and Vervier, which yield about 1,000 tons of carbonate of potash annually. Now, only 15,000 tons are made per annum by Leblanc's process. In 1868, 62,000 tons of wool were imported into Britain from Australia alone, and from this 7,000 to 8,000 tons of carbonate of potash might have been recovered, the value of which is £260,000. Yet it was all wasted! And this estimate does not include the fats of the *suint*, which are worth an even greater sum.

Now, it is evident that there is here a profitable source of economy. So far as I am aware, no work in this country saves its washings. The water all goes to pollute the nearest river.

The use of carbon disulphide has again been introduced, and it is to be hoped with better success, for methods have been devised whereby the wool is not injured by it, but is even rendered better than when scoured by the old process of washing with carbonate of soda and water, or by soap. The process is due to Mr. Thomas J. Mullings. Briefly described, it consists in exposing the wool, placed in a hydro-extractor, to the action of bisulphide of carbon; the machine is then made to revolve, and the excess of solvent is expelled, carrying with it the fatty matters; the solvent finds its way into a tank, from which it flows into a still, heated with steam; the carbon disulphide, which boils at a very low temperature, distills over, and is again ready for use, while the residue in the still consists of *suint* washed from the wool. To remove the last trace of carbon disulphide from the wool in the hydro-extractor, cold water is admitted, and when the wool is soaked, the machine again revolves. On expulsion of the water, the wool is ready for washing in the ordinary machines, but with cold water only instead of hot soapsuds.

The distinguishing features of Mr. Mullings' process are, method by which loss of carbon disulphide is avoided, and the extraction of that solvent by means of cold water. The apparatus consists of a hydro-extractor or centrifugal machine of special construction, fitted with a bell-shaped cover, which can be lifted into and out of position by means of a weighted lever. The rim of this cover fits into an annular cup filled with water, which surrounds the top of the machine, forming an effective seal or joint. Upon the spindle of this machine is suspended, as in ordinary forms of the hydro-extractor, a perforated basket, and in this basket is placed the wool to be treated. The cover being closed, the carbon disulphide is admitted, and passing through the wool, the greasy matter is dissolved, and along with the solvent enters a reservoir. The machine is now set in motion, and the bulk of the solvent is drawn off. Cold water is then admitted, and the machine being again caused to rotate, the whole of the bisulphide is expelled. It is a curious fact that, although wool soaks remarkably easily with carbon disulphide, and at once becomes wet, cold water expels and replaces almost all that liquid. This operation takes about twenty minutes, and at one operation about 1½ cwt. of raw wool may be treated. The wool is then washed in suitable washing-machines of the ordinary type, but with cold water, no soap or alkali being employed. The bisulphide of carbon, mixed with water, flows into a reservoir, provided with diaphragms to prevent splashing, and consequent loss by evaporation. From its gravity it sinks, forming a layer below the water; it is then separated and recovered by distillation, and may be used in subsequent operations.

The point in which this process differs from the old and unsuccessful ones formerly tried, is in the expulsion of the carbon disulphide. It was imagined that it was necessary to expel it by means of heat or steam. Now, when wool moist with bisulphide is heated, it invariably turns yellow. No heat must, therefore, be employed. As already remarked, the solvent is expelled with cold water.

The residue, after distillation of the carbon disulphide, is a grayish-colored, very viscous oily matter, still retaining a little bisulphide, as may be perceived from the smell. It has not the composition of ordinary *suint*, inasmuch as it contains no carbonate of potash, and indeed little mineral matter of any kind. A sample which I analyzed lost in drying 36·2 per cent., the loss consisting of water and carbon disulphide. It gave a residue on ignition amounting only to 1·6 per cent. of the original fatty matter, or 2·5 per cent. of the dried fat. The oil appears, from some experiments which I made, to be a mixture of a glycerine salt and a cholesterine salt of fatty acids. It distills without much decomposition, giving a brown-yellow oil, which fluoresces strongly, and has a somewhat pungent smell. The molecular weight was determined by saponification with alcoholic potash, and subsequent titration of the excess of potash employed. This was found to equal 546·3. This would correspond to a mixture of 18·7 parts of stearate, palmitate, and oleate of glycerine, with 81·3 parts of the same acids combined with cholesteryl. But this is largely conjecture. The boiling point of the oil is high, much above the range of a mercurial thermometer, so that it is difficult to gain an insight into its composition.

An objection which has been raised to this process is that the use of such an easily inflammable substance as bisulphide of carbon is attended by great risk of fire. Were the bisulphide to be exposed to free air, there might be force in this objection; but there is no reason why it should ever be removed from under a layer of water. The apparatus, to make all safe, should not be under the same roof as the mill; and no open fire need be used in the building set apart for it. It is easy to rotate the centrifugal machine by a belt from the mill, but better by a small engine attached, the power for which can be conducted by a small steam-pipe, and the distillation of the bisulphide can also be conducted without danger by the use of steam, as its boiling point is a very low one. The question may be naturally asked, "How do the wool and fabric made from the wool scoured by this process, compare with that scoured in the usual way?" To answer this question I may refer to a test made by Messrs. Isaac Holden & Co., at their works at Roubaix. A sample of wool was divided into two portions, one of which was scoured by the usual method, and the other by the turbine or Mullings' process. Skilled workers then spun each sample to as fine a thread as possible. Now the thinness to which a wool can be spun is evidence of its power of cohesion—in other words, its strength. The weight of 1,000 meters of the wool cleaned by the new process bore to that scoured by the old process the proportion of 1,015 to 1,085, showing that a considerably finer thread had been produced. And in total quantity, 67·53 kilos. of the former corresponded to 71·77 kilos. of the latter, showing a proportionately less waste. Such fine yarn had never before been obtained from similar wool. The yarn of the soap-washed wool could not be spun, for it could not withstand the strain; whereas, that scoured by the new process gave an admirable thread.

Another test to which it was subjected may be cited. It is the custom in France, before the wool is scoured, to put it through a sorting process, by which all the short lengths are weeded out. On a quantity exceeding 11,000 kilogrammes, half of which was scoured by the turbine process, and half by the ordinary process, the former in scouring lost in weight 2 per cent. less than the latter, although the short length extracted from the moiety thus treated weighed only 10 kilogrammes, while that taken from the other weighed over 150 kilogrammes. This saving, even with the unequal treatment, amounted in value to from 30 to 40 centimes per kilogramme.

In order that the importance of this application may be realized, I shall conclude with some figures:

The raw wool imported into England, in the year 1882, amounted to 1,487,169 bales, its total value being about £22,000,000. The cost of washing this wool by the old process, with carbonate of soda, amounts to about ⅛d. per lb. of the raw material. The cost for the total quantity of wool imported is at least £1,214,000. But it is customary to wash wool with soap, especially for the combing trade, and the cost is then about 1d. per lb. The cost of scouring by the new process is about £1 5s. per ton, or 0·13d. per lb. Taking the least favorable comparison, were all the imported wool (home-grown wool is here left out of the calculation, for want of sufficient returns) cleansed by the turbine process, the actual saving would be £1,214,500 *minus* £315,700, or nearly £900,000 per annum.

It is thus seen that there is room for a very important economy in the treatment of wool. I have endeavored to show how economy may be practiced in scouring by the old process with soap, and how one dye stuff may be profitably recovered. It is to be hoped that means of extracting other dyes from the residue may soon follow. Unless the process were too costly to repay the trouble of extraction, it would be well worth practicing; for it would not merely be a solution of the problem of how to avoid waste, but would at the same time prevent the pollution of our streams, now, unfortunately, only too rarely pellucid; and were the last process to have as successful a future as I hope it may have, a very important saving of expense would result, and a large quantity of valuable fatty matter would no longer be thrown away.

COAL AND ITS USES.*

By James Pyke.

The records from which geologists draw their information can scarcely be compared to written or printed histories. There are, however, nations of whom no written account exists, who perhaps never had any written history, but about whom we are still able to gather from other sources a vast amount of information. Their houses, their monuments, their weapons, and their tools have survived, and these tell us the kind of life, the state of civilization, and the skill of the men to whom they belonged; from the contents of their tombs we learn what manner of men they were physically; sometimes a sudden change in the appointments and belongings of the folk indicates that tribes which had for a long time inhabited a district were driven out and replaced by a new race. Thus, then, from waifs and strays we can piece together a fairly connected account of the events of a period long antecedent to any written history.

The investigations of Dr. Schliemann on the supposed site of the city of Troy furnish a good example of this method of research. He found lying, one on the top of another, traces of the existence of five successive communities of men, differing in customs and social development, and was able to establish the fact that some of the cities had been destroyed by fire, and that later on other townshad grown up over the buried remains of the earlier settlements. The lowest layers were, of course, the oldest, and the position of each layer in the pile gives its date, not in years, but with regard to the layers above and below it.

Now, from time immemorial nature has been at work building up monuments and providing tombs which tell us what were the events going on, and what kind of inhabitants the earth had long before man made his appearance on its surface. The monuments are the rocks which compose the ground under our feet, and these, like many ancient monuments of human construction, are the tombs of the creatures that lived while they were being built.

Many facts testify that the earth's crust did not come into existence exactly as we find it now, but that its rocks have been built up by the slow action of natural agencies. These rocks constantly inclose the remains of plants and animals, and as it is evident that neither plant nor animal could have lived in the heart of a solid rock, this fact shows that the rock must in some way have gathered round the remains that are now found in it. Again, many of these remains, or fossils, belonged to animals that lived in water, the larger part, indeed, to marine creatures. This indicates that the rock was formed beneath the sea, and when we examine the way in which the constituents of the rock are arranged, we frequently find it to correspond exactly with the manner in which the sand and mud that rivers sweep down into the sea or lakes are spread out over the bottom of the water. In a pile of rocks formed in this way it is clear that the lowest is the oldest of all, and that any one stratum lying above is younger than the one beneath it. Further, the occurrence of rocks inland containing marine fossils far above the sea level shows that the sea and land have changed places. When, again, we find that the fossils of one group of rocks differ entirely from those of a group lying above them, we learn that one race of creatures died out and was supplanted by a new assemblage of animal forms.

These general remarks will, I trust, give some notion of the evidence which is available for reconstructing the history of those remote periods with which geology deals, and of the kind of reasoning which the geologist employs for interpreting the records that are submitted to him.

We will now briefly examine, by aid of these methods, the group of rocks in which coal occurs in Great Britain, and see how far we can read the story they have to tell.

The group with which we have to deal is called the carboniferous or coal bearing system, and it includes four classes of rocks, viz.: 1, sandstone; 2, shale or bind; 3, limestone; 4, coal and underclay.

We will take the sandstones and shales first. They are grains of sand known to mineralogists as quartz, and consisting of a substance called silica by chemists. The grains of sand are bound together by a cement which in some few cases is identical in composition with themselves, and consists of pure silica, but usually is a mixture of sandy, clayey, and other substances. The shales are made up very largely of clay, mixed, however, usually with sand and other substances, forming a conglomerate. Both sandstones and shales are divided into layers or beds, and are said to be stratified. It is this stratified or bedded structure that gives us the first clew to the way in which these rocks were formed. Rivers are constantly carrying down sand and mud into the sea or lakes, and when their flow is slackened on entering the still water the materials they bring down with them sink and are spread out in layers over the bottom. The structure of the sandstones and shales shows that they were formed in this way; they often inclose the remains of plants that have been carried down from land, and occasionally of animals that lived in the water where they were deposited.

The next we have to consider is limestone, which is mainly made up of a substance known to chemists as calcium carbonate, or carbonate of lime.

In some districts, especially in volcanic countries, springs occur very highly charged with carbonate of lime. The warm springs of Matlock are a case in point; they are probably the last vestige of volcanic action which was in operation in that neighborhood during carboniferous times. Limestone is chiefly formed by the agency of small marine creatures of low organization. By the aid of these animals the carbonate of lime is brought back to a solid form; at their death their hard parts fall to the bottom and accumulate in a mass of pure limestone, which afterward becomes solidified into limestone rock.

The information that limestone gives us is this:

When we find, as is often the case, a mass of limestone hundreds of feet thick, and composed of little else but carbonate of lime, we know that the spot where it occurs was, at the time it was formed, far out at sea, covered by the clear water of mid ocean; and when we find that this limestone grows in certain directions earthy and impure, and that layers of shale and sandstone, thin at first, but gradually thickening out in a wedge-shape form, come in between its beds, we know that in those directions we are traveling toward the shore lines of that sea whence the water was receiving from time to time supplies of muddy and sandy sediment.

The next class of rocks are the clays that are found beneath every bed of coal, and which are known as *underclays*, or *warrant*, or *spavins*. They vary very much in mineral composition. Sometimes they are soft clay; sometimes clay mixed with a certain portion of sand; and sometimes they contain such a large proportion of silicious matters that they become hard, flinty rock, which many of you know under the name of *gannister*. But all underclays agree in two points: they are all unstratified. They differ totally from the shales and sandstones in this respect, and instead of splitting up readily into thin flakes, they break up into irregular lumpy masses. And they all contain a very peculiar vegetable fossil called *Stigmaria*.

This strange fossil was for a long time a sore puzzle to fossil botanists, and after much discussion the question was fairly solved by Mr. Binney by the discovery of a tree embedded in the coal measures, and standing erect just as it grew, with its roots spread out into the stratum on which it stood. These roots were Stigmaria, and the stuff into which they penetrated was an underclay. Sir Charles Lyell mentions an individual sigillaria 72 feet in length found at Newcastle, and a specimen taken from the Jarrow coal mine was more than 40 feet in length and 13 feet in diameter near the base. It is not often these trees are found erect, because the action of water, combined with natural decay, has generally thrown them down. They are, however, found in very large numbers in the roof of the coal, evidently having been tossed over, and lying there flat and squeezed thin by the pressure of the measures that lie above them.

Lastly, we come to coal itself—a rock which constitutes a small portion of the whole bulk of the carboniferous deposits, but which may be fairly looked upon as the most important member of that group, both on account of its intrinsic value and also from the interest that attaches to its history. That coal is little else but mineralized vegetable matter is a point on which there has for a long time been but small doubt. The more minute investigations of recent years have not only placed this completely beyond question, but have also enabled us to say what the plants were which contributed to the formation of coal, and in some cases even to decide what portions of those plants enter into its composition. It is a thing so universally admitted on all hands, that I shall take it for granted you are all perfectly convinced that coal has been nothing in the world but a great mass of vegetable matter. The only question is: How were these great masses of vegetable matter brought together? And you must realize that they were very large masses indeed. Just to take one instance. The Yorkshire and Derbyshire coal field is somewhere about 700 to 800 square miles in area, and Lancashire about 200. Well, in both these coal fields you have a great number of beds of coal that spread over the whole of them with tolerable regularity and thickness, and very often with scarcely any break whatever. And this is only a very small portion of what must have been the original sheet of coal, so that you see we have to account for a mass of vegetable matter perfectly free from any admixture of sand, mud, or dirt, and laid down with tolerably uniform thickness over many hundreds of square miles.

At one time it was supposed that coal was formed out of dead trees and plants which were swept down by rivers into the sea, just in the same way as shales and sandstones were formed out of mud and sand so swept down. The fatal objection to this theory, however, is that rivers would not bring down dead wood alone, but they would bring down sand and mud, and other matters, and that in the bottom of the sea the dead wood would be mixed with these matters, and instead of getting a perfectly unmixed mass of vegetable matter, we should get a mixture of dead plants, sand, mud, and other things, which would give rise to something like coal, but something very different, as any one who tries to burn such coal will soon find out, from really good, pure house coal. So that this theory, which is generally known as the "drift" theory, was totally inadequate to account for the facts as we know them.

The other theory was that coal was formed out of plants and trees that grew on the spot where we now find coal itself. On this supposition it is easy to account for the absence of foreign admixtures of sand, mud, and clay in the coal; and we can also understand very much better than by the aid of the drift theory how the coal had accumulated with such wonderful uniformity of thickness over such very large areas. This theory was for some time but poorly received; but after the discovery of Sir William Logan, that every bed of coal had a bed of underclay beneath, and the discovery of Mr. Binney, that these underclays were true soils on which plants had undoubtedly grown, there was no doubt whatever that this was the real and true explanation of the matter.

* From a paper lately read before the Association of Foremen Engineers.