LECTURES ON MINING

DELIVERED

AT THE SCHOOL OF MINES, PARIS

VOL. I.

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LECTURES

ON

MINING

DELIVERED

AT THE SCHOOL OF MINES, PARIS

BY

J. CALLON

INSPECTOR GENERAL OF MINES

TRANSLATED AT THE AUTHOR'S REQUEST

BY

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H. M. INSPECTORS OF MINES

IN THREE VOLUMES

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TRANSLATORS' PREFACE.

The dearth of treatises on mining in the English language is a sufficient reason for this translation, and, therefore, a preface from us seems to be hardly necessary. We cannot, however, allow our readers to remain ignorant of the distinguished career of the author, who entrusted us with the translation of this part of his work, and we have, therefore, drawn up a short account of his life from the biographical notices which appeared in the *Annales des mines* for 1875 (Tome VII, p. 422, and tome VIII, p. 55).

Pierre Jules Callon, a grandson of an English engineer who settled in Normandy, was born on the 9th of December 1815 at Le Houlme in the neighbourhood of Rouen, and died on the 8th of June 1875, at Paris. He was educated in Paris, at the *Collége Charlemagne*, the *École polytechnique*, and the *École des mines* consecutively, and was appointed professor at the *École des mineurs* of Saint-Étienne in May 1839. He was transferred to the *École des maîtres-ouvriers mineurs*, at Alais, in 1845, and to the *École des mines*, Paris, in 1848. In the last mentioned school he exercised the duties of assistant professor of Mining and Mechanics till 1856, and then of ordinary professor until 1872, when he obtained leave of absence on account of the failing state of his health.

Besides the appointments just mentioned he held many others, such as, consulting engineer and director of the mines and iron works at La Grand'-Combe, Aubin, Denain and Anzin, Marles, la Loire, Layon-et-Loire, Ronchamp, Saint-Avold, and Décazeville, and of others in Belgium, Spain and Sicily.

Callon took an active part in the four great exhibitions which have been held in London and Paris. At each of the last three he was a member of the international jury, and he made a masterly report on *Mining machinery and processes* in 1867. He was created "Knight of the Legion of Honour", in 1850, and "officer" in 1865. In 1855 he was promoted to the grade of "Ingénieur en chef", and in 1872 to the rank of "Inspecteur-général des mines".

Although highly educated in his profession he was also eminently practical, or, to use the words of M. Dupont who pronounced his funeral oration (*Annales des mines*, tome VII, 1875), "he was a thorough master of the Art of Mining".

Method and order were the guiding principles of Callon's professional career, and in him these qualities were combined with unflagging attention to duty and to work. He was the author of numerous papers and reports on geological, mining and engineering subjects; and during the latter years of his life he worked assiduously at his treatises on machines and mining. Of each of these works only two volumes have been published, of the three which were intended to complete them; but sufficient materials have been prepared to enable M. Boutan, formely one of Callon's pupils, to edit the last volumes.

Clement Le Neve Foster
W. Galloway.

1st May 1876.

AUTHOR'S PREFACE.

This volume includes the first part of the *Lectures on Mining* which I have delivered at the Paris School of Mines during a period extending over many years. The first volume of my *Lectures on Machines* has already been published several months.

In the preface to that work I gave the reasons which induced me to undertake the publication of treatises on these two subjects with which I am now actively engaged, so that it is unnecessary for me to repeat them here; and I will only add that I have endeavoured to imbue this work with the same practical character as the first, and to describe the most recent improvements which have been introduced into the art of mining.

These improvements have been very great during the last thirty or forty years, and if we compare a colliery of the year 1830 with one of the immense establishments which have sprung up in various countries of late, especially in the

North of France, we might almost say that they have nothing in common but the object for which they were created, namely the production of coal. They are essentially different in many respects : in the scale on which the output is carried on, in the power, and even in the very nature of the means employed.

Thus, the power of pumping and winding engines, more especially of the latter, has been greatly augmented; ingenious mechanical appliances have been invented for ventilating the workings; methods of working, especially for thick deposits, have been studied and improved; the mechanical preparation of ores has been entirely remodelled; new processes have been contrived for traversing ground which has been hitherto impassable, etc.

Lastly, there have been important alterations even in the details themselves ; the means for raising and lowering the workmen, underground haulage, and even the manual operations of the miners in their working places have all been remodelled, or are in course of being modified in a more or less complete manner.

The object of making these various changes in the art of mining, as well as in other industries, is to reduce the general expenses by concentrating and increasing the means of production, and to economize manual labour by the gradual introduction of machinery.

It may be justly said that mining is an industry which is eminently susceptible of improvements of this kind, not only because there is usually no lack of capital to assist in carrying them out, and no want of intelligence and ability in the management; but also because it has been necessary, in a general way, to endeavour to make the supply keep pace with the demand, rather than to find a market for the products; and to devise means to combat the scarcity of workmen, rather than to find employment for all the available hands.

It may even be said that, with a constantly and rapidly increasing consumption, it will become more and more difficult, and may soon become impossible, at least in the case of certain products, to maintain an equilibrium between the demand and supply, on account of the double difficulty arising from the limited area of the coal-fields, and the scarcity of workmen.

A knowledge of the various means which may retard or prevent this disturbance of equilibrium is therefore indispensable to the miner, and the importance of applying them with intelligence is so great that it may be ranked as a matter of public interest.

In the present work I propose to describe these various means, and to give the details which are necessary in order to form an idea of their importance, and, enable them to be applied in practice.

From this point of view I think that this publication will have an intrinsic usefulness, and will not be a mere repetition of old treatises, such as M. Combes' *Traité d'exploitation des mines*, a work which was undoubtedly valuable at the time of its first appearance.

TABLE OF CONTENTS.

CHAPTER I.

DEFINITIONS AND INTRODUCTION.

PARAGRAPHS 1 TO 39. — PAGES 1 TO 49.

CHAPTER II.

VARIOUS EXAMPLES OF DEPOSITS.

PARAGRAPHS 40 TO 55. — PAGES 50 TO 67.

CHAPTER III.

PROSPECTING OR SEARCH FOR MINERALS, AND EXPLORATORY WORKINGS.

PARAGRAPHS 56 TO 75. — PAGES 68 TO 86.

§ 1. — Prospecting or search for mineral.

§ 2. — Exploratory workings.

CHAPTER IV.

PROSPECTING BY BORING.

PARAGRAPHS 76 TO 108. — PAGES 87 TO 136.

§ 1. — General observations on boring.

§ 2. — Boring tools.

§ 3. — Machines employed in boring.

§ 4. — General boring operations.

§ 5. — Various data relating to borings.

CHAPTER V.

BREAKING GROUND.

PARAGRAPHS 109 TO 144. — PAGES 137 TO 192.

§ 1. — Preliminary observations.

§ 2. — Description of the operations.

§ 3. — Applications and sundry numerical data.

CHAPTER VI.

APPLICATION OF MACHINERY TO BREAKING GROUND.

PARAGRAPHS 145 TO 168. — PAGES 193 TO 222.

CHAPTER VII.

TIMBERING AND WALLING.

PARAGRAPHS 169 TO 203. — PAGES 223 TO 266.

§ 1. — Timbering.

§ 2. — Walling.

§ 3. — Numerical data relating to timbering and walling.

CHAPTER VIII.

MAKING AND SUPPORTING EXCAVATIONS OF SPECIAL FORMS AND DIMENSIONS.

PARAGRAPHS 204 TO 222. — PAGES 267 TO 289.

CHAPTER IX.

MAKING AND SUPPORTING EXCAVATIONS IN VERY WATERY STRATA.

PARAGRAPHS 223 TO 245. — PAGES 290 TO 319.

CHAPTER X.

GENERAL REMARKS ON LAYING OUT, OPENING UP, AND WORKING A MINE.

PARAGRAPHS 246 TO 266. — PAGES 320 TO 340.

CHAPTER XI.

DESCRIPTION OF THE PRINCIPAL METHODS OF WORKING.

PARAGRAPHS 267 TO 338. — PAGES 341 TO 404.

§ 3. — Appendix on the employment of stowing or filling-up.

APPENDIX.

EXPLANATION OF THE PLATES.

LECTURES
ON
MINING.

CHAPTER I.

DEFINITIONS AND INTRODUCTION.

(1) We propose to describe the different technical processes which constitute what is called the *art of mining*, the object of which is to search for, extract and prepare, whether for sale directly to the consumer or for a further elaboration, the different useful mineral substances which exist at or below the surface of the earth.

The subject is vast and for more reasons than one deserves to attract attention.

In an economic point of view, the art of mining constitutes an industry of the greatest importance whether on account of the value of the products created every year, or on account of their nature which has rendered many of them objects of *first necessity*. It has been so since the moment that men ceased to live in the savage state, built themselves settled dwellings, and began to make tools.

In a scientific point of view, it may be said that the art of mining has been the direct cause of the birth and progress of several natural sciences, especially of mineralogy and geology.

Lastly, *in a technical point of view*, it is certain that we owe to the working of mines and to the material difficulties, often considerable, against which the miner has to contend, many ingenious, daring and powerful processes which have afterwards passed into the general domain of industry.

We need only recall the following facts : in the Middle Ages it was for mines that the first works for husbanding water as a motive power were made and the first hydraulic machines set to work on rational principles; it was also for mines that the first steam-engines were set to work, about a century ago, and the first railroads established; and lastly the necessities of working and dressing have caused apparatuses for ventilating, sorting, classification, etc., to be invented and multiplied from which general industry has since derived its profit.

Even at the present day, in spite of the progress realized by industry in so many different directions, a large mine in full work with its apparatuses for pumping and winding, its means of ventilation, its machines for raising and lowering the workmen and for dressing the minerals, offers one of the most remarkable specimens of human activity and its triumph over matter.

(**2**) Such, therefore, in a few words is the extensive field we have to travel over.

The first step to be made in our study is to define the *deposits* in which are found the useful substances that the miner seeks, in order to fit them for the wants of society.

The French law of the 21st April 1810 which regulates mineral property in France and Belgium and which formerly regulated it in the Rhenish Provinces on the left bank, begins in the following manner :

« Article I. *The masses of mineral substances or fossils enclosed in the interior of the earth or existing at the surface are classed, relatively to the rules of working each of them, under the three heads of mines, openworks, and quarries.*

« Article II. *As mines will be considered all such as are known to contain in veins, beds or masses : gold, silver, platinum, quicksilver, lead, iron in veins or beds, copper, tin, zinc, calamine, bismuth, cobalt, arsenic, manganese, antimony, molybdenum, graphite, or other metallic substances, sulphur, coal, fossil wood, bitumen, alum and sulphates with a metallic base.*

« Article III. *The openworks comprehend the ores of iron called alluvial, pyritous earths fit for conversion into sulphate of iron, aluminous earths and peat.*

« Article IV. *The quarries include slate, sandstone, building and other stone, marble, granite, limestone, gypsum, puzzuolana, trass, basalt, lava, marl, chalk, sand, flint, clay, kaolin, fuller's earth, potter's clay, earthy substances and pebbles of all sorts, pyritous earths regarded as manures, all worked open or with subterranean galleries.* »

(**3**) This classification into *mines*, *openworks* and *quarries* (in which the deposits of rock-salt are omitted, though afterwards classed with the mines), depends, as may be seen, upon the *nature of the substance* composing the deposit and involves different regulations for the property of this deposit.

A mine can only be worked in virtue of a deed of concession deliberated on in Council of State, which regulates the rights of the proprietors of the surface to the produce of the mine conceded.

The openworks belong to the proprietor of the soil; but he is bound to work them in such a manner as to satisfy, as much as possible, the wants of consumers; if he fail to do so the consumers may be authorized to work in his place. The selling price in the first case, and the rent in the second, are settled by mutual consent or by experts. However, peat can be worked only by the proprietors of the soil or with their consent. The working of peat cannot be begun even by a proprietor without a declaration having been made to the authorities, and under the condition of conforming, in carrying out the works, to the local conditions imposed by regulations of the public authorities, with a view to husbanding the deposit properly for the general good.

Quarries belong entirely to the proprietor of the soil. When they are opencast they can be worked under the simple supervision of the police, observing the general or local laws or regulations. If they are underground they are subject to the same administrative supervision as mines, principally with a view to the safety of the men and the property.

This somewhat complex system is as it were the resultant of two currents of ideas which guided the legislators to whom we owe the law of 1810, on the one hand the desire to keep within the conditions of the civil code which expressly says that ownership of the soil comprises possession of the surface and all that lies beneath it; on the other hand, in presence of a surface cut up into small holdings as it is in France and of subdivisions established without any relation to the position of a deposit in the bosom of the earth, the fear of seeing important deposits remain unworked, in consequence of the excessive parcelling out of the soil or of the financial inability or indifference of the proprietors of the surface.

These, therefore, have only been allowed the *free disposal* of substances that are abundant and common, which can generally be worked without much expense and are not likely to remain unworked. On the contrary, as has been said above, regulations have been made concerning the rarer substances, of which the holders are limited in number in a given locality, and where it is important to assure their being worked and husbanded. Finally, the proprietors of the soil have been deprived (save of an indeterminate part of the products) of all deposits that are relatively rare or expensive to work, and the working of which is important for the interest of the public and has been considered as exceeding in general the powers of one proprietor; a new kind of property has been made of these deposits, distinct from that of the soil, limited according to the nature of the deposit and the most convenient mode of working, and without consideration for the arbitrary divisions of the surface property. This new property is given to a grantee who has proved that he has sufficient financial means and who accepts a certain set of conditions.

There is no need for us to occupy ourselves any further with this system which only concerns the administration of the *property* of a given deposit and has no definite relation to *the mode in which the deposit is found in the bosom of the earth*, or what is called its mode of occurrence, on which depends the manner in which it will be worked. It is from this last point of view that we must seek a classification of the deposits, and we find a starting point in the law itself which distinguishes in Article II, cited above, the masses of mineral substances under the names of *veins*, *beds* and *masses*.

It is essential to give precisely the sense of these three words; the result will be a sort of geometrical definition of these different deposits, which will serve as a starting point for a description of the works that may have to be carried out in searching for the deposits or during the actual working itself.

In order to arrive at this definition it is necessary to recall the ideas that are generally admitted by geologists concerning the different phases through which our earth has passed since the commencement of geological times. We will do this as concisely as possible.

(4) The whole earth seems to have been originally in a state of igneous fusion, forming a sort of more or less pasty magma.

This explains its spheroidal shape, a little flattened at the poles and bulged out at the equator in consequence of its movement of rotation, its mean density, very much greater than that of bodies observed on the surface, conformably to the most simple laws of hydrostatics, the increase of temperature which has been proved to exist as you descend below the surface, which is at the rate of 1°F. for every 54·7 feet (1°C. for 30 metres) and which continues at the greatest depths reached by man, and lastly the existence of hot springs, the temperature of which at the source itself sometimes rises nearly to that of boiling water.

Going still further, it is supposed that this igneous fluidity still exists at the present day and that our earth is merely a liquid mass covered by a solid crust of a certain thickness. This thickness is even supposed to be very small compared with the earth's radius.

It would only be necessary, in fact, to go down a few miles, supposing the law of increase of temperature to continue at the rate of 1°F. for 54·7 feet (1°C. for 30 metres), in order to reach a heat which would suffice to melt nearly all the substances we know. Besides, the *actual presence* of melted rocks in the interior of the earth is made manifest by volcanic phenomena, which bring these rocks to light in a state of more or less perfect fluidity and with a mean density greater than that of igneous rocks of more ancient origin and coming from a smaller depth.

Admitting, therefore, this hypothesis that the earth was once a globe in the state of igneous fusion and that it is so still, save a relatively thin crust (not many miles in thickness), we can in some measure reconstitute the history of the successive phases through which it must have passed.

(5) In the beginning, when the surface of the earth was still very hot, water could not exist there in the liquid state and the earth was surrounded by a dense atmosphere, which, judging from the mean depth and extent of the seas, must have exerted a pressure many hundreds of times greater than that of the present atmosphere. Under this enormous pressure the substances at the surface were kept in a fluid state both by heat and by the action of water, which, under the combined influence of great heat and a strong pressure, acted as an energetic solvent.

The temperature of the surface went on diminishing gradually and at last the most refractory substances began to solidify; these solidified masses extended little by little, joined on to one another and finally formed a very nearly continuous crust. This crust contracting by the cooling, *which was then more rapid at the surface than in the interior of the earth*, exerted an always increasing pressure on the subjacent melted mass. The reaction of this mass caused the crust to split and some of the molten matter was squeezed up through the fissures and overflowed on the surface, forming the first mountains which appeared on our globe; these mountains are distinguished by their mammellated and tuberculated forms, such as the ranges which constitute the primitive central core of France.

When these first inequalities of the soil were once produced and as soon as the temperature of the surface allowed water to exist there in the liquid state, a new class of phenomena began and still continues at the present day, viz., *deposition of sediment*. Water falling as rain on the surface began to furrow the ground, carried off the detritus in its course and deposited it at the bottom of lakes and seas where it finally discharged itself.

It must be understood that the effects of this furrowing were then incomparably greater than they are now, because an accidental cooling of the atmosphere to the extent of a few degrees, which produces rainfalls whose importance is measured nowadays by tenths of inches or at most a few inches, might then correspond to differences of *many atmospheres* in the elastic force of the vapour.

Under this powerful and probably nearly continuous action the sedimentary rocks must have rapidly increased in thickness, and as the increase of temperature in penetrating below the surface was then much more rapid than nowadays, the beds at some depth soon found themselves in conditions of temperature and pressure which explain the special facies and extensive metamorphism presented to us by these first sedimentary rocks wherever we can observe them.

The first outpouring of eruptive rocks, which diminished the internal pressure, was followed by a period of repose during which the fissures closed, the earth's crust thickened, continued to cool and began once more to squeeze the liquid mass. It exerted a gradually increasing pressure on the interior until a second eruption was necessary in order to re-establish the equilibrium.

This second eruption changed the relative level of different parts of the surface; one point formerly under water emerged, another formerly dry land was submerged. The deposition of sediment was thus, or could be, interrupted at a given point, but it was continuous *on the globe as a whole* as long as there was any ground above the general level of the waters.

(**6**) Such was the history of the earth as long as the crust continued to cool, by radiation into space, more rapidly than the interior of the globe by conduction.

At last a moment arrived when an equilibrium was established between the heat that the earth's surface loses by radiation, and that which it receives on the one hand from the sun and on the other from the stream of heat poured out by the still heated internal mass.

From that moment the crust ceased to contract and as the internal mass continued to cool and consequently to diminish in volume the mechanism of the periodical elevations was found to be radically changed. The earth's crust, instead of splitting under the reaction of the internal mass, tended to detach itself from it and remain as it were suspended around it in a sort of unstable equilibrium, until the formation of folds or fissures broke this state of equilibrium and allowed the solid part to seek a new point of support upon the subjacent mass.

Hence new mountains were formed, essentially distinct from the preceding ones by the mechanism of their formation, and remarkable as a rule by their long chains and the relative rarity and occasional complete absence of eruptive rocks at the surface.

These phenomena of foldings and fissures have been reproduced at various epochs, accompanied by alterations of level which have changed the locality where sediment was being deposited and caused unconformities or pauses in the stratification.

One of the great problems of geology, and one to which Mr. E. de Beaumont has devoted himself with so much good fortune, is the classification of the various chains of mountains according to age, and their relation to, or accordance with, the classification of sedimentary rocks which has been introduced by their study.

It may be supposed that as the crust becomes thicker and more solid these disturbances of equilibrium ought to become *more rare*, but probably also *more intense*, when they come to be manifested after a long period of repose.

There is nothing to forbid the future reappearance of similar phenomena; indeed their reappearance is highly probable, if not certain. If we picture to ourselves the grand diluvial phenomena which would be produced by a great chain of mountains like the Alps or the Andes suddenly rising up and changing the position of the seas, and if we consider on the other hand the very recent appearance of man on the earth's surface, we are led to ask ourselves the question whether the history of the human race is not destined to be included altogether between two of these great periodical cataclysms of which we have evidence in the past and a return of which must be looked for in the future.

(7) Without dwelling upon this last train of thought we shall sum up as follows the consequences of what we have been explaining.

The observer who studies the rocks which compose the earth's crust will easily be able to separate them into two great categories essentially different in origin.

The one comprises rocks of *igneous origin*, or *plutonic*, *eruptive*, *crystalline* rocks (all these words are equivalent) which belong to the first solid crust of the earth, or have come to or near the surface at divers epochs in consequence of the phenomena of elevation produced by one or other of the actions described above.

The other category comprises rocks of *aqueous origin*, called also *neptunian*, *sedimentary* or *stratified* rocks, which constitute an essentially continuous series on the globe as a whole. They began to be deposited from the first moment that rain furrowed the uneven surface of the ground and are still being formed at the present day.

Rocks of igneous origin are distinguished by their massive, crystalline or subcrystalline structure and by the effects that they have often produced at their contact with rocks into which they have penetrated in a melted state; lastly, their essential character is the absence of true stratification.

Rocks of aqueous origin are formed mainly (but not solely as we shall explain further on) of detritus more or less rounded by water with particles of the most varied dimensions; they constitute series of *beds* or *layers*, of clay or shale, sand or sandstone, conglomerates more or less cemented, etc., etc., the essential character of which, on the contrary, is to be stratified, in consequence of the successive deposition of layer after layer of sediment at the bottom of the sea, lake or river.

(8) These different rocks, igneous or sedimentary, have generally been more or less displaced from their original position by the mechanical actions of which we have spoken. It may indeed be said that such is usually and normally the case with the sedimentary rocks that we can observe at the surface, because, as these rocks have been essentially deposited *under water*, whilst at present they form

dry land, there is so to say a *presumption* that they are no longer in place and have been more or less elevated.

These changes of level have been produced on the very largest scale, as stratified rocks with marine shells have been found up to the tops of the highest mountains. One consequence of these elevations, which did not escape the first geological observers, must have been the formation of a certain number of fractures affecting both igneous and sedimentary rocks and subordinate either to a centre or more commonly to an axis of elevation. These fractures or fissures, due to different points of a given area having been acted on by unequal elevatory forces, are generally accompanied by alterations of level, the effect of which is that points on the two sides of the fissure, which coincided before its formation, are now no longer opposite to one another.

These fissures are generally filled with fragments of the adjacent rocks; they have received the names of *faults*, *throws*, *heaves*, *slides* or *slips*.

As, however, they have been produced by forces acting in the interior of the earth, it may happen that at the time of their formation they have traversed the entire thickness of the earth's crust and have been put in communication from below with the internal mass still in a liquid state. It has been possible for this mass to be injected by the action of forces analogous to those which produce volcanic phenomena and so to form what is properly called a *dyke*. Or else, exposed in a more or less direct manner to atmospheric agencies, the same mass in contact with air and water may have given rise to various chemical reactions; these in their turn may have caused certain substances in the state of vapour or solution to fill the fissures and form deposits, either there or at the surface, totally different in nature from the enclosing rocks.

Hot springs, which we observe especially in those points of the globe where the presence of such fractures may be presumed, are only very feeble representatives of the outflows which took place when the fissures had just opened.

These springs were then much more mineralized than they are at the present day, and this greater mineralization would doubtless reappear if the fissures were reopened or if new ones were formed.

(9) Accepting what has just been said as a natural and almost necessary consequence of the fundamental hypothesis concerning the primitive state of the globe, and as one that in all cases agrees with the observed facts, we are in a position to define what is called a *vein* and what is called a *bed*.

A *vein* or *lode* is one of the fissures or cracks formed in rocks (whether igneous or sedimentary) by the disturbances of equilibrium to which the crust of the globe has been periodically subjected, and filled, either at the moment of its formation or subsequently, by special substances which have come from the interior of the earth either in the molten state or in the state of vapour or solution.

A *bed* or *seam* is one of the layers of a given sedimentary rock, produced either by simple deposition of sediment, or, in addition, by some special phenomenon essentially contemporaneous with the rocks in which it is enclosed; that is to say, it is a layer posterior to the subjacent layer and anterior to the overlying one.

In a purely geometrical point of view, that is to say considering only its form, a vein, *if it is in its original position*, is a kind of large, more or less vertical, lenticular mass, having two dimensions which are in a way indefinite relatively to a third. From the same point of view, a bed, if it is in its original position or one approaching to it, presents the same general shape of a large lenticular mass, with this difference that it is placed horizontally. It has, or may have, in a horizontal sense, the same extent as the sedimentary rocks of which it forms a part and in the vertical sense a limited dimension;

A *mass* is a deposit which in its origin approaches more or less clearly a vein or a bed, but differs from these in not satisfying the geometrical definition which has been given, *i.e.* that of a lenticular mass having two dimensions which are very great and indefinite relatively to the third. The mass has been formed after the surrounding rocks in the case of a vein and is contemporaneous in the case of a bed.

These general definitions must be completed in order to arrive at a sufficiently precise idea of these different kinds of deposits.

(**10**) Let us begin by saying what are the elements by means of which we define their nature and their mode of occurrence in the interior of the earth.

Assimilating veins and beds to kinds of large lenticular masses, which run *indifferently* through igneous or sedimentary rocks in the case of veins, or which are *necessarily* in a sedimentary rock and parallel to the stratification in the case of beds, we distinguish in each of these deposits : the *roof*, the *floor*, the *thickness*, the *outcrop*, the *covered outcrop*, the *strike* and the *dip*.

The roof and the floor are the geometrical surfaces that separate the deposit from the rocks in which it is inclosed; the roof is the surface above the deposit, the floor, the surface on which it lies. These terms roof and floor are also applied to the rocks themselves which are situated immediately above or below the deposit. It is in this sense, for instance, that a bed is said to have a good or a bad roof, according as the rocks are firm or require to be supported by timber.

In the case of a vein the roof and floor are called the *walls*, or *cheeks;* these words are not used for beds, but might be conveniently employed for the sake of brevity.

It will be observed that when a portion of a bed has been elevated more than 90° (there are many examples of this) and is therefore turned upside down, the roof takes the place of the floor and *vice versâ*. Care must therefore be taken, in speaking of the roof or floor of the bed in such a position, to say whether it is considered in its present position or whether allowance is made for its being turned over.

It will generally be best to use this second supposition and speak of the *true roof* and the *true floor* of the bed.

The *thickness* (or *width* in the case of lodes) at a given point is the distance from the roof to the floor, measured perpendicularly to these surfaces considered for a small extent as parallel planes.

The *outcrop*, or *basset* (*broil* or *bryle*, Cornwall) is the succession of points where the deposit shows itself at the surface.

The words *chef* or *tête* are employed in French for an outcrop covered up, after the formation of the deposit, by more modern rocks. These terms are especially used in the collieries of the departments of the Nord and the Pas-de-Calais where the Coal Measures are covered by barren rocks, or *dead measures*, of Cretaceous age.

Comparing any deposit, say a seam of coal, to a simple plane coinciding sensibly with that of the roof and floor, we may say geometrically that the outcrop of such a deposit is its intersection with the surface of the ground, and that its *chef* or *tête* is its intersection with the base of the barren rocks which cover it.

The *strike* of a bed or vein, in the same line of geometrical ideas, will be obtained by cutting the surface of the deposit by a horizontal plane and taking the tangent to the curve formed by the intersection.

The *dip* will be obtained by cutting the deposit by a vertical plane perpendicular to the strike and taking the tangent to the curve of intersection.

These two definitions can be comprised in one enunciation by saying that, supposing a plane tangent to the surface of the deposit at a given point, the horizontal line in this tangent plane will be the strike at this point, and the dip (*) will be the angle made by the line of greatest slope in this plane with the horizontal plane.

The orientation of the line of strike is given by the angle which it makes with the true or the magnetic meridian. The angles are generally taken starting from the North, and it is clear that to represent any strike it suffices to take an angle of 0° to 90° either East or West of the meridian. The angle will vary from 0° to 180°, if, according to custom, it is reckoned only on one side from North to South passing by East.

The amount of the dip is described numerically by the acute angle which the plane tangent to the deposit makes with the horizontal plane; but in order to determine the direction it has been agreed to take the dip in descending, and it is represented graphically by an arrow at right angles to the strike, the point of which is supposed to be directed downwards.

(*) The words *hade, underlie* and *underlay* express the amount of inclination from the perpendicular

It is easy to see that the dip and strike may be determined by a single notation, if it is agreed to measure the angle made by this arrow in the direction of its point with the North and South line, this angle being able to vary from 0° to 360°.

Thus for instance, a deposit with its strike running 35° East of North and dipping West at an angle α might have its orientation completely determined by saying that it has a dip α in the direction $270° + 35° = 305°$, or graphically by drawing a line $P'_1 P_1$ perpendicular to the strike MM′, marking by an arrow the direction in which it goes downwards and denoting the amount of its inclination α (*see* figs. 1 and 2). Considering the various above-mentioned elements as a whole, it is said that a bed or vein is regular when these elements do not vary, or only vary very gradually, from one point of the deposit to another. The bed or the vein is disordered or irregular when the variations are sudden or abnormal.

These principles being settled we will return to the deposits which can be at once defined geometrically with exactness.

(**11**) We will first speak of beds. A bed is fundamentally one of the layers of a given sedimentary rock.

If it is purely and simply the product of sedimentation, that is to say if it is composed of detritus brought down by water, it will form, as we have said, a bed of shale, clay, sand, sandstone or more or less hard conglomerate, according to the size of its components and their state of aggregation. These beds alternate more or less often in the whole thickness of the formation, the alternations having been produced at the time of the deposition according as the circumstances were modified. As a rule, on account of the sediment being widely spread over the bottom of the sea or lake, each bed will vary in thickness only very gradually from one point to another, and will be bounded, in its original state, by an obviously plane and horizontal surface.

Clay, shale, slate, sandstone, and many building materials owe their origin to this simple sedimentary action. Their present consistency may be due to the prolonged action of pressure to which they have been exposed, or to metamorphic phenomena.

But it has often happened also that the sedimentary action has been combined with certain chemical or physical phenomena of precipitation, evaporation, or concentration; these are explained either by the presence of mineral springs of a more or less complex composition which burst out at the bottom of the lakes where the deposition of sediment was going on, or by changes in the contour of the ground preventing a lake from receiving enough water to compensate for the effects of evaporation.

It is thus, for instance, that an explanation is afforded of the hardness of certain rocks which were originally sand and are now agglutinated by a calcareous or siliceous cement, the formation of the beds of gypsum in the neighbourhood of Paris, the deposits of sulphur in Sicily, the beds of iron ore intercalated in so many formations, the copper shales of the Mansfeld district, the beds of rock-salt of the department of the Meurthe, etc.

(**12**) The action of organisms whether of the vegetable or animal kingdom has also often intervened and played an important part.

It is thus more particularly that the beds of fossil fuel were formed, the working of which constitutes such an important industry at the present day.

We must suppose that a bed of this kind was formed in circumstances more or less analogous to those which produce peat nowadays; that is to say, that such a bed was formed in a basin or in a gulf by an accumulation of detritus of plants which had grown on the spot, at a time when the basin or gulf had been nearly filled up by sediment leaving a sort of swamp where the water was shallow enough to allow plants to grow. After they had been growing for a more or less lengthy period a depression set in, and the deposition of sediment began again to fill up the basin, until at last plants could grow once more.

The circumstances suitable for the production of beds of fossil fuel have existed at various epochs. It may even be said that they still continue at the present day.

At no time, however, do they seem to have united so many favourable conditions as when the Coal Measures properly so-called were deposited.

At this privileged moment of the earth's history, the temperature was higher and less variable than nowadays; the atmosphere was probably richer in carbonic acid and was certainly charged with a much larger quantity of watery vapour. The result of all these circumstances combined was a force of vegetation and of meteoric phenomena of which tropical countries at the present day can only give us a very faint idea.

It is thus that we explain both the enormous accumulation of vegetable matter and the enormous thickness of sediment presented by the great coalfields, such as those of Belgium, the North of France, Westphalia, England and North America, etc., etc.

The transformation of the organic matter into coal, having the external characters and combustible properties observed at present, is explained by a slow alteration, due to prolonged pressure and increasing temperature, to which a given bed has been subjected, in proportion as the sedimentary deposits or new beds of fossil fuel accumulated above it.

All that is now needed is an explanation of the number of seams of coal, *often very considerable*, presented by a great basin (there are about 140 at Mons including the seams which are too thin to be worked and which are termed in French *passées*; at least as many seams may be counted in the basin of the Ruhr and on an average the latter are thicker).

In order to explain these frequent recurrences it must be supposed that the crust of the globe was not then very thick, and consequently that it was less firm than at present and more often subjected to oscillatory movements such as are observed in our day. Furthermore, under the increasing weight of a great thickness of sediment the crust no doubt would bend and the basin become deeper though narrower, and in this manner a series of beds could be deposited successively under a depth of water that varied within certain limits, the level of the water of the basin however remaining constant.

Such is the idea that ought to be formed of the origin of coal basins. This hypothesis explains better than others, or rather it is the only one that explains in a satisfactory manner, the details of the structure of the seams, the usually small quantity of earthy sedimentary substances which are found mixed with the carbonaceous matter, and the differences of quality generally exhibited by seams, according to their age in the same basin or according to the age of the basin itself. In other words, it explains why the lowest and most ancient seams are anthracitic in character, and why the highest and most recent are lignites still retaining more or less of a vegetable structure.

This general explanation is amply sufficient for the miner, and if it does not entirely satisfy the chemist, the mineralogist or the geologist, because it does not account for every little detail of all the facts observed, it must be recollected that Nature in her laboratory acts upon *masses* and makes use of *pressure* and *time* on an immense scale; these are circumstances which may entirely change the play of affinities which we observe in our experience.

(**13**) The action of organisms of the animal kingdom is less important for us, in an industrial point of view, than that of vegetable organisms; they have, however, played a certain part, and sometimes a predominant one, in the formation of certain beds of sedimentary rocks. Many beds of limestone are chiefly made up of remains of shells. Some thick formations even (like the Chalk) are almost exclusively composed of an immense accumulation of small microscopic shells; — this same operation is still going on at the bottom of deep seas, in places where the enormous amount of the pressure and the absence of light would have been thought to forbid the existence of animal life.

(**14**) To recapitulate therefore what has been said (in N^{os}. 11 to 13), we shall give the name of *bed* to a variety of deposits, viz: — to a mechanical deposit, a chemical precipitate, a residue from evaporation or even to an accumulation of organic matter whether of the vegetable or animal kingdom, or often, lastly, to a complex whole due to the simultaneous action of several of these different modes of formation. A bed is intercalated in stratified rocks; its original form is that of a large horizontal lenticular mass, varying in thickness in an insensible manner in passing from one point to another; it has been essentially formed under water; it is younger than the bed which constitutes its floor and older than its roof. Such would be the very simple definition which might be given of the mode of formation and nature of a bed, if, on the one hand, it was formed with theoretical regularity, and if, on the other hand, it had remained in its original position.

This, however, is not generally the case, and without entering here upon long details, which would encroach on the domain of the mineralogist and geologist, we must consider the different irregularities which may present themselves to the miner, because he should be prepared to meet them and be competent to appreciate their signification and importance.

We shall consider in sucession : Those irregularities which may be looked upon as contemporaneous with the formation of the bed itself, those which are posterior to its formation but which affect principally or exclusively the bed itself, or which at least need only be considered with regard to this bed, and, lastly, those which are posterior to the formation of the sedimentary rocks in which the bed is enclosed and affect the whole of these rocks.

(15) Irregularities contemporaneous with the formation of a bed. — These irregularities have the common character of only showing themselves very gradually and in a somewhat insensible manner, regularity and continuity being fundamentally, as we have already said, the characters of a deposit formed under water. They are firstly *changes in thickness*, and secondly *changes in nature.*

A change in thickness which is really contemporaneous with the deposit, ought generally to show itself so gradually as to be in some measure insensible to the eye in a working place, that is to say so as not to alter in an appreciable manner the parallelism of the roof and floor in a distance of a few yards.

A seam of coal after having been a yard or more thick in one part of a coal basin may thin out gradually in another part to two feet, 18 inches, 1 foot, or even less and become unworkable ; or it may even disappear altogether. Another, on the contrary, may preserve an almost uniform thickness and be workable over the whole of the basin. It may be said, in general, that in a large basin, in the different points of which contemporaneous deposits may have been formed under very different conditions, there is no reason *à priori* why a given bed should be developed uniformly over the whole extent of the formation, and such a development is the exception rather than the rule.

Changes of nature contemporaneous with the deposition of the bed may show themselves under various circumstances, and like changes in thickness have generally the common character of only appearing gradually. A bed of iron ore by an increase in the proportion of purely sedimentary matter will become a simple bed of ferruginous sandstone; a seam of coal, pure in one place, will become gradually charged with earthy matter, either uniformly disseminated or concentrated in distinct layers between the laminæ of coal, and it will thus be changed gradually into a bed of more or less carbonaceous shale.

A seam is said to be *ribbed*, if, while preserving more or less the same thickness, it shows a distinct succession of small interstratified layers of coal and shale (fig. 3); it is said to *split* if one of these layers of shale, or *partings*, becomes so large that one seam is divided into two distinct seams that have to be worked separately (fig. 4).

A seam of coal may become charged, not with sedimentary particles, but with ferruginous matter in the state of carbonate of iron, if whilst vegetation was in full action in one place it was more or less hindered in another by mineral springs which deposited for instance peroxide of iron; this mineral in contact with organic matter would have passed to the lowest stage of oxidation and the protoxide would have combined with the carbonic acid.

A seam will therefore be in one place a seam of coal, and in another a seam of clay ironstone more or less charged with carbonaceous matter.

(**16**) **Irregularities in a bed produced after its formation.**—These irregularities may also consist in changes of thickness and of nature; but they will appear with characters essentially different from those of which we have just spoken.

Changes in thickness will be due to the fact that, during the movements to which the whole formation will have been subjected after its deposition, the different beds will have been exposed to compressing forces varying from one point to another. If the mass forming the deposit under consideration was at this time in a more or less plastic condition, it may now exhibit a series of swellings and pinchings up, constituting the *beaded* structure. The *swellings* may have all sorts of dimensions, and the *nips* which separate them may even result in the complete disappearance of the seam for a certain number of yards. These variations of thickness generally occur sufficiently rapidly to affect visibly the parallelism of the roof and floor (fig. 5).

If the overlying or underlying beds had not the same degree of plasticity as the deposit, they may have been fractured whilst the deposit only swelled up or was drawn out, and then the projecting angles of these rocks may be seen penetrating into the mass, whilst the latter infiltrates in some way into the smallest fissures and the whole shows a thoroughly abnormal and irregular appearance which is called a *trouble* (fig. 6). It may happen that a seam is *regular* when it has a certain dip, *troubled* when it has some other dip.

Changes in thickness may also be observed in the neighbourhood of one of the fractures which, as already stated, have generally accompanied movements of the earth's crust. As these ruptures have usually been attended with a change of level, it is easy to conceive that as one of the walls of the fracture slid upon the other there was a considerable amount of friction, enough to bend the beds in directions contrary to that of their relative sliding, and subject those that were sufficiently plastic to a sort of drawing out analogous to what is observed between two swellings. There may thus be all sorts of shades, according to the nature of the rocks, between a clean sharp fracture and a simple bending or drawing out of the beds in the plane along which the fracture has tended to be produced (fig. 7 to 9).

Another change of thickness may also appear where the deposition of a bed has been accompanied or immediately followed by a partial erosion before the deposition of the overlying bed. This circumstance is distinguished by the strata below the bed being regular and by the bed itself being so *in its lower layers*, whilst the *upper layers* only are of unequal thickness or even non-continuous. An irregularity of this kind constitutes what is called a *balk;* in the gypsum quarries in the neighbourhood of Paris it is by no means an uncommon phenomenon (fig. 10).

Changes in nature posterior to the deposition are caused by circumstances which have exposed certain parts of the bed to special influences.

Thus, a bed near its outcrop or its covered outcrop will be, or will have been, exposed to atmospheric agencies, the prolonged action of which is shown by the disintegration of the mass and its more or less complete oxidation. Thus, a seam of coal will become friable and iridescent and will only furnish small coal near the outcrop, and at the outcrop itself even a thick seam will perhaps be only represented by a thin layer of blackish earth, the greater part of the carbonaceous matter having been removed by a sort of slow combustion.

The neighbourhood of a fault communicating with the surface may give access to atmospheric agencies and thus cause the same alterations that are seen near the outcrops (fig. 11 and 11 *bis*).

On the other hand, if this fault was at one time filled with solutions or gases capable of acting chemically, the alterations may exhibit different characters; for instance, an iron ore may be found charged with iron pyrites in the neighbourhood of a fault that gave rise to sulphurous emanations.

If substances in a state of igneous fusion have been injected into the fault, the rocks will be seen to harden and as it were frit together on approaching it; coal will take a peculiar appearance and change into a sort of dense coke deprived of volatile matter, etc.

(**17**) **Posterior irregularities affecting the whole of the rocks.** — These irregularities are the consequences of the disturbances of equilibrium to which the earth's crust has been periodically subjected.

We may distinguish : folds or contortions of beds, faults or changes of level, and local interruptions or suppressions.

These three kinds of irregularities must be defined with precision.

In the case of *folds and contortions of beds* the idea may be formed *à priori*, and observation confirms it, that the simplest manner in which the earth's crust would have split at any given moment under the reaction ot the internal masses compressed by it, or have folded in order to follow the shrinkage of these masses, would have been in a straight line, or, more correctly, according to an arc of a great circle of the terrestrial sphere.

In the first case the rocks will have been driven back to the right and to the left by the eruption of igneous rocks, and will have formed on each side a series of folds or swellings, similar to the bendings pointed out in the second case.

The normal condition, in some measure, of sedimentary rocks in the neighbourhood of an axis of broken equilibrium, is therefore to form a more or less clear series of undulations exhibiting alternately what are called saddles and troughs. The nearer the beds approach the axis of disturbance the more are they elevated and contorted, and they sometimes reach a vertical position or are even tilted over beyond it.

On the contrary, as we recede from the axis, the tiltings up diminish in importance and at a sufficient distance are only represented by slight undulations or bendings.

It may therefore be said that the normal condition of a bed is no longer to be horizontal, but to exhibit sometimes a very slightly inclined or undulating surface, when it is sufficiently distant from the axis where the rupture of equilibrium occurred to which it owes its present position, sometimes an extremely undulating surface, the folds of which on a large scale are arranged parallelly to this axis.

The foldings in question appear with various characters : —

Sometimes they are mere undulations one after the other, the concave part being turned alternately up and down ; a vertical section at right angles to the strike gives a series of sinusoids with greater or less dips at the points of inflection (fig. 12).

Sometimes the beds show a more or less broken profile, the different parts exhibiting dips varying from 0° to 90° and even going beyond the vertical. These inverted parts are called *rearers*, whilst those where the roof and floor preserve their original position are called *flats;* the angle joining a rearer to a flat, which is often very acute, is called a *hook*.

One and the same bed may present a succession of rearers and flats so that a given vertical pit may intersect it at more than two places (fig. 13).

It sometimes happens that the axes of the saddles and troughs, or the hooks which on a large scale are parallel to the general strike of the beds, oscillate in reality about this strike, so that in following them along the length of the basin they are found to have a small inclination, sometimes rising, sometimes falling, which is called their *pitch* or *dip*. The pitch is not exactly the same in one point of the basin for the different hooks, especially for the two hooks which bound a given rearer; the result is that the number of rearers is not everywhere the same, and in following the strike of a given flat a rearer may be seen to arise dividing it into two distinct flats; this rearer may increase in size by the divergence of the upward hook from the downward hook, and disappear further on by the convergence of these same hooks.

These conditions, with which a mining engineer should be completely familiar, give rise to strange and complicated appearances in the graphic representation of the workings, to which we will return further on.

Faults and changes of level are a natural or, one might say, necessary consequence of these foldings and contortions. Following the same train of ideas it must be imagined that the fractures have a tendency to be produced in two principal directions : the one parallel to the axis, due to the fact that the forces which cause the disturbance of equilibrium are distributed along this axis, the other at right angles to the same axis, due to the fact that these forces do not act in all parts of this axis with equal intensity.

There may also be more than two directions of fractures in a given district; but it will not, as a rule, be impossible to arrange their different directions in lines depending upon axes of fracture more or less distant.

Lastly, the *interruptions or local suppressions* will be a natural consequence, on the one hand, of the production of these fissures which have generally been accompanied by more or less important changes of level, and, on the other hand, of the enormous denudation to which it is admitted that many rocks have been subjected. It is thus that coal basins are often seen, where the beds are disturbed in the highest degree (such as those for instance of Belgium and the North of France), no longer exhibiting externally any trace of this complicated structure, all the inequalities of the ground having disappeared, having been planed off as it were by diluvial agencies. These denudations often play a very important part.

A certain bed formerly continuous over a great tract of country may have been so far denuded as to leave nothing but small outlying patches to bear witness to its original extent.

(**18**) Such are the principal variations that may be exhibited in the mode of occurrence of a stratified deposit. There is plainly a wide difference between the simple definition of a bed, which served us as a starting point, and the point where we have just arrived. For the simple idea of a large lenticular mass unlimited in a horizontal direction, exhibiting a thickness and a composition sensibly uniform, we must substitute the more general and much more complex idea of a deposit that may vary in thickness and in nature from one point to another, either in consequence of contemporaneous or posterior phenomena, of a deposit enclosed between two surfaces, which, instead of being sensibly plane and horizontal, may be, and generally are, at least slightly inclined, and often contorted and folded upon themselves in a very complicated manner, of a deposit which, instead of forming a continuous whole is found to be cut up and parcelled out like the squares of a chess-board, with this condition that the different squares are sometimes carried to very different levels and that some of these squares, or occasionally nearly all, may be totally or partially suppressed by later phenomena of denudation.

It is easy to understand what complications may arise from the co-existence and the superposition in some manner of all these disturbances in a given bed, and it will be seen that if a mining engineer wishes to understand his ground, he will often require not only general theoretical knowledge but also a large local experience.

(**19**) If we now pass to veins we shall be able to define them rapidly, either by their analogies with beds, or by their differences from them; analogies or differences which are connected with the mode of formation of these two kinds of deposits.

It has been said (N° **9**) that a vein is a fissure or crack, produced in any rocks in consequence of a disturbance of equilibrium between the earth's crust and the subjacent melted mass.

This crack, due to causes acting at the base of the earth's crust, tends to traverse its entire thickness and thus to be put into more or less direct and easy communication with the atmospheric agencies on the one side and with the central mass on the other.

Furthermore, this crack remains more or less open, either because some igneous rock, porphyritic or otherwise, was injected into it as soon as it was formed, or because it does not exactly follow a plane surface and has been generally accompanied by a relative displacement of the two sides, in consequence of which the two faces of the crack can no longer fit into one another exactly (fig. 14).

Into this more or less gaping opening the melted substances forming the central mass were able to penetrate and be injected under the influence of causes somewhat analogous to those which nowadays produce the eruption of volcanic lavas. Either with or without such injections, the central mass may have given off divers vapours which came up and formed deposits on cooling, covering the sides of the fissure with crystals. Atmospheric agents may also have penetrated to the mass and have given rise to various reactions and more or less complex solutions, which in their turn made deposits, forming crystals by the wet way.

It may be supposed that these different actions took place successively during a long period of time; the nature of the vapours or solutions may have changed in the course of time, resulting in effects of double decomposition which explain the presence in veins of fixed and insoluble substances, which seem to have been unable to come there directly; and finally, as has been already said, under the combined action of time and high pressure, the chemical phenomena may have been essentially different from those that may be observed in the comparatively instantaneous reactions of our laboratories.

It must further be imagined that after a longer or shorter period of time the fracture was finally obliterated, either by the fact of its being filled up or by the gradual solidification of the mass at its base. Nevertheless, this fracture remains in the rocks as *a plane of least resistance*, which may be easily broken should the equilibrium be once more disturbed either in the immediate neighbourhood or at some more or less distant point. In consequence of such a reopening the same phenomena of filling up might be reproduced, although giving rise to different chemical reactions.

There will thus be, finally, an extremely complex filling up, in which, by means of attentive and repeated observations, we shall be able to recognize not only the order in which the substances of one period were deposited, but also the number and relative age of the different periods.

Such, on the whole, is the theory which a miner should hold on the formation of veins. Without pretending to explain all the details of the phenomena of filling up (which will be the business of the chemist and mineralogist, and which has already been attempted with success by Berthier, de Sénarmont, Ebelmen, Daubrée etc.), this theory suffices, in the general terms in which it is framed, to guide the miner in his work, and to prepare him for the different changes of character that may be presented in working a mineral vein or lode.

We will now begin to discuss in a somewhat detailed manner these peculiarities, supposing that the veins in question are well marked and principally filled by sublimation or by deposition from solutions.

(**20**) **Structure of veins.** — The veins in question differ essentially from beds by their structure. In both kinds of deposit a subdivision into bands more or less parallel to the roof and floor may be observed, but in veins this parallelism is not nearly so plain, nor have the bands the same regularity or continuity,

These bands are crystalline or at least subcrystalline; they are formed of special substances essentially distinct from those contained by the enclosing rocks or *country*. They have a tendency to be repeated symmetrically reckoning from the two walls of the vein. Sometimes the central part of the vein is left vacant in places and forms what are called *druses*, *vugs* or *tick-holes*, the sides of which are covered with the points of the crystals of the last band which was deposited there (fig. 15).

When the interior of a vein shows fragments of the enclosing rock (*country*) or fragments of a first filling up broken by the reopening of the vein, the same banded or ribboned structure is generally reproduced round the different fragments (fig. 16).

We distinguish in a mineral vein or lode :

1° The *filling up* properly so-called, formed of fragments of the enclosing rocks or *country;*

2° The *veinstone* (*gangue*), or barren substances;

3° The *ores*, or useful substances.

The veinstone and the ores have the same origin and there is no absolute distinction between them. Blende for instance is a veinstone in a vein worked only for lead; it will be *ore* if the vein is also worked for zinc and it will be *the ore* if no other metallic substance is worked.

Fluor spar is commonly a veinstone in a vein of tin or copper. It is, on the contrary, *the useful substance* in some cases.

As to the filling up, properly so-called, it is sometimes very slight and at other times forms the principal mass of the lode. The proportion of the filling up depends mainly on the strength or weakness of the enclosing rocks. With a very firm rock the vein will be, as it is said, *well collected together*, and will only contain veinstone and ores; with a loose or friable rock the fissure will be partly filled up with fragments that have fallen in from the hanging wall and the vein will be *ramified* or *disseminated*.

There may be, therefore, every sort of intermediate structure between a vein reduced to a mere single clean fracture (fig. 17), and a more or less thick zone of breccia, whose nuclei are fragments of the enclosing rocks cemented together by the veinstone and ores which ramify through the spaces left between the fragments (fig. 15).

We also distinguish in lodes or veins the *selvages*, *digs* or *gouges*, substances of a clayey nature derived from the alteration of the enclosing rock, which has either been ground down by the enormous friction which has accompanied the relative movement of the hanging wall upon the foot wall, traces of which may be found in the polished and regularly striated surfaces of the walls, or which has been more or less deeply attacked by the solutions which deposited the ores and veinstone.

These selvages or digs are not always found; it sometimes happens, on the contrary, that the substances composing the lode adhere very firmly to the enclosing rock which has preserved its hardness. When they do exist, however, they are useful to the miner for *hulking* the lode and thus facilitating the breaking down of the rest, while at the same time the proportion of *smalls* will be diminished.

(**21**) **Variations in width.** — In a bed a variation of thickness is *the exception* (*see* N° **15**); in a vein it is in some measure *the rule*. A fissure which is not perfectly plane and is accompanied by a change of level of the two sides, necessarily gives rise (fig. 14) to a chasm of variable width and to an appearance which, when looked upon on a large scale, recalls the beaded structure which was pointed out in the case of beds as an accidental circumstance.

There is this difference that the variations in width will occur less rapidly with veins; the parts, whether swelled out or pinched up, will hold out longer, and there will be gradual passages from one to the other. In what we have just said we suppose the vein to be crossing a homogeneous rock or, at all events, one that is scarcely attacked by the acid solutions which have filled it.

If the vein alternately crosses rocks that are not acted on, such as siliceous ones, and rocks that are acted on, like limestones for instance, there will be variations in width of a totally different origin; the vein will have its normal width in the insoluble rocks, and it will swell out in the calcareous rocks, if we suppose that the liquids were able to eat away the walls and perhaps at the same time, in consequence of the action of the carbonate of lime, precipitate the metallic oxides held in solution. We may thus explain not only the accidental swellings out that are met with sometimes when a vein penetrates into calcareous rocks, but also the accumulations of riches often exhibited by these swellings out, the circumstance which has produced the *swelling out* by the corrosion of the walls having at the same time produced the *enrichment* by the precipitation of the metallic oxides. These may have remained in their natural state or have been afterwards transformed by the arrival of other solutions, or evolutions of gases, into sulphides or other compounds.

(**22**) **Variations in richness.** — The mass of a vein or lode is not everywhere homogeneous, in the sense that the proportion of the different substances contained is not the same from one point to another, or, in other words, that the actual value of the deposit in a given working place is not proportional to its width.

It might be said that these variations in richness occur without obeying, in general, any well defined laws. The most exact, or rather *the least vague*, result which may be stated upon this subject, is that observation shows there is a tendency of the rich parts to form *shoots* following approximately the line of greatest dip. In other words, if we look at the longitudinal section of a lode, we shall often find that the rich parts at one level correspond with the rich parts at the level below, and so with the poor parts, although perhaps varying somewhat in extent.

The different rocks that a vein traverses appear also to play a certain part, even when none of them can be acted on by solutions, and when they have nearly the same average composition in silica and in bases. In a given metalliferous district one rock is known to enrich and another to impoverish the veins which cross it. In many cases this influence can only be attributed to thermo-electric phenomena which may have been at work whilst the deposition of mineral was going on. This is a mere surmise and not, for the present at least, an exact explanation. It may also have happened that the rocks have opened and preserved a more or less easy communication, according to their mode of fracture, with the vapours or solutions coming from the interior.

(**23**) **Variations in composition**.—We have just said that the richness varies in following a vein along the strike, and that we cross alternately rich zones or *shoots* of a certain length, and then more or less completely barren zones of a similar or often greater length.

In pursuing one of these metalliferous *shoots* along the dip, the following variations are often observed :

First of all it happens, from a phenomenon analogous to that which has been pointed out for seams of coal, that the *shoot* is poor near the outcrop, because the metallic substances, sulphides or others, exposed to the action of atmospheric agencies, have been oxidized and have disappeared in a state of soluble salts, often leaving no other residue than a more or less ochreous deposit. This deposit is sufficiently common and sufficiently characteristic to have received a special name from miners. It is what is called *the gossan* of veins.

Certain masses of iron ore are thus merely the effusion and spreading out at the surface of deposits which in depth become more and more charged with sulphur and turn into deposits of pyrites.

Below the outcrop, but above the general level of the valleys of the country, atmospheric agencies will still have been able to act although less energetically. Associated with galena will be found the carbonate, the sulphate, or the phosphate of lead; with copper pyrites, the green carbonate of that metal; with blende, calamine, etc., etc. These associations of oxidized ores with more or less complex sulphides are what the miners of Spanish America designate by the name *colorados*.

Lastly, below the general level of the valleys the ores are found unaltered by atmospheric agencies. According to circumstances they continue without change in their average composition to the greatest depths hitherto reached, or, on the contrary, they gradually change their nature. For instance galena may be seen to become richer or poorer in silver; blende gradually to replace galena; tin ore to make room for copper pyrites, etc.

It is important to notice this circumstance of a variation of composition in depth; because, although we may infer from its mode of formation that a vein will extend to a great depth, it by no means follows that we are justified in predicting its richness, its poverty or even its composition eighty or a hundred fathoms deeper.

In fact it is easy to understand that in proportion as we go down on a vein, points are met with where the pressure, depending on the temperature, has been exerted with rapidly increasing intensity and has been able to bring about certain differences in the chemical reactions.

(24) Variations in strike and dip. — Theoretically, as a vein or lode may be compared to a sort of large flat lenticular mass, the lines of dip and strike are straight lines.

In practice, as may be imagined, it may be quite otherwise, if the enclosing rocks after the formation of the vein have been subjected to the disturbing causes, which in the case of beds produce the folds and contortions already mentioned (N° **17**).

A vein under these conditions would present an irregular appearance which would seem to be entirely incompatible with the origin assigned to it.

However, putting aside this case, even when the enclosing rocks have undergone no important or complicated disturbance after the formation of the vein, it is not difficult to conceive deviations in the lines of dip and strike in various ways :

Firstly, these lines are not strictly straight. *Even in wholly homogeneous rocks* they can only be regarded as slightly undulating lines oscillating about a certain average dip or strike.

Secondly, if this homogeneousness is wanting, if you pass from one kind of rock to another, from a shale for instance into a sandstone, it is to be expected that the lines of dip and strike should undergo a certain inflexion, as all sorts of rocks do not tend to break in identically the same manner.

Lastly, supposing that whilst there is a tendency for a fissure to be formed in a certain direction, there is at the same time a pre-existing joint along which the rock will easily split nearly parallel to that direction, we must imagine that the fissure deviates in order to follow the joint for a certain distance and resumes its own true direction further on.

This last result, which is readily understood and may be easily verified by the most simple experiments, leads to important consequences.

If this joint of easy separation is in the direction of the stratification in a given stratified rock, the vein will follow the stratification itself and will take the name of *bed-vein* or *flat* (fig. 19) (*).

If this circumstance is repeated several times along its course, so that the vein alternately cuts through the beds and runs parallel with them, the result is a so-called *step-vein*, because the line of dip or strike seems to represent a flight of steps (fig. 20).

If the joint is the line of separation of two rocks, igneous or sedimentary, which are not contemporaneous and consequently are merely placed side by side without being, so to say, welded one to the other, the vein will be called a *contact vein* or *contact deposit* (fig. 21).

Lastly, if the joint of easy division is another older vein, the deviation takes place as in the preceding cases, and the more modern vein is said to be *dragged along* in the older vein.

(**25**) **Ramifications.** — The splitting of a bed is quite a special circumstance which is produced, as we have seen, when one of the partings gradually becomes so important, that the two parts of the deposit finally constitute two distinct beds.

(*) If nearly horizontal it is called a *floor* in Cornwall. *Translators.*

These bifurcations are much more frequent in veins and are then called *branches*.

Branches may be contemporaneous with the formation of the fracture, from its not having been perfectly sharp and clean; they may be of later date, if they are only due to large fragments falling from the hanging wall on to the footwall.

On first meeting with such a split the miner may be somewhat at a loss to know which branch represents the main vein and which it is best to follow. It might be said that it is the branch which deviates the least in strike from the average strike of the vein, or that it is the foot wall branch rather than that on the hanging wall. It might also happen that the presence of such branches indicated a sort of general irregular fissuring of the rock by which the fracture would terminate and that the deposit did not go any further. In this case it is said that the vein *splits into branches*.

(**26**) **Ending of veins along their strike.**—A vein, that is to say a fissure filled with useful substances derived from the interior, which has therefore been important enough at its origin to traverse at least the greater part of the earth's crust and thus to be put into more or less immediate communication with the internal igneous mass, is an important phenomenon, which is usually connected in a more or less direct manner with some great disturbance of the equilibrium of the crust of the globe. It will, therefore, generally be of great length varying from a few hundred yards to several miles. A vein may terminate along the strike, because the fissure did not extend any further and in this case it ends either like a wedge, or by a sort of general splitting up into small branches.

The vein may also be *cut off*. This expression is used in the case of a vein running against some large fault beyond which it is no longer found. This is what may happen when the fault, supposed to be older than the vein, is so sharp that it has destroyed all connection between the rocks on each side of it; so that a fissure which arose on one side was propagated up to the fault but stopped there without crossing it.

(**27**) **Ending of veins in depth.** — What has just been said of the extension along the strike may be repeated of the extension in depth. The latter must be very great and it appears that nowhere with the depths hitherto reached, which do not yet exceed 400, 500, or at most 550 fathoms in the deepest mines, can it be said that we have really reached the limit in depth of a well marked deposit. All that has been reached is the limit of the deposit of a given useful substance or the limit of the mechanical means that had been employed for working it, but not the limit of the fissure in which this deposit had been formed.

(**28**) The preceding details (N^{os} **9** to **27**) give a summary of what must be understood by deposits occurring as beds and those occurring as veins or lodes. We have pointed out how such deposits would appear in the normal state and what is the character of the different irregularities which they may exhibit.

We have hitherto been discussing the case of one solitary deposit; this, however, is not a state of things usually occurring in nature, for mineral deposits are rarely found singly. This last characteristic is set forth by laying down the rule called the principle of the *parallelism of the deposits*.

This must be considered separately for beds and for veins.

In the case of beds, it may be said that the fact of there being a workable deposit in a given stratified rock may lead one to suppose, up to a certain point, that there are similar deposits above or below it; for it is quite natural to suppose that the special circumstances which were able to form a workable bed of iron ore, coal, or other substance, may have had a less ephemeral character than those that caused an interruption or the return of the very simple phenomenon of deposition of sediment at a given place.

In fact it is rare, for instance, to find a *solitary* seam of coal in a series of rocks belonging to the Coal Measures. We have said that there might be more than a hundred. It is rare not to have at least two or three.

These different beds are *nearly* parallel; we say only nearly, because it will have often happened with the successive depressions necessary to produce the series of beds, that the changes of level did not occur uniformly; so that one part of a basin may have remained above water or deeply submerged whilst at the same time at another place the formation of coal was still going on. In such a case if it is possible to distinguish certain horizons in the whole formation, these will not be absolutely conformable to one another and will not all be equally developed in the different points of the basin.

In the case of veins, the principle of the parallelism of deposits is both less precise and used in a wider sense than in the case of beds; *less precise*, because the fissures formed parallelly to an axis of disturbance of equilibrium are not confined to such an exact parallelism as that of the layers of stratified rocks; *in a wider sense*, because, independently of the fractures parallel to the axis, there is a tendency to form others in a direction nearly at right angles to the first, and because pre-existing fractures may be reopened.

We may, therefore, have (in fact we generally do have in a well marked metalliferous district) not only one vein striking in a given direction, but also a first series of veins which will be more or less exactly parallel to it, and besides these, one or several other series of veins running in as many distinct directions.

We will cite examples later on.

(**29**) If these fractures are multiplied in a comparatively confined area the result is a number of intersections which constitute in the complex network of deposits kinds of *peculiar points* upon which a few observations must be made.

Theoretically, when two veins cross in such a manner that their strikes do not cut one another at too acute an angle, it will be easy to distinguish the *intersector* or younger vein, from the *intersected* or older vein. As a characteristic of the first the levels driven on it are continued in a straight line. In the second, on the contrary, as there has generally been a movement of the rocks on the hanging wall of the intersector relatively to the rocks on the foot wall, the two parts of the intersected vein are no longer opposite one another, and the levels driven, which are merely the horizontal traces of the intersected deposits, are no longer simple prolongations the one of the other. In this case the intersected vein is said to be *heaved* or *thrown* by the intersector.

It will be remarked that the same circumstances may occur with a bed.

Thus, any deposit, whether vein or bed, which is met by a fracture or fault accompanied by a relative displacement of the two walls, will be generally heaved or thrown by this fault.

On arriving at this fault and crossing it the deposit will no longer be met with on a prolongation of the line hitherto followed. The miner has then to solve a question of much practical importance, viz., to decide on which side he ought to proceed in order to find the heaved part.

(**30**) It may happen that the miner is guided by certain material indications. He may meet on the other side of the fault some well-marked bed of rock the position of which on the hanging or foot wall of the deposit may be known; or he may derive some information concerning the direction of the throw from the bending of the beds where they come in contact with the fault, or by the presence of a sort of trail of the substance of the deposit in the plane of the fault (figs. 8 and 9).

In the absence of these material indications it is generally admitted (experience shows it and it is easily conceived by reasoning) that when there is a heave, the movement to which it is due is *a simple sliding of the hanging wall, which descends relatively to the foot wall along the line of greatest slope.*

It must be understood that this rule is only an approximation. It supposes that the sinking of the hanging wall along the foot wall, or the rise of the foot wall along the hanging wall, according as it is a question of a depression or an elevation, is a simple movement of translation causing a constant vertical throw along the fault. It is not always so, and *it cannot be* always so, because there is usually a point where the fault is seen to begin or end and where the throw is *nil.*

Starting from such a point a fault is often seen to increase in importance, or *the heave to become greater*, in proportion as one gets further away. In this case the relative movement should be considered no longer as a simple shifting but rather as a rotation round an axis at right angles to the plane of the fault; this, as is well known, is the most general movement that may be considered in a plane when it is a question of a solid body quite invariable in shape.

Be this as it may, *these increases of throw* do not occur sufficiently sharply to prevent our considering the fault at a given point as having shown itself in the sense just pointed out.

This being the case, on arriving at a fault the observer has to place himself straight in front of the plane of the fault without crossing it and examine whether the prolongation of this plane passes above his head or under his feet, or what is the same thing, whether he reached the fault on the *foot wall* or *hanging wall side*. Admitting that the hanging wall part has gone down relatively to the foot wall part, there is in the first case what miners call a *throw downwards* and in the second a *throw upwards*. That is to say, it would be necessary to *go down* or *up*, according to the case taken, following the line of greatest dip of the fault, in order to find *the point of the deposit thrown, which coincided with the point occupied by the observer before the throw took place*.

If a horizontal plane is imagined here, prolonged till it intersects the plane of the fault, these two planes will form two supplementary angles and it is easy to see that the rule given above may be expressed by saying that, in order to find the deposit, you must follow *on the side of the obtuse angle*.

The rule enunciated thus is known as *Schmidt's rule*, or *the rule of the obtuse angle*.

It must be considered purely and simply as a consequence of this fact : *In a throw caused by a fault, the hanging wall part has generally slipped downwards on the foot wall along the line of greatest dip*.

(**31**) The other part of the deposit will be found by applying Schmidt's rule, that is to say *in going upwards* if the plane of the fault *passes under the feet of the miner*, *in going downwards* if this plane passes over his head. The search may be made by actually going up or down in order to ascertain the amount of the throw, if it is the first time that the fault is met with; but it is not usually in this manner that the level which intersected the fault will be prolonged.

Let MO (fig. 22) represent the horizontal trace of a given deposit, or the axis of a level driven on the deposit up to a point O, where it suddenly comes up against a fault the horizontal trace of which is discovered to be BS.

The two arrows denote the supposed directions of the dips of the deposit and the fault.

If the amount of each dip is also given, the line OT, the horizontal projection of the trace of the deposit on the plane of the fault, may easily be laid down. To do this it is only necessary to cut the two planes by a second horizontal one. There will be two intersections O′M′ and O′S′ respectively parallel to OM and OS, the intersection of which will give a point O′ belonging to the line OT sought for.

According to the direction denoted by the arrow for the dip of the fault the level MO is on the hanging wall side of the fault. It is necessary, therefore, to go up on the line of greatest dip OX in order to find the point which coincided with the point O before the throw. This point is at D′ for instance.

Draw D′T′ parallel to OT, this line will be the horizontal projection of the trace, on the plane of the fault, of that portion of the deposit which is on the foot wall. This parallel will cut the line OS at S. Through S draw SA parallel to OM and you get the line of strike of the deposit beyond the fault. The part of the deposit which is on the hanging wall side of the fault is bounded by the indefinite line TOV; that on the foot wall side by the indefinite line T′SD′C, parallel to TOV and the interval between these two lines is the projection of *a sterile space*, in which there is no point of the deposit.

In the trihedral angle SABC, we know the dihedral angles A and B which correspond to the edges SA, SB, and the plane angle ASB $= c$ opposite the edge SC. It will be possible either by construction or by calculation, knowing the amount l of the throw along the dip, to find the length and direction of the various roads that might be followed starting from O in order to meet with the heaved deposit, or at all events, if the value of l is not known, the relation between all these lines may be determined.

Take XOD = B and erect D′D perpendicular to the line OX, the length OD is the quantity denoted by l. It is the *amount of the throw measured along the dip of the fault.* Rotating D to D_1 the line SD_1C_1 represents the edge SC rotated into a horizontal plane. By dropping OF perpendicular on SC_1, we obtain the true length of the shortest distance between the two traces TOV and T′SD′C.

Through the point O let us take a vertical plane at right angles to SA and having OY as trace. It will cut the plane SAC along the line of greatest dip. Rotating this intersection round OE as a hinge the angle OEG will be the angle A and the perpendicular OG will represent in true size the smallest distance between the two parts of the deposit. Lastly, in the plane ASB, SO will be the horizontal distance in the plane of the fault and OE the smallest horizontal distance.

The graphic construction gives, as may be seen, the relation between these different distances and their absolute size if one of them is known.

(**32**) They may also be obtained by calculation in a very simple manner.

Denoting by l the length OD, which, as we have seen, is *the amount of the throw along the dip of the fault* we shall have :

$DD' = l \sin B$, *amount of the throw in a vertical sense.*

$OS = l \cot a$, *horizontal throw in the plane of the fault.*

$OE = OS \sin c = l \cot a \sin c$, *horizontal throw.*

$OG = OE \sin A = l \cot a \sin c \sin A$, *throw measured at right angles to the plane of the deposit.*

$OF = OS \sin a = l \cot a \sin a = l \cos a$, *amount of the throw in the plane of the fault.*

From a known formula we have :

$$\cot a \sin c = \cos c \cos B + \sin B \cot A.$$

We deduce in succession:

$$\operatorname{Cot} a = \frac{\cos c \cos B + \sin B \cot A}{\sin c}$$

$$\operatorname{Tang} a = \frac{\sin c}{\cos c \cos B + \sin B \cot A}$$

$$\operatorname{Sec} a = \sqrt{1 + \operatorname{tang}^2 a} = \frac{\sqrt{\sin^2 c + (\cos c \cos B + \sin B \cot A)^2}}{\cos c \cos B + \sin B \cot A}$$

$$\operatorname{Cos} a = \frac{\cos c \cos B + \sin B \cot A}{\sqrt{\sin^2 c + (\cos c \cos B + \sin B \cot A)^2}}$$

The following table may consequently be formed:

$$OD = l$$
$$DD' = l \sin B$$
$$OS = l \frac{\cos c \cos B + \sin B \cot A}{\sin c}$$
$$OE = l (\cos c \cos B + \sin B \cot A)$$
$$OG = l (\cos c \cos B \sin A + \sin B \cos A)$$
$$OF = l \frac{\cos c \cos B + \sin B \cot A}{\sqrt{\sin^2 c + (\cos c \cos B + \sin B \cot A)^2}}.$$

Using the plan or the above calculations and making allowance for the various conveniences of working, we can examine which direction ought to be followed in order to find the deposit which has been thrown and so continue the workings. It will generally be found most convenient to proceed horizontally, either in the plane of the fault SO or by a *crosscut* along OE; but it must be remarked that the road OE is not always possible, because the perpendicular OE on the trace SA might fall, in some cases, not on this trace itself, but on its geometrical prolongation. This would happen for instance if the throw in the plane of the fault occurred towards B, or *to the right hand*, and not towards S, or *to the left hand*.

In the same way the perpendicular OG might not fall inside the angle ASC and in this case in proceeding towards OG you would not meet with the thrown deposit, but only with its ideal prolongation beyond its intersection with the fault.

(**33**) Such are the consequences which are deduced in applying Schmidt's rule both to beds and lodes.

Experience proves that this rule is *applicable in a large number of cases*; so that, usually, when a miner arrives at a fault he does not hesitate to say, after having examined its bearings, that he has before him a *throw upwards* or a *throw downwards* and works on accordingly.

It may happen, however, and this must be remembered, that a mere inspection of the spot does not suffice to show the miner which way he ought to proceed horizontally and he may be obliged to have recourse to a graphic construction to ascertain it.

This would happen, for instance, if the circumstances were as shown in figure 25.

On arriving at O, it would evidently be necessary to follow upwards along OX to find the point D projected in D′; but would $D'S_1$ or $D'S_2$ correctly represent the trace of the part of the deposit on the foot wall, in other words would the horizontal throw in the plane of the fault be to the left hand or to the right? That would depend upon the respective amounts of the dips of the deposit and the fault. It is easily seen that with a flattish fault and a steeply dipping deposit the throw could be towards S_1, and that it could, on the contrary, be towards S_2 under inverse circumstances.

(**34**) Schmidt's rule although frequently applicable in practice must not be considered as fundamentally infallible. When it is a question of slight irregularities, which may be looked upon as depressions with a local character and *after the formation of which the rocks have not been subjected to other important disturbances*, we may consider the fractures to have been produced in a manner analogous to what happens in a landslip; that is to say, that they took place following a certain slope, along which there was a sliding, and Schmidt's rule may evidently be applied under these circumstances. It is no less evident, however, that if, after the occurence of this disturbance, the rocks had been subjected as a whole to a considerable amount of elevation, *the direction of the dip* of the fault might have been reversed; the foot wall would have become the hanging wall and *vice versâ*, and at the present day we should observe that the direction of the sliding was contrary to what is indicated by the rule.

It is also possible that the rule may have been at fault even at the time of the formation of the fracture; this case may have happened if the elevation was accompanied by horizontal thrusts, such as might be caused by the violent intrusion of an igneous rock across other strata. More or less inclined fractures might then occur and the upper prism might be forced to slide upwards along the plane of fracture.

Schmidt's rule would be also at fault *and would give no indication whatever* in two other cases :

On the one hand, for a vein, if the fault *intercepted* the vein instead of *crossing* it.

On the other hand, for a bed, if there was a marked and persistent change in the strike or dip of the bed beyond the fault; so that the fracture observed was only due to the more or less acute angle to which the beds were bent (fig. 24).

It must further be remarked that when two fissures meet *intersecting one another at an acute angle*, the throw observed is sometimes merely a false appearance, because the heaved vein may be the more modern. This is due to the same circumstance which produces *bed-veins* and *contact veins;* that is to say, if the more modern fracture met the older one at a small angle it will have swerved to follow it for a certain time, and will take its regular course a little further on. As the bed-veins and contact veins are not rare we must expect also pretty frequently to meet with these false throws, and numerous examples of them might be cited.

Lastly, two faults on meeting may seem to throw one another mutually. This *double throw* will generally be due to the fact that the older fracture, after having been thrown by the newer, was subsequently reopened, causing the rock masses on each side of it to be shifted once more and the throw of the second fault to be drawn along by this same movement.

(**35**) Independently of the circumstances *common to beds and veins* which occur on their meeting with faults and of which we have just spoken, we must also consider, in the case of veins, the influence that these junctions may exert upon their richness.

Theoretically this influence ought *à priori* to be looked upon as probably good rather than unfavourable; because this double fracture in two different directions must facilitate the communication with that great internal laboratory, from which we have said the useful substances that fill the veins have been derived.

The influence of which we speak must not of course be exaggerated, and the commonest case will perhaps be one where this influence has not been exhibited in a sensible manner. However, there are some extremely clear examples of the contrary, and instances are cited of mines which have given enormous riches accumulated in two lodes near their junction only, so that the workings along the strike were very restricted and only formed in plan four short branches, representing a sort of cross around the junction.

(**36**) The above details (N^{os}. **9** *et seq.*) furnish particulars, concerning the origin of veins and beds and their condition in the bosom of the earth, which ought to be familiar to every miner, so that he may be able to know where he is and find his way in the midst of the varied phenomena with which he is liable to meet. It is highly necessary in all mines to preserve a record of all these phenomena so as to arrange future workings.

This object is attained by keeping a register of progress on which should be noted down (stating precisely the place and date of the observation and with sketches to assist if necessary) the section of the deposit, the nature and quality of the enclosing rocks, the dip, strike and in general the different features which characterise its mode of occurrence at the points of observation.

Furthermore, all the workings must be represented in plan, section and elevation. This representation is very simple and easy when the deposit may be compared to a kind of large almost flat lenticular mass. In this case, in fact, a horizontal plane for a bed and a vertical plane parallel to the strike for a lode will suffice to represent clearly and almost in their proper size, on the scale adopted, the workings caried out on the deposit. The subsequent disturbances, however, which this deposit may have had to undergo and which it generally has undergone in a more or less violent manner, give rise, as we have already said (N° **17**), to complex appearances with which the miner should make himself familiar.

Theoretically a horizontal section in the deposit should merely be a single straight line, because it is the intersection of two plane surfaces. But a series of undulations or a series of rearers and flats, having their axes or hooks perfectly horizontal, will give for one and the same deposit a series of parallel straight lines (fig. 25).

If these axes or hooks have a certain pitch or dip the appearance will become much more complex. The straight lines will cease to be parallel and will become converging lines joining on to one another by more or less decided curves (fig. 26).

If the amount of pitch changes, more or less elongated closed curves or curves with indefinite branches are obtained with the appearance of which the miner should make himself well acquainted. Thus, for instance, figure 27 represents the horizontal section of consecutive trough and saddle, the axes of which form a curved line with the concavity upwards. Figure 28 represents the reverse case where the axes are inclined downwards on both sides from a given point. Figures 29 and 30 correspond for the rearers and flats to figures 27 and 28 for the saddles and troughs.

Suppose a working zone included between two given levels; the levels driven along the strike could pass, thanks to the inclination of the axis, from the flats to the rearers, or *vice versâ;* the horizontal projections of the two lines of level will be close to one another in the rearers, supposed to be nearly vertical, and relatively very distant, on the contrary, in the flats which are supposed to have only a slight dip. The appearance will be that of figure 31 where the lines A', B', C' represent for instance the lower tramway and the lines A_1, B_1, C_1 the return air-course which has been left in the upper part of the workings. The horizontal distances between the corresponding lines A' and A_1, B' and B_1, C' and C_1 vary inversely as the dips of the parts of the seam in question.

(**37**) The appearance produced by a fault obeying Schmidt's rule and meeting a deposit compared to a plane may be seen by going back to figures 22 and 23, where you get in projection a barren space included between two paralled lines TOV, T'SC.

If a fault dies away, these two lines cease to be parallel and are replaced by two lines which converge towards the point where it is observed that the throw begins to be felt (fig. 32).

If, starting from its origin, the throw goes on increasing more and more, the lines get further apart and the breadth of the barren space becomes greater and greater, as is shown in the above-mentioned figure 32.

If the throw is seen to begin at some point and then, after having been more or less considerable for a certain distance, to become *nil* again at some other point, the barren space will begin at nothing, then gradually enlarge, afterwards become narrower and finally end off at nothing (fig. 33).

If the deposit thrown, instead of being comparable to a plane, ought to be compared to a more or less folded plane surface, the two lines such as TOV and T'SC (fig. 22) are any identical curved lines, which in the case of a single sliding have been displaced parallelly. The barren space which they enclose in plan thus receives a winding shape and varies much in width.

Lastly, if the throw took place contrary to Schmidt's rule a zone where the deposit is doubled, as it were, is found in plan, instead of a barren space.

(**38**) After the standard deposits, or beds and veins, fulfilling the definitions laid down above, we come to those known in the mining law by the name of masses.

Masses are bodies of mineral which by *their mode of formation* come more or less completely into the category either of beds or veins properly so-called, but which in their general features and by *their irregular shapes* do not fulfil the geometrical definition of these deposits, in this sense that they have not *two dimensions which may be looked upon as indefinite compared with the third.* They are often egg-shaped or rounded masses, *of which two dimensions at least are limited and comparable one with the other*

The production of the mass may be due, in the case of a deposit of sedimentary origin, either to contemporaneous agencies which have brought together a large accumulation of matter in a limited space, or to the fact that subsequently to its deposition inequalities of pressure, due to elevation, have caused the deposit to assume the beaded structure, and a mass may be in some measure *one of the swellings*.

In the case of deposits formed like veins, that is to say subsequently to the enclosing rocks, it may be supposed that, instead of a system of extensive fissures depending on *an axis of elevation*, there are simple cracks of small extent depending on *a centre of elevation*, and that the substances arrived at or near the surface by kinds of chimneys more or less analogous to those which are exhibited by the craters of volcanoes.

We may thus have all the varieties of phenomena that are presented to us in volcanic regions : *eruptions of igneous rocks* which have come to the surface forming either domes or more or less extensive sheets according to their degree of fluidity ; and *aqueous eruptions* which have formed more or less complex deposits, and of which the Geyser in Iceland gives us an example at the present day.

Such appears to be the origin of a large number of deposits.

An igneous origin, for instance, would be attributed to the masses of iron ore of the Iron Mountain and Pilot Knob (United States of America) which rise up as isolated hills above the surrounding country. An aqueous origin, on the contrary, would be attributed to other masses of iron ore which seem to be the opening out, at or near the surface, of chimneys which become contracted in depth ; to the deposits of calamine which occur in many places with the pretty constant characters of irregular masses, limited along the strike and in depth, and situated in the midst of calcareous rocks in pre-existing fissures enlarged by the action of solutions, whilst at the same time the enclosing rocks were more or less completely transformed into dolomite; to the deposits of phosphate of lime recently discovered in many localities in the South west of France, etc.

The name *bedded mass* is given to a mass interposed between stratified rocks and differing from a true bed only by its limited extent along the strike, compared with its thickness.

An *erect mass* is a mass which stands in the same relation to a lode as a bedded mass to a bed.

These erect masses often occur in the form of contact veins or bed-veins. It is not always easy to distinguish at first sight in this last case, whether a given deposit is a bedded mass or an erect mass. The prosecution of workings, however, permits us to see whether the parallelism with the strata continues everywhere, or whether some point is not met with where this parallelism is at fault, or whether we do not find the vent or channel by which these substances have been poured out either between the planes of bedding of a sedimentary rock, or between two different rocks, or lastly at the surface of the ground.

(**39**) Finally, in order to complete these general ideas, we must add that many deposits, whilst coming more or less under one of the above heads, have received, on account of some peculiarity of character or mode of formation, special names which it is important to know.

The name of *interlaced masses*, or *stockworks*, is given to masses of igneous (*) rock penetrated by a great number of little veins of metallic ores which cross in various ways. It may be supposed that the mass, split in all directions, was exposed to vapours or solutions bringing these metallic substances; or else that these substances, originally disseminated in a more or less intimate manner in the mass in a state of fusion, subsequently concentrated themselves together in certain points at the time of the solidification, by a certain molecular movement of which we have instances in other places.

The name of *stockworks* is principally applied to certain deposits of oxide of tin which are found in England and in Germany.

Alluvial ores is the name given to ores found in alluvia and which are derived like these alluvia from the destruction of older rocks and the reassorting of them by running water. They are certainly beds as far as their origin is concerned, in the sense that the

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(*) Masses of *sedimentary* rock, also, crossed by innumerable strings of tinstone may be seen in Cornwall. *Translators.*

rock is due to the action of water; but this action has been displayed under special conditions essentially distinct from those which formed the beds of the true sedimentary rocks. The particles of ore instead of forming distinct and continuous seams are simply disseminated in an irregular manner in the midst of sterile substances which constitute the mass of the alluvial rocks.

These alluvia contain, for a given volume, very small quantities of useful matter; but they may be very important on account of the large scale on which they are sometimes formed, for instance, in Siberia, California, Brazil, etc.

Under this same name of *alluvial ores* are described certain ores of iron which are met with in many parts of France in the form of rounded, isolated grains, enclosed in a clayey or sandy matrix and filling up irregular cavities in the limestone rocks. The oolitic structure is here only an imitation of the appearance which the mechanical action of water gives to the gravel which it carries along. In reality each grain has had its present shape from the beginning and the ore has been formed in place by the action of acid ferruginous solutions, which attacked the limestone with effervescence and left as result a deposit of oxide of iron.

These ores have, therefore, exactly the origin described above. They are not *alluvia*, but *masses* having the same origin as lodes, as has been said in the preceding N° **38**.

These masses, moreover, may have very various dimensions. Some will be observed not larger than a few cubic yards. Others have been worked with a horizontal diameter of 10 to 15 fathoms and have been followed downwards to a depth of 20 to 30 fathoms. The removal of the ore in these masses, or pockets, brings to light the traces of the erosion of their walls and also of the sides of peaks of limestone which have sometimes remained undissolved in the midst of the masses of ore. Some of these peaks or needles have been observed with a vertical height of 133 feet (40 metres), being 6 feet 6 inches (2 metres) in diameter at the summit and 13 feet (4 metres) at the base.

A deposit is said to occur in *reniform masses*, in *nodules*, in *concretions*, etc., etc., when it appears to have been originally more or less irregularly disseminated through a rock and then subsequently concentrated around different points by certain molecular movements. Such, for instance, are the flints or the nodules of iron pyrites in the Chalk, the kernels of galena in certain beds of Triassic sandstone, the nodules of clay ironstone in certain beds belonging to the Coal Measures, etc.

It is also easy to imagine the casual deposits designated in German by the name *Rasenläufer*, literally *grass-runners*, which are small masses of mineral extremely limited in extent which do not appear to join on to any large, definite, workable deposit.

They must be looked upon either as concentrations of matter pre-existing in the rock, though not forming one of its normal constituents, which subsequently collected into the nodules or concretions mentioned above, or as substances introduced afterwards by some later phenomenon *analogous*, excepting the scale, *to that which produces workable veins*. Their origin may be conceived, *à priori*, on the supposition that, as all rocks are shown by the daily experience of mines to be more or less permeable to surface water, they may also be permeable to solutions or vapours coming from the interior. In this manner a fracture causing a simple fissure which does not belong to any great geological disturbance might perchance contain, in an adventitious state, substances foreign to the composition of the enclosing rocks, *vein substances*, without our being warranted in inferring the existence of a deposit containing enough ore to pay for working.

It must be understood that the different circumstances which have been able to bring about these small local and unconnected deposits, these *irregular deposits* of useful mineral substances, are in nowise, by their nature, exceptional. We are, therefore, often likely to meet with such deposits, and from a first indication we must not conclude the certain existence of a workable deposit until its extent and richness have been specially studied and recognized.

This observation is quite essential. It is for want of sufficient attention to it in starting new concerns, that mining industry affords by the side of the most brilliant results the contrast of so many examples of deception and ruin.

CHAPTER II.

VARIOUS EXAMPLES OF DEPOSITS.

(**40**) The general information given in the preceding chapter on the origin and modes of formation of different deposits of mineral substances, as well as on the very various peculiarities that may be exhibited by them, should be familiar to every one who wishes to apply himself to the technical part of mining. It is equally necessary either in order to form a rational plan for laying out workings on a given deposit or series of deposits, or for the daily management of the work itself.

We shall now consider some examples of these deposits and shall dwell upon the circumstances particularly interesting to the miner that each of these examples presents.

(**41**) Firstly, it must be understood that the scale on which these deposits occur varies *between the widest limits*, from insignificant dimensions quite inadequate to justify any attempt at working commercially, up to the very largest proportions, containing quantities of useful substances which would suffice to supply the wants of the whole world for very many years.

The most remarkable example that can be instanced from this last point of view is that of the great coal basin West of the Alleghanies. A single seam of coal of this basin, called the Pittsburg seam with an average thickness of 7 feet 2 ins. ($2^m.20$, varying from 3 feet 3 ins. to 13 feet), has been discovered over an area of 14,000 square miles and seems to have occupied before it was denuded at least 54,000 square miles.

At 1,000 tons per foot thickness per acre it would yield 64 thousand millions of tons, which would be the consumption of the whole world for 300 years at the present rate of from 210 to 220 millions yearly. It must further be remarked that it is a question here of *only one* seam of *a single* coal basin of the country. If we were to take into consideration the whole of the Coal Measures of the United States we should find that they occupy a total surface of about 200,000 square miles or nearly the extent of the whole of France.

We may also cite in the East of France, in Luxemburg and Lorraine, the fine deposit of oolitic hydrous oxide of iron which is found in the Oolitic rocks just above the Supraliassic marls.

This deposit stretches out in a pretty continuous manner along the left bank of the Moselle from Nancy nearly to Luxemburg, cropping out on the sides of all the valleys which reach up to the great escarpment that forms the Eastern boundary of the great plateau of the Meuse and the Moselle. Its length from North to South is at least 62 miles (100 kilometres). Its width estimated only from the greatest distance, from East to West, between the places where it is known, and where it is worked at present without pumping machinery, certainly exceeds 12 miles (20 kilometres), at least in the Northern part. Admitting that every square yard will yield 2 tons 9 cwt (3 tons per square metre) it may be calculated that with an area certainly exceeding 772 square miles (200.000 hectares) there are at least between five and six thousand millions of tons. This represents for the works which are supplied from this deposit, no matter how great their activity, a future in some measure indefinite, which must however be reckoned not by centuries but by thousands of years.

Compared with the annual consumption of iron in the world this is in about the same proportion as was furnished by the preceding example relatively to the consumption of coal. Of course deposits of such magnitude are nowhere in the hands of one mining company; a company generally has only a concession of limited extent on a deposit of any importance. It is considered as having a satisfactory future before it when it has reserves capable of being worked, on a scale corresponding with the amount of the general expenses, for a period which will allow the whole original capital employed in the affair to be redeemed by a moderate annuity.

This last consideration is quite essential, and it may be said that whatever is the nature of a deposit, whatever the richness of the ore that it produces, the first condition that it ought to fulfil in order to be profitably workable — in order to have *an appreciable commercial value*, independently of any interest in a scientific point of view — is that the substance to be worked should occur *in sufficient quantity*. Too much stress cannot be laid upon this point, and it cannot be too often repeated that *nothing*, so to say, is known of a mine when the only information consists in the mineralogical and even chemical nature of a specimen obtained from it. A specimen of *galena*, for instance, may be as rich in lead as the theoretical composition of this ore admits, it may contain as much silver as you please, without there being any reason why the deposit which furnished the specimen should be workable. The only conclusion to be formed is that there may be *matter for a further examination;* any other more positive inference would be premature.

(**42**) We do not intend to give detailed descriptions, monographs, of the different coalfields or other important deposits. Such descriptions belong to the domain of the geologist. We shall, therefore, confine ourselves to a few examples, chosen so as to reproduce the principal peculiarities pointed out in the course of the preceding chapter.

(**43**) 1st EXAMPLE. **Coalfield west of Mons.** — The Mons basin is nearly in the centre of an extensive zone of Coal Measures, which, excepting where there are local interruptions —one series perhaps contemporaneous with the deposition, the other often due to the superposition of younger rocks — can be followed on the surface from the Ruhr basin (Westphalia) through Aix-la-Chapelle, Liége, Namur, Charleroi and Mons, as far as Valenciennes, Douai, Béthune and Hardinghem; moreover it is perhaps joined to the South Wales coalfield passing under the Secondary rocks of the South of England.

All the coalfields distributed along this extensive zone are arranged in two principal directions, the point of convergence of which is at Douai; they have certain general features of resemblance which lead to the supposition that they are contemporaneous and formed under the same conditions. They have the character of marine strata, deposited in deep narrow gulfs formed by the folds and contortions of the older rocks on which they rest. The section (fig. 35) is taken nearly from North to South at right angles to the general strike of the strata.

In looking at this section various observations will be made :

1° The number of seams shown is very great; and if they are all supposed to be prolonged under the centre of the basin preserving very nearly their parallelism, the total thickness of the Coal Measures will be found to be more than 3,000 yards.

This number of seams and this great thickness point out both the frequency of the depressions that the bottom of the basin underwent and the great amount of the sedimentary action that was going on whilst the Coal Measures were being deposited.

2° All the beds in the southern part exhibit a series of folds, or of rearers and flats, indicating a violent action after the deposition, which was expended partly in elevating the strata and partly in pushing them sideways towards the North.

The result of this, immediately after the elevation, was a very broken outline at the surface of the ground, of which no trace remains at the present day. The Coal Measures simply rise to a rather higher level at the South than at the North, but the whole is covered over by dead measures sensibly horizontal, the thickness of which increases in passing from South to North.

It is the increase in thickness of these rocks, which are very watery and difficult to traverse, which has caused the workings to be mainly concentrated, up to the present time, South of the axis of the basin.

The very broken outline of the Coal Measures forms a strong contrast with the nearly plane and scarcely undulating surface which covers the edges of the various beds, and this shows one of the most remarkable examples that could be quoted of the immense scale on which the phenomena of denudation must have taken place.

3° In spite of active working the average depth attained at present is not more than 500 yards, and the mining has been carried out quite as much in the district of the rearers as in that of the great Southern flats, which follow the rearers, as far as the axis.

The great Northern flats, situated beyond the axis are almost intact. The conclusion, therefore, is that the Mons coal basin has a great future before it and that it can not only keep up its production during a great number of years, but also increase it to a certain extent; for we may be perfectly sure that the art of mining will not stop either before the difficulties of piercing through the thick dead measures which cover the Northern flats, or before those that may be presented by ventilation and haulage at a depth of 1,000 yards, 1,500 yards or more.

4° The Mons basin is further remarkable for the distinctness with which the quality of the coals varies with the depth of the seams.

This change, moreover, takes place in the manner most often observed and which seems to have a relation to the different conditions of temperature and pressure, to which the substances have been subjected and according to which they have been covered with more or less thick deposits.

Thus, the lower seams are more or less anthracitic or dry, and burn with a short flame in consequence of the disappearance of the greater part of the volatile elements; above these come the seams of fat and caking coals, or coking coals, characterised by a larger proportion of volatile elements rich in hydrogen; then lastly come the flaming coals, more or less dry, in which the volatile constituents are more and more charged with oxygen and give rise on distillation to a smaller proportion of hydrocarbon compounds.

2nd EXAMPLE. **Liége coalfield.** — The Liége basin, remarkable as being one of the first where coal was worked on the continent, is a second swelling or spreading out of the great Coal Measure zone which has just been mentioned. The very early working of this basin is due to the fact that the Coal Measures crop out to the surface in many places instead of being covered over, as they are almost every where at Mons, by dead measures difficult to pierce through.

Figure 36 is a section nearly North and South on the same scale as the preceding one. Compared with that of the Mons basin it exhibits certain analogies and certain differences.

The width of the basin is not very different, although that of the Mons basin is a little greater. The number of workable seams is smaller, but nevertheless considerable. The lists which appear to be the most exact give 116 at Mons and 83 at Liége.

The section, moreover, shows that here also the principal movement which disturbed the seams after their deposition was felt on the South side of the basin from a pressing back which produced some folds. This movement even brought up lower rocks so as to overlie the Coal Measures. We can also distinguish a region of rearers and flats in the South part of the basin which only shows the lower seams, followed, as we go northwards, by a great trough-like undulation, which corresponds to the great Northern and Southern flats of the Mons basin and which includes the complete series of seams.

The surface of the soil is more broken at Liége than at Mons; nevertheless its outline is far from corresponding with the peculiarities exhibited by the seams of coal in the bosom of the earth. This outline is even less broken in the district of the rearers than it is more to the North where the seams are less disturbed. The signs of denudation on a very large scale are here also easily to be recognised. Thanks to this action, the upper seams have been entirely removed over all the Southern part of the basin and the lower seams exhibit by their folds a series of outcrops belonging alternately to a flat and a rearer. Between two consecutive outcrops of a seam it happens alternately either that the seam exists in depth or that the hook that united the corresponding flat and rearer existed above the present level of the ground, so that the upper parts of the flat and rearer forming the hook have been carried away by denudation.

The seam, therefore, no longer exists between the two outcrops. The miner expresses this by saying that the seam makes its hook *in the air*.

Figures 35 and 36 give examples of both the above arrangements in the Southern parts of the sections that they represent.

It will be noticed that the Liége basin is crossed by a series of faults nearly parallel to the strike, the most important of which (that of Saint-Gilles) is known for a very great distance. These faults have a throw in the direction of the obtuse angle or according to Schmidt's rule.

The Liége coalfield, on account of having been worked at an earlier date and containing fewer seams, has not the same future before it as the Mons basin; nevertheless great riches still remain there.

We cannot distinguish in the series of seams the same regular succession of qualities as in the Mons basin. The quantity of fat coals fit for making coke is relatively much greater; or in other words the anthracitic coals and the dry coals with long flame are not developed there as at the base and top of the Mons coalfield.

(45) 3rd EXAMPLE. — **Newcastle Coalfield.** — This coalfield, one of the largest in England, is remarkable for its great extent rather than for the number of its seams. In fact not more than a score of workable seams are reckoned in the whole of the coalfield and generally not more than a dozen *in a given point of this basin*; they are however thicker than in the Mons and Liége coalfields. Their average thickness is decidedly more than 3 feet and that of the two principal seams (High main and Low main) reaches two yards ($1^{m}\cdot82$). These thicknesses, as will be seen further on (chapter XI), are exceedingly favourable for working.

Besides, the Coal Measures are very little disturbed from their original position, which is also an advantageous circumstance in working, as much from the point of view of the cost as from the fact that a very large daily output can be obtained from a working area of given extent.

Lastly, the enclosing rocks are generally firm enough to require only a very small expediture of timber in props, compared with what has to be used in *rearing* seams, especially in Belgium.

The measures are frequently intersected by faults, or dykes, striking East and West. The most remarkable of these is the ninety fathoms or Main dyke, which throws the beds vertically about 180 yards (165 metres). It furnishes another example of the magnitude with which, as has been remarked at different times, the denuding agencies have operated. It is evident, in fact, that after the formation of this throw the surface of the ground must have presented a great escarpment formed by the rocks of the foot wall. At the present day this escarpment has entirely disappeared, so that on the two sides of the fault the surface of the ground is absolutely level and covered by the waters of the same marsh.

Figure 57 gives a section from North to South of part of the Newcastle Coalfield. The regularity of the seams compared with the disturbed outline of those of the Liége and Mons Coalfields will not escape notice. The great fault just mentioned is shown on the section.

(46) 4th Example. — **The Gard Coalfield (concessions of the Grand'Combe)**. — Figure 58 is a section made along a broken line, on an average in a North-West and South-East direction, across the principal part of the Gard coalfield, which rests to the East and West on mica-schist and disappears on the South under a covering of Triassic rocks.

The Coal Measures here closely resemble those of the centre and South of France, and differ from those of Belgium and the departments of the Nord and Pas-de-Calais by the lithological characters and peculiarities of the strata. The sandstones and conglomerates are much more abundant and the shales, on the contrary, very much rarer.

The seams of coal are less numerous, but individually very much thicker.

It is thus that in the Grand'Combe mines two distinct zones may be clearly distinguished, separated by a great interval of 528 yards

(500 metres), formed principally of beds of sandstone with scarcely a trace of coal.

The lower zone contains only 3 seams, but one of these is 36 feet (11 metres) thick.

The upper zone contains 11 seams. The total thickness of these 14 seams exceeds 98 feet (30 metres) and consequently gives *per acre of Coal Measures* a smaller quantity than the Mons and even the Liége Coalfields, but a *larger quantity than the Newcastle Coalfield.* However, the area occupied by the seams and in fact the total richness of the coalfield are less than those of these other basins, although for the commerce of the South of France and the shores of the Mediterranean it is of considerable importance.

It will be remarked on the section that the seams are generally pretty regular in the Western part of the coalfield. This part is separated from the Eastern district by a great fault, which, if one is coming from the West, must be looked upon as having a downthrow East, bringing the upper zone against the lower, and producing a change of level of more than 328 yards (300 metres). The section also shows that this great throw is in connection with a rearer which only affects the seams of the lower zone. The fold must have affected the upper seams also, but in the place where the section is taken they have been removed by denudation.

(**47**) 5th EXAMPLE. — **Ronchamp Coalfield.** — The Ronchamp coalfield (Haute-Saône) is deposited at the Southern foot of the Vosges; it crops out only in the Northern part and soon disappears to the South under Permian and Triassic rocks. Although much less developed than the preceding coalfields it is of considerable local importance on account of being near the industrial district of Mulhouse.

It contains only two seams of coal, and even the lower one of these does not exist everywhere. It has, on the contrary, a marked sporadic character, which may be attributed to the fact that, being near the base of the Coal Measures, it was formed at a period when the inequalities of the older rocks, on which the Coal Measures rest, were not yet everywhere covered over by the new deposit in course of formation.

The section (fig. 59) shows several protuberances or bosses, of which the two principal are the intersection, in the plane of the section, of two disturbances nearly parallel to the strike of the beds which have been crossed by the workings as they proceeded in depth. These protuberances must apparently be considered as having been formed after the Coal Measures, or at least as having been increased since their deposition, on account of the manner in which the beds are bent on approaching them.

It is not yet known what becomes of the seams to the dip, beyond the second of these bosses.

The section (fig. 59) is drawn like the preceding ones on the scale of 1 to 25,000, so as to facilitate by the mere inspection of the figures the comparison of the different coalfields which have been mentioned.

The above examples, the number of which might be greatly multiplied, will suffice to show, while keeping within the general terms to which we are bound, under what various aspects with regard to extent, number, thickness, and principal peculiarities, seams of coal, which we have considered as types of *stratified deposits* (*), may occur.

(**48**) 6th EXAMPLE. — **Metalliferous district of Przibram (Bohemia).** — As an example of deposits in lodes, forming a complex system, we will first of all cite the district of Przibram, in Bohemia, which, though abandoned after having been worked for many centuries, was taken up again in 1848 by the Austrian government. It employs at the present time several thousand workmen and some of the mines have already attained a depth of more than 400 fathoms (**).

The numerous lodes of this district have very various strikes which may be referred to four principal directions, viz N. 45° W.,

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(*) Information upon this interesting subject will be found in numerous monographs in the *Annales des mines* and other technical works, and especially in that of M. A. Burat, entitled *Les houillères de la France en* 1866.

(**) The Adalbert Shaft, which is perpendicular, has reached the depth of 546 $\frac{3}{4}$ fathoms (1,000 metres) from the surface. *Translators.*

N. 10° W., N. 8° E., N. 24° E. The lodes appear to have been formed in the above order, each of these systems being generally thrown, in the case of an intersection, by the following system.

These deposits belong evidently to the type of concretionary lodes, as is shown by their structure in bands parallel to the walls, the superposition of which indicates the order in which the different substances arrived or were deposited. In some places, instead of the ores being distinctly separated, they form intimate mixtures with the quartzose veinstone constituting a sort of quartzite impregnated with metallic sulphides; this character denotes a rapid filling up by a saturated solution; which would have formed an immediate deposit or have congealed, so to say, into a sort of confused mass. The composition of the filling up is very complex and exhibits no less than sixty-four different combinations, which may be classed under three periods of filling up. The first is characterised by the arrival of metallic sulphides with quartz, the second by the arrival of a barytic veinstone, and the third by the arrival of a calcareous veinstone, the late deposition of which is proved by its often enclosing angular fragments broken off from the former filling up.

The lodes very often exhibit well marked gossans at their outcrop and traces of oxidation in depth to more than 100 fathoms from the surface. They thus unite all the principal peculiarities enumerated in the preceding chapter, and form a series of deposits of a kind of standard character.

Figures 40 and 41 show a plan and section of one of the principal mines of the country (Maria-Adalbert Mine). The section affords a good example of a net-work of lodes and branches and the plan shows what kind of idea ought to be formed of the rectilinear course of a lode and the parallelism of two given lodes (*).

(49) 7th EXAMPLE. — **Metalliferous district of Saxony or the Erzgebirge.** — The lodes of the Erzgebirge form another example of a great system of mineral veins, no less standard, while at the same

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(*) See Article by MM. Michel Lévy and Choulette, *Annales des mines*, 1re livraison 1869.

time more extensive and more complex, than the preceding one.

The Erzgebirge constitutes a mountain mass ending off on the Southern side by an abrupt slope, at the foot of which stretch out the Tertiary rocks of Bohemia, and forming on the North a slightly undulating plateau of gneiss, mica-schist and clay-slate. This range of hills is cut up in divers ways, and bounded at its base, by the most various eruptive rocks (granite, diorite, porphyry, trachytic and basaltic rocks, etc.) belonging to very different ages. This diversity shows plainly that the earth's crust in this district has been subjected to frequent disturbances, and that many of the phenomena of elevation, which have been produced at more or less distant points and at divers epochs, have resounded there; the last echo, so to say, being the numerous hot springs which are evidently connected with the most recent eruptive rocks.

This diversity and succession of phenomena explain at the same time the large number of lodes occurring in this district and their very various and complex fillings up due to their frequent reopenings.

Figure 42 is a plan on a reduced scale of the whole of the lodes in the immediate neighbourhood of Freiberg. The result of a long series of observations has been to classify these lodes according to three principal directions, making angles of 8°, 24° and 64° with the North and South line (on the East side) and two comparatively rare directions making angles of 49° and 80°.

The system at 24° is the most important both by itself and by its enriching influence when it meets the other systems. It occupies a zone more than 9 miles long by 2 miles wide.

We may furthermore distinguish four directions of cross lodes, much less continuous than the preceding ones and running in a totally different manner, as these directions, 99°, 116°, 126° and 160°, always make an obtuse angle with the North and South line.

The first lodes exhibit a series of periods of filling up in which eight successive epochs may be distinguished. The first, or oldest, is characterised by the arrival of the metallic sulphides (blende, more or less argentiferous galena, iron pyrites and mispickel) and the last by the arrival of the silver ores. The first appears to be contemporaneous with the Trias and the last probably took place towards the close of the Tertiary epoch.

The successive shocks appear to have occurred at intervals during the long Secondary and Tertiary periods and perhaps extended even into the Quaternary period.

The first important metallic products would correspond to the Triassic epoch, which seems to have been everywhere a remarkably metalliferous period, and the last, which are characterized by the relative abundance of the precious metals, would be *very modern* (although situated in the very ancient rocks of Saxony), as appears to be generally the case with similar products in America.

Casting a glance on figure 42, it is easy to understand how such an extensive and complex net-work of fractures has given rise in the past to the numerous phenomena of intersections, re-openings and successive fillings up observed by the miner; and at the same time we shall understand how that which has been *an effect* in the past may become *a cause* in the future. In other words, a district which has been the scene of so many successive dislocations is on that account all the more liable to experience the rebound of new disturbances of equilibrium which may occur within a sufficiently short radius.

(50) 8th EXAMPLE. — **District of Cornwall.** — The metalliferous district of Cornwall is distinguished from the Erzgebirge by the nature of its products, which are ores of copper and tin (instead of being principally ores of lead and silver), and by a greater simplicity of the deposits worked.

However, the same general conditions are found there : particularly an evident relation, as to their position and general course, with divers granitic masses arranged very nearly in a line running E. 25° N.; equally well ascertained relations between the richness of the lodes and the nature of the enclosing rocks, and, lastly, a certain change of nature with the depth, consisting generally in the relative increase of copper ore compared with that of tin (*).

(*) At present the copper ore has been diminishing in quantity and giving place to tin ore as the mines have been deepened in the Camborne district. *Translators.*

Figure 43 is a section, on the same scale as figure 40, of one of the principal mines of Cornwall [Fowey Consols (*)].

A comparison of these two sections shows plainly a very great analogy in the general arrangement exhibited on the whole by these lodes, although they occur in two places very distant from one another and were probably formed independently.

These two figures may be looked upon as constituting a sort of type, which will be approached more or less by the peculiarities which we may expect to meet with in a group of well developed mineral veins.

The Cornish mines have been worked for a very long time. At a remote epoch the Phœnicians came to Cornwall to get their supplies of tin, which was obtained by treating the alluvial ore; this *stream-tin* is still worked in some places at the present day. Underground mining was subsequently resorted to, firstly for tin and then for copper.

Many of these mines are interesting on account of their large plant and especially their pumping machinery. It is in Cornwall that steam was first employed for draining mines on a large scale; and a long series of practical trials have led to many improvements resulting finally in the type known by the name of the *Cornish Engine.*

(**51**) 9th EXAMPLE. — **Deposit of Montchanin (Saône-et-Loire).** — As an example of a mass deposit we may quote the colliery of Montchanin which belongs to the Southern part of the great coal-field of the department of Saône-et-Loire.

The principal mass worked occurs in the form of a swelling about 550 yards (600 metres) along the strike, 50 yards and more in thickness in the middle, and 160 yards (150 metres) along the dip, which is directed northward at an angle of 70°. The horizontal sections (fig. 44), taken at two different depths, give an idea of the remarkable peculiarity of this deposit.

It has been discovered that the principal mass is accompanied by

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(*) Not at work at the present time. *Translators.*

other less important masses, situated in the same general plane of stratification. The whole, in fact, is nothing but a large seam, or series of seams close to one another, which in other parts of the coalfield have their regular course, but which at Montchanin have been folded so as to form a remarkable example of *beaded structure* on a very unusual scale. An exact idea will be formed of the arrangement affecting the principal Montchanin deposit by looking upon it as a great swelling, produced in a series of seams separated by thin partings of shale in the manner pointed out in N° **16**. The mass in question comes altogether, therefore, as far as its origin is concerned, into the class of stratified deposits; it is *a seam with a beaded structure* if we consider it as a whole, *a mass* if we consider particularly the great swelling of which we have just spoken.

The mode of occurrence described for Montchanin is found again at Creusot situated on the North side of the same coalfield.

Taking the whole of the coalfield, this peculiarity is only a local occurrence, because in other places, especially at Blanzy, the seams of coal are found to be quite regular, or at all events they are only disturbed by sharp faults which do not, as a rule, alter their thickness and in no wise recall the beaded structure.

(**52**) 10th Example. — **Deposit at Mokta (Algeria).** — The deposit of Mokta el Hadid (Algeria) has been worked for some years, and in 1872 yielded 372,000 tons of iron ore exported entirely from the port of Bône. It occurs in the form of a great mass cropping out at the surface on the side of a hill, and appears to be stratified conformably with the old garnet-bearing schists on which it lies.

The horizontal distance from one wall to the other is sometimes as much as 72 fathoms (130 metres); but the true thickness of the mass, which has but a small dip, is from 50 to 65 feet (15 to 20 metres). In horizontal section it is roughly elliptical in shape with an average area of rather more than 2 ½ acres (1 hectare). It has been proved to extend in this manner for a vertical height of 50 fathoms.

This mass in reality is only an accidental swelling of a bed which has already been followed in a level for 500 fathoms to the North-West with an average thickness of 16 feet 4 inches (5 metres), and which probably extends also on the opposite side to the West or South-West.

This bed is connected with a great bed of limestone which occurs interbedded with the schists, the second in ascending order of the 5 or 6 similar beds which succeed one another in the known thickness of the schistose formation. The iron ore merely appears to form extensive lenticular masses in the bed of limestone, as if more or less abundant chalybeate springs had come out in different parts of the basin where the rocks were being deposited. The Mokta mass was probably formed near the outflow of one of these springs.

Similar deposits occur in other parts of Algeria, especially at the Kharezas, although it is not possible to say that the ore is continuous from Mokta to the Kharezas, a distance of 12 miles. It seems as if discontinuity were the more probable condition, in spite of the evident analogy and very probable synchronism of the formations.

It is under similar geological conditions that we find the deposits of Sardinia, and probably those of Anjou, Sweden, and Lake Superior; so that the deposition of these ancient rocks appears to have been accompanied in various places by considerable ferruginous emissions, analogous to those that have occurred at other epochs. These different deposits would, therefore, be identical, as far as origin is concerned, with the ores that are known in the Secondary rocks, such for instance as those of the North-East of France already mentioned (N° **41**) and which occur also in other places in great abundance, especially in the Cleveland district of England; they are, however, very different in appearance on account of the metamorphic action to which they have been exposed, and different also by a usually higher percentage and superior quality.

(**53**) 11th EXAMPLE. — **Deposit of the Stahlberg near Müssen.** — As another massive deposit of iron ore, we will cite the celebrated deposit of spathose iron ore at the Stahlberg, a section of which is shown in figure 45. This deposit, like the preceding, is remarkable for the quality of the ore; it furnishes the variety of cast-iron known as *Spiegeleisen*, a special market for which is insured by the great development which the Bessemer process has received of late years.

(**54**) 12th Example. — **Deposit of iron ore of Saint-Pancré (Moselle)**. — In the same district as the immense deposit of iron ore mentioned in N° **41**, many other deposits occur; but they differ essentially by their age which is much more recent, by their mode of formation, by their extent which is comparatively limited, and lastly by their superior quality and richness.

These deposits are masses, or rather a series of masses, occurring in hollows or spread out on the surface, the origin of which is exactly like that of the ores improperly called alluvial, described in N° **39**.

Instead of a stratified deposit like the oolitic hydrous peroxide of which we have spoken, we have a *massive* deposit formed by a process analogous to that which has produced *lodes*.

Furthermore, the former class of deposits, the oolitic brown iron ores, have a tendency to give a granular iron, on account of the phosphate of lime contained in the fossils which may frequently be seen in them; whilst the latter have a tendency to give a fibrous iron, on account of the sulphur which is rarely absent in these massive deposits of iron ore.

Figure 46 exhibits a section of one of them, viz., that of Saint-Pancré. It shows that the different pockets or cavities, composing the deposit, have, in spite of their irregularity, a certain tendency to arrange themselves along certain definite lines. These deposits in a line must be looked upon as cracks which have been filled by solution. They constitute, therefore, true lodes as far as their origin is concerned, and the beaded structure is due to variations in *solubility* in the surrounding rocks from one point to another or, variations in *composition* of the acid liquids they contained; in this manner one or several series of masses were produced, with various dimensions, united to one another by more or less narrow channels.

(55) The different examples given above point out the mode of occurrence of stratified deposits, deposits in veins or lodes, and, lastly, massive deposits, having either the same origin as a bed, or the same origin as a lode, but differing from them in not having the same geometrical characters.

We see what extreme variety may be exhibited by these deposits in their extent or their detailed peculiarities, and we can understand that, in forming an estimate of the value of any given deposit, no *à priori* theoretical considerations can make up for the want of direct observation of the facts.

The course to be followed in making such observations, and the right estimation of the consequences to be deduced from the facts ascertained are things with which mining engineers should render themselves familiar. The first can be explained systematically, as will be seen hereafter; but the second is eminently *peculiar to the engineer;* it requires general theoretical knowledge, a certain natural acuteness and also acquired experience for which nothing else can make up.

We insist upon this last point, and we consider that the education of a mining engineer is not complete from the point of view in question unless he has examined *for himself*, *down to the very smallest details*, a large number and a great variety of deposits.

CHAPTER III.

PROSPECTING OR SEARCH FOR MINERALS AND EXPLORATORY WORKINGS.

(**56**) In the two preceding chapters we have seen how the differents deposits of mineral substances are supposed to have been formed, and what very various peculiarities they may exhibit, in consequence of their origin and of the numerous disturbances to which hey have been subjected, either during, or after their formation.

It may be truly said that the discovery of mineral deposits, at all events of such as have been worked for some time, has generally been due to external indications observed accidentally; in the present state of the art, however, we may consider that we possess a certain number of data, by means of which the miner may *assist chance*, if this expression is allowable, and proceed systematically and rationally to carry out works, which enable him, first of all, to prove *the material existence of a deposit in a given point*, and then, what is equally indispensable, to ascertain *in what measure it will pay for working.*

We shall designate by the name *prospecting* any work which the miner undertakes in order to prove the material existence of the deposit, and by *exploratory workings* those workings which he carries out on the deposit itself and which he generally has to make in order to decide whether the deposit is capable of being worked with profit.

§ I. — Prospecting or search for minerals.

(**57**) The search for minerals in any given district should not be undertaken unless there is some previous indication as a reason for it; because, save the most ordinary building materials, the mineral substances to which the art of mining is applied are sparingly distributed in nature; and in any given point of the earth's surface we are authorized to suppose, *à priori*, that these substances do not exist.

More or less proximate indications of their existence may be deduced :

1° From a knowledge of the geological structure of the country;

2° From the presence at the surface of the ground of fragments of veinstone or of ore;

3° From the presence of the outcrops;

4° From material traces or traditions of ancient workings;

5° Lastly, from the existence of deposits which are now being worked in the neighbourhood.

It is advisable to give a few details on the value which should be attached to each of these indications.

(**58**) The geological structure of the ground sometimes furnishes *positive*, sometimes *negative* indications.

It is evident, for instance, that the existence of an igneous rock, such as granite, shuts out the possibility of there being coal *at the same point*; but this conclusion only holds good *for the very point under consideration*; and it is known, for instance, that a large number of more or less developed coalfields in France are scattered over the primitive central plateau, and thus rest either upon granite itself or upon such ancient rocks as gneiss or mica-schist.

As an example *of a positive indication* it may be said, on the contrary, that the presence *of the Coal Measures, properly so-called*, may fairly lead us to suppose that coal is present also. It is rare, in fact, unless in the case of a mere insignificant patch of the rocks, that the Coal Measures do not contain some workable seam of coal, and we have seen from the example of the Belgian coalfields that they sometimes contain a very large number.

It may also be said that the existence of Permian rocks may lead us to conjecture the presence of copper; that of the Trias, and more especially of the Variegated Marls, the presence of rock salt (at all events in the North-East of France); that of the supraliassic Marls the proximity of iron ore (North-East of France, Cleveland, etc.) It is evidently the business of geology to furnish these indications, which, on account of their generality, have by themselves only a secondary value for the miner in practice.

(59) The presence at the surface of the ground of fragments of useful substances (*shoad-stones*), or even of sterile substances known to be often associated with the first, is an indication which deserves to attract attention. In prospecting a country, an examination should be made of all denuded parts, escarpments, sides of valleys, etc., and particularly of ravines and beds of the different water courses.

Standing in the bed of a torrent we find everywhere, in some measure, a collection of mineralogical specimens derived from all the region higher up. Each mineral species has its own value from the point of view under consideration. Among rocks consisting of mica-schist, for instance, we shall attach very little importance to fragments of quartz with a simply resinous or even saccharine fracture, as this substance frequently occurs interposed in reniform lumps between the folia of the schist. Well crystallized quartz will deserve more attention.

Substances that are foreign to the composition of the rock and known to be pretty commonly veinstones of lodes, such as calc spar, fluor spar, barytes, etc., will deserve still more attention.

The same thing will be the case, *à fortiori*, if spots of pyrites, or galena, or any traces of a green colouring due to the decomposition of copper ore, etc., are found on breaking these fragments.

In carrying out observations of this kind it is necessary to ascend the beds of the torrents step by step, examining the sand and pebbles carefully and minutely in order to ascertain how high up the fragments, which awakened attention by their special nature, are found, and thus to discover the point whence they are derived. An idea of the distance of this point may be formed from the more or less rounded shape of the fragments, due consideration being paid to their hardness.

When this point has been discovered it will only remain to examine whether the substances noticed have a purely adventitious character in the rock, or whether they belong to a deposit apparently of some extent. This verification is quite essential, for the first case is perhaps that which presents itself most frequently to the observer.

Mineral springs furnish us with indications with regard to soluble substances, analogous to those obtained from fragments of rock concerning insoluble substances. It is thus that brine springs, or springs charged with chloride of sodium, have led to the discovery, in the East of France, and especially in the department of the Meurthe, of thick beds of rock salt which are being actively worked at the present day.

(**60**) If by direct observation, or by proceeding in the manner described in the preceding paragraphs, we have ascertained the presence of an outcrop, this outcrop should be made the subject of a special examination. As the lode is *of a different nature* to the enclosing rocks and has been exposed to *the action of the same atmospheric agents*, it will not have resisted in the same way. It will often appear at the surface, either as a hollow or in relief, according as its hardness is greater or less than that of the enclosing rocks. It is in this manner that hard quartzose lodes are seen standing out above the surface of the ground in the form of prominent walls many feet high running sometimes for a distance of several hundred yards. These outcrops are a certain indication of the presence of a lode; but as a rule they do not give any information about its richness, since the metallic substances have generally been oxidized and removed in the state of soluble salts often leaving behind nothing but an ochreous precipitate, from the amount of which, in certain cases, may be inferred the quantity of certain metallic sulphides, such as iron or copper pyrites, which the deposit originally contained.

This ochreous precipitate itself is often absent, and the outcrop only shows by a few slight accidental discolorations any sign of its original richness in ore. Even if an outcrop contains no ore whatever, it is still worthy of investigation if it exhibits a certain continuous character. Therefore the first care, after having lit upon some point of an outcrop, should be to make sure whether this continuity exists.

In case it is not apparent at the surface, a few pits may be sunk to endeavour to ascertain the strike and dip of the deposit and to infer from these, allowing for the outline of the ground, the approximate position of the line of outcrop. This line should be staked out, and efforts should be made to discover other points of the outcrop by digging trenches at intervals, at right angles to its presumed strike, and carrying them down till rock in place is met with.

When at least three points of the outcrop, not very far apart and situated at different levels, have been determined in this way, a plane passing through these three points, in the case of a lode or bed, may be taken provisionally, on account of possible disturbances of the deposit between these three points, as representing the position of the deposit in the bosom of the earth; it will also serve as a basis for settling upon the best manner of exploring the deposit in depth.

If it is a massive deposit with two comparable horizontal dimensions the preliminary excavations should be carried on so as to circumscribe it in every way.

(**61**) It may happen that the presence of the deposit is indicated, not by an outcrop the existence of which may be actually ascertained, but by the vestiges of old workings which removed this outcrop, were extended more or less in depth, and are no longer apparent at the surface, save by more or less irregular excavations and heaps of *attle* or refuse, left by the ancients or "old men".

These indications may be rendered complete by heaps of slag resulting from the metallurgical treatment of the ore, by the ruins of stamps or of furnaces and, lastly, by more or less precise traditions concerning the former workings and the reasons for their having been abandoned.

This set of data deserves to be examined with attention and prudence. The remains of heaps of refuse and slag will furnish, from a mineralogical and metallurgical point of view, indications concerning the nature of the ores and of the veinstones.

Endeavours should be made to penetrate into the old workings, not so much in order to find the ore *in situ* (because it has generally been very thoroughly removed by the "old men") as to obtain a general idea of the nature of the deposit.

Lastly, we should try to find out, as far as the traditions permit, the true reasons of the abandonment of the workings. Tradition is often quite silent on this point, or only gives very vague indications, without any appearance of authenticity or precision.

It is thus that we find traces of immense old workings in Spain attributed to the Phœnicians; in Greece works have been put up the principal object of which is to treat again the old lead slags derived from smelting ores that were worked for several centuries by the republic of Athens. It is thus also that in France all old workings, about which there is no positive tradition, are invariably attributed to the Romans, although mining appears to have been practised by the Gauls before the conquest. Other more modern workings are reputed in France to have been made by the English, and are said to have been abandoned either during the Hundred years war, or later, during the religious wars. This latter case, for instance, appears to be that of a certain number of metalliferous mines of the Aveyron; Germans had been brought to work them and after Saint-Bartholomew were expelled as being both foreigners and protestants.

When the abandonment is not due to political events, it should be asked whether it is due to the exhaustion or impoverishment of the deposits in depth, or to material dificulties such as those of drainage, which increased as the workings became deeper and more extensive. It may be said that we have machinery at the present day, that was then unknown, for dressing the poor ores finely disseminated through the veinstone, for raising the ore from underground and for draining the workings; it may further be said that the use of powder has effected a great economy in breaking ground. These favourable circumstances, however, may be compensated for and even overbalanced by one single fact of considerable importance, viz., the enormous increase that has taken place in the price of labour.

It is no answer to this last observation to say that these things have merely a relative value and that it matters little if the rate of wages has risen, provided that *a proportional increase* has shown itself upon all the other articles of commerce.

In reality this proportionality does not exist in regard to labour. In the Middle Ages, for instance, labour was abundant or *offered;* metals on the contrary were rare or *in demand.* Nowadays the conditions are reversed, and the general economic law by which *supply* and *demand* are bound together cannot fail to produce its natural and certain effects, although its action may be altered by force for a moment.

The examination of the circumstances which have led to the abandonment of a mine requires, therefore, to be made with discrimination. It is certain that mines have been abandoned more than once in consequence of the rise in the price of labour, or, speaking economically, in consequence of what comes exactly to the same thing, viz., the relative depression that has taken place in the price of metals.

A depression of this kind in the value of silver occurred at the time of the discovery of America and caused many mines in Europe to be abandoned. A similar depression is in a fair way to be produced gradually in the value of gold, in spite of everything, since that metal has been so largely worked in California and in Australia.

We must, therefore, admit that it is possible for a mine to have been worked at a profit formerly, whilst now it would no longer pay, even if it were supposed to be virgin ground and it were simply a question of doing now exactly the same work that was done then. We insist upon this point, because people are often too apt to exaggerate the consequences of the technical progress attained in the art of mining, and to believe that what has been *done by the "old men"* may *on that account and à fortiori* be done by us. This is evident *from a material point of view;* but as, even at the present day, the direct labour-cost amounts to at least one half, if not two thirds or more, of the value of the product, in spite of the more extended use of machinery, it need not be so *from an economic point of view*, if the cost of labour for a given quantity of a product has increased more rapidly than the saleable value of this quantity. A certain silver mine, for instance, could be worked formerly at a profit, when the average produce for every workman employed was, we suppose, 5 *dwts*, and his daily pay equal to 5 *d.;* whilst nowadays it would be no longer workable, even if technical improvements have doubled the individual produce from each workmen, if his pay amounts to, or exceeds 1 *s.* 8 *d.*

(**62**) Lastly, the inferences drawn from the existence of deposits worked in the neighbourhood are worthy of consideration and have often led to very important results.

In the first place, attention should be paid to the principle already mentioned of *the parallelism of the deposits*, which means, in a general manner, that a deposit worked in a given point renders *probable* the existence of one or more deposits related to it; this probability is sufficient, theoretically and of itself alone, to justify prospecting or searching on both sides of this deposit. It is explained, as we have said, *for a bed*, by this consideration, that the circumstances which have produced a certain bed, peculiar by its character or composition, may have been more permanent, less ephemeral, than those which have caused the mere simple deposition of sediment; *for a lode*, by this other consideration that one of the great disturbances of equilibrium, such as have taken place in the earth's crust, would generally produce not a simple fracture but a system of parallel fractures, or even several systems of fractures arranged according to definite directions. (See N^os^ **28** and **29**.)

In the second place, the comparison to be made may present itself under another aspect, in this way, that instead of searching for deposits parallel to a given deposit which is being worked, we should look for the continuation of this deposit itself in places where it is not seen. This, for instance, is what will happen if the Coal Measures, on one side of a coalfield that is being worked, are seen to dip and disappear under a covering of more modern strata.

How far do they extend under these rocks? Is there not a hope, if we can penetrate through these rocks by suitable workings, of finding and utilizing the Coal Measures on which they rest?

These are not purely theoretical speculations as might be supposed; they have, on the contrary, a very direct practical interest, and very important consequences have often arisen from them.

Thus it is purely and simply to the application of them that we owe the existence of the collieries of the departments of the Nord and the Pas-de-Calais, which nowadays form the most important group existing in France.

This group was completely untouched and even unknown 150 years ago when the collieries of Belgium were already known along the long zone which extends from Liége to Mons. On arriving near the French frontier, the Coal Measures, already partially covered over at Mons, disappeared entirely under a continuous mantle of barren or dead rocks (see N° **43**). The idea naturally arose of searching for the continuation of the coal zone, following the direction that it has in Belgium, between the frontier and Valenciennes, and then between Valenciennes and Douai. This is what has been done, but not without very great labour, on account of the watery nature of the dead measures that had to be traversed. The result of these labours has been, firstly, the creation of the Anzin mines which are in the hands of a powerful company, without rival in France, and, as far as concerns output, not second in importance to any in the world, and, subsequently, the creation of the Aniche mines which are also, at the present time, on the high road of development.

This was the state of things up to about 1855. In order to satisfy the wants of an increasing consumption, the consideration which a century beforehand had led to the discovery of the Coal

Measures on French soil was once more taken up, and a further continuation was sought for in the same direction, that is to say in the neighbourhood of Arras. These explorations did not succeed until it was ascertained that the general direction of the zone of Coal Measures bent towards the North after leaving Douai and passed, not by Arras, but by Lens and Béthune. Once on the right road, people set to work prospecting vigorously, and gradually advanced westwards; it is thus that, within the last twenty years, the fine mines have been created which mark out to a certain extent on the surface the subjacent Coal Measures from Douai to a point West of Béthune.

These same considerations have also been applied of late years in the department of the Moselle, in order to find the continuation towards the South-West of the great Sarrebruck coalfield, which was seen to disappear under more modern rocks in the neigbourhood of the French frontier.

Important results had been obtained by various French companies, which had been formed for the purpose of prospecting and had already ascertained the existence of the Coal Measures, at accessible depths, over more than 46 square miles. These territories, however, were wrested from France after the unfortunate war of 1870. The same jealous care which presided over the fixing of the limits of our frontier in 1815, so as not to leave in France any known part of the coalfield, stripped us in 1871 not only of the continuation which we had discovered, but also, as far as it was possible, of the great deposit of iron ore mentioned above (N° **41**) and of the principal works which had been put up for smelting it.

In our opinion, what has been done in the departements of the Nord and the Pas de-Calais, as well as in that of the Moselle, may be repeated in other parts of France, although perhaps on a smaller scale, and we have here a class of considerations which should not be lost sight of, as they may yield important results in more than one instance.

§ 2. — Exploratory workings.

(**63**) We will suppose that workings carried on in the spirit of the above observations (N° **58** *et seq.*) have led the prospector to prove the substantial existence of a deposit in a given point. If the deposit crops out, this verification has been made by simple excavations at the surface. If the deposit does not crop out, on account of its being covered over by more modern deposits, it has been reached either *by pits* (the process adopted in the last century for discovering the Coal Measures of the department of the Nord) or in a more rapid and less costly though also less precise manner, *by one or more bore-holes*, made by processes which will be described further on and which have been employed of late years for prospecting in the Pas-de-Calais and the Moselle. It now remains to examine whether the deposit in question can be utilized commercially, that is to say, whether it admits of being worked permanently or at all events for a certain length of time. A condition to be satisfied, which is *necessary* though not sufficient, is that it should be of an adequate extent, *i. e.* possess a certain continuity, a certain stability, without which it would evidently never pay the first costs incurred in starting the mine.

(**64**) In the case where the deposit crops out, after having got all the information that can be derived from the geological examination of the ground, from a few trenches made for studying the outcrops and from penetrating into the old workings, the next thing to be done is to attack and explore the deposit in depth.

The attack may be made either by adit levels or by shafts.

If the contour of the ground permits it, the attack by an adit has the advantage of reducing the expense of the first starting and carrying on the work, because there is no cost for putting up machinery at first, and no cost for lifting the mineral or pumping water. The adit may be begun on a point of the outcrop of the deposit and be a level along the strike, or else it may be outside the deposit and driven at right angles to its strike; this is what is called a *crosscut.*

The level on the deposit has the advantage of studying it as we proceed, the crosscut that of studying the *country*, and, consequently, of discovering parallel deposits if there are any.

The choice between these two systems of attack depends essentially on local conditions.

The exploration on the deposit itself ought to consist of drivages made at different levels, joined by winzes, and a few short crosscuts driven into the two walls so as to determine thoroughly the strike, the dip and the true thickness of the deposit, as well as the manner in which the substance to be worked occurs distributed in it.

An attack by adits cannot always give very decisive results if there are old workings on the deposit; for these old workings often go down to the level of the neighbouring valleys or even below, and it would be necessary to go much too far away to obtain a starting point and consequently to drive far too long an adit, if one wished to make it a *sine quâ non* to reach the deposit in some virgin part below these old workings.

This would cause an expenditure of money and especially of time which it may be expedient or necessary to avoid. In such cases the attack is made by a shaft.

An inclined shaft may be sunk, starting from some point of the outcrop, or a vertical shaft starting on the hanging wall side so as intersect the deposit at the depth at which it is wished to study it.

The inclined shaft corresponds to the level on the course of the deposit, the vertical shaft to the crosscut.

It will often happen that an attack by a shaft will be preferred to one by a level, because the cost of starting and higher price per fathom will be compensated by a shorter length of this work and shorter time in carrying it out, and by the advantage of reaching the deposit at a lower level and of thus obtaining more decisive ideas concerning its nature in depth. Lastly, we may be led to combine both modes of attack, to drive a crosscut and sink an inclined shaft which will meet at a given point of the deposit. This mixed system will combine the advantages of both methods and give special facilities for ventilation.

(**65**) When the deposit does not crop out at the surface, as in the above mentioned cases for the departments of the Nord, the Pas-de-Calais and the Moselle, the most natural course, which, in fact, has been adopted of late years, seems to be to establish the material existence of the deposit by one or more borings which at the same time supply information about the nature and thickness of the barren rocks which cover it, and then to attack the deposit by vertical shafts; these are sunk from the commencement so that they may be subsequently converted into regular working shafts, when once the deposit has been reached and studied, and the possibility of working it has been decided upon.

(**66**) It must be admitted, in all cases, that, exploratory workings require *money* and *time*. Time especially is an *indispensable* element, without which it would be impossible to *solve*, indeed it would be wrong to *put*, the question, whether a given deposit is capable of being worked in a lasting manner.

The question, in fact, does not admit of a positive answer, until it is known whether the deposit exhibits a sufficient extent, and, in this area a proper concentration of the useful substance; and these results cannot be arrived at, with certainty, unless the exploratory workings have been executed on a sufficient scale.

The general question once put, the answer to be made requires an attentive and rigid examination of a mass of technical, commercial and economic questions.

(**67**) We should, firstly, ask ourselves, what is the amount of the expenses that will have to be incurred to start the regular working.

These expenses include, in the first place, the cost of the underground workings and surface works properly relating thereto; of workshops for preparing the substances wrought (dressing floors, patent fuel works, coke ovens, smelting works, etc.); then the accessory expenses for magazines and repairing shops, for lodging the agents and workmen, for recruiting the latter; the expenses for husbanding waterpower and for making roads; the expenses of the financial service until regular work is begun.

(**68**) The second question refers to the net cost of the future workings.

This is a delicate matter, because the net cost generally varies *inversely* (we do not say in the *inverse ratio*) as the amount annually produced, and because this can only be fixed beforehand in a tolerably approximative manner.

The most reasonable hypothesis must be made, and starting from this hypothesis we fix the net cost, taking into consideration the probable general expenses, the direct cost of mining estimated from the indications supplied by the exploratory workings, the expenses for further treatment of the ore estimated either from trials, or from the nature of the ore and a comparison with results obtained elsewhere.

The starting points in these calculations should be the prices of labour and materials in the country; but it must not be forgotten that the workings about to be established may effect very considerable changes in these items.

If, for instance, from the country being thinly populated it becomes necessary to bring in workmen from abroad, then it is not the present price of labour in the country that must be reckoned, but rather that of the country from which the staff is recruited, increased by the premium which will have to be given to the workmen to induce them to leave their homes.

If wood suitable for timbering the mine has not yet any special use in the country, it may be cheap though not abundant. If the mine consumes much, it will become necessary to obtain it from a distance, and the price will be, not the present local price, but that of the country whence it is derived, with the cost of carriage in addition.

(**69**) Where will markets be found? This commercial question admits of very different solutions according to the substance to be worked. Certain substances are in pretty general use, but of small intrinsic value; so that the cost of carriage may easily double, treble, or increase still further the price at which they could be had at the mine itself.

Such, for instance, is the case with coal. The proper outlet for the produce of a given coalfield is the consumption that takes place around it within a radius such as to allow its produce to arrive there at lower prices than those of the coalfields with which it has to compete.

Beyond this radius the resistance met with will increase with the distance from the centre of production, and the amount of sale will depend upon the sacrifices that mine owners of other coalfields are able or willing to make in order to keep up the competition.

If the consumption is small and insignificant within a given radius, there will be no market at all, and the coalfield will necessarily remain unworked, unless, at the time the mines are started, some industry is set on foot to consume the produce, such as iron or glass works, etc.

In fact, at the present day in France there are coalfields, with well ascertained riches, which are waiting for markets, without which it is impossible at present to derive any profit from them, because there is no market on the spot and no means of transport for seeking one at a distance. What we are saying of coal may be said of many other substances, iron ore for instance. The finest deposit of iron ore is not workable unless it is within reach of blast furnaces to consume it; these may either be put up specially to treat it on the spot, or economical means of transport may be established in order to convey the ore to existing blast furnaces.

Thus the splendid deposit of Mokta-el-Hadid in Africa, known for ages, could not be worked until it was connected with a shipping port, Bone, by a small railway of 21 miles, which has no other traffic than the carriage of this ore.

In 1872 the amount conveyed was 372,000 tons as we have said above. Not a single ton would have been raised if it had not been for the railway. On the other hand, without the Mokta deposit there was no reason for making the railway; so that the cost of making the line should be considered as forming part of the expense of first starting the mine.

(**70**) Contrasting with these cumbrous substances of little value on the spot, which cannot be sent about everywhere, and the sale of which has always a certain local character, we must consider costly substances such as certain ores of copper, of argentiferous lead, etc., and still more the metals derived from these ores, in cases where we suppose that the mine devotes itself to the metallurgical treatment of them. These substances travel easily, thanks to their great value for a given weight; they have local outlets only for retail sales, and the sales by wholesale are concentrated in a small number of markets. Thus London is the great market for metallic copper, and Swansea for copper ores; it is thus that lead is principally sold in London, Havre and Marseilles; zinc in Paris and Hamburg; tin in London and Rotterdam, etc.

The prices often vary in these different markets very considerably; but it is usually on account of the general circumstances affecting commerce, and not ordinarily on account of a new mine that has been started, for one mine has not *usually* sufficient importance in itself to influence the prices in the world.

(**71**) An essential distinction should, therefore, be made between mines, according to the nature of the products that they furnish for consumption.

For one kind, the importance of the working is regulated *by the amount that can be sold.*

For others, it is in some measure only regulated *by the amount that can be produced by the mine.*

Setting mines of the *first kind* to work may cause the selling price to be lowered considerably, however little the owners may seek to supplant the produce of other localities in the market.

In the case of the *second class*, we have generally only to take into consideration the usual current prices in a given market and the expenses to be incurred, including carriage, to extract the product and deliver it at this market; the difference will give an idea of the average profit to be realised by the undertaking.

(**72**) Such are the considerations which ought to be uppermost in our minds when we devote ourselves to exploratory workings. It cannot be too often repeated that the subject requires much prudence and caution, independently of the special knowledge of the miner necessary for executing the works and forming a technical estimate of their results.

We should not be afraid of devoting to these preliminary works both the money and especially the time that are indispensable in order to arrive at a rational estimate of the value of a given concern.

In making estimates we ought generally to allow a considerable margin, and consider that the consequence of the regular setting to work of the mine will usually be an increase in the price of labour and materials, and also, at all events in certain cases, a reduction in the selling price.

Lastly, in carrying out all these operations, it must not be forgotten that, taking a given number of cases of prospecting, the greater part do not end in discovering deposits worthy of regular exploration in depth, that of these explorations the greater part likewise do not end in creating regular workings, and that, finally, for these last the profits only represent on an average, in spite of brilliant exceptions, a very small interest on the total amount of capital devoted to mining industry.

We think, however, that a concern of this kind, well studied and well matured, may be quite worthy of the attention of capitalists who are looking for long investments. We think that the consumption of many of the products of this industry, coal and iron for instance, is increasing at such a rate that it is not probable that the means of production will be able for some time to keep pace with it. In more than one place already the day may be foreseen, at no very great distance, when deposits which are nowadays furnishing important supplies will be exhausted. Some coal mines will not see the end of this century, and in a hundred years a large number will be exhausted in their turn. However, others will have to supply the void that they will leave in the production and will also have to face the new wants of consumers, and it may seem doubtful whether they will be able to do so entirely. We think it is therefore evident that capital employed at the present time in an undertaking of this kind is sure to afford eventually, save certain possible contingencies, rapidly increasing profits, provided that the richness of the deposit is sufficient to ensure its being worked for one or two generations.

The prices of labour may rise, indeed certainly will rise; the same thing may happen with many articles of consumption; but at the same time mineral fuel will become more and more rare and sought after. As it constitutes for most industries *an article of first necessity*, as indispensable, so to say, as bread is for the food of mankind, with this difference that we are not able to increase its production indefinitely, it may be concluded with certainty that its price will rise in time, at a greater rate than that of other articles of trade (whether it be a question of labour, of agricultural produce or products of manufacturing industries).

(**73**) Summing up all the different considerations set forth in this chapter, it seems to us that the conclusion may be stated as follows : —

Taking examples from the past, it would indeed be found that mining is one of the industries which have given, on an average, the smallest remuneration for the total amount of capital employed; but there is reason to believe that capital which has remained unproductive has very often been employed without discretion and without sufficiently long preliminary investigations. So that, by *following another track*, that it to say, by not passing too soon from the *exploratory period* into the *real working period*, the capital exposed to the contingencies inseparable from these explorations is limited, and the capital which we resolve to expend subsequently, *after a thorough investigation from the different above-mentioned points of view*, may be looked upon as allowing an estimate to be formed of its probable revenue, quite as exact as that of many undertakings in which capitalists do not hesitate to embark every day.

In a word, mining has always a certain hazardous character which cannot be positively disputed; but if an undertaking of this kind is *well studied* and *well matured*, from the points of view of the engineer, the merchant, and the capitalist, the hazard is found to be greatly diminished, and, provided the results of the investigation are satisfactory, *such a concern deserves every attention from earnest capitalists.*

CHAPTER IV.

PROSPECTING BY BORING.

§ 1. — General observations on Boring.

(**74**). In the preceding chapter we have seen how we may be induced to seek, under the more modern overlying formations, for the continuation of beds of greater or less importance, which crop out and are worked in other localities.

The method which naturally occurs to one as that which should be employed in the first instance, is to sink vertical shafts in the formation to be explored until they reach the bed, and starting from the points where it is met with, to drive a series of exploring galleries along the strike and towards the rise as far as may be thought proper, in order that the continuity and other points affecting the workable condition of the bed may be made sufficiently clear. But the sinking of such shafts might be very tedious and expensive, if the dead measures are thick and full of water. Such an undertaking cannot be entered upon without misgivings, so long as the continuity of the deposit remains only a more or less plausible hypothesis which has not been confirmed by actual observation. It may, and indeed often does happen, moreover, that several parties may be competing separately for the same concession, and that it would be of great advantage to obtain, by active prospecting, the distinction of having *discovered* the looked for deposit. Such a distinction, without establishing a positive title to obtain the concession, cannot fail to be taken into account, to some extent, by the administrative authority which, according to the terms of the law of the 21st April 1810, is entrusted with granting concessions of minerals.

(**75**) A method of prospecting comparatively economical and speedy is employed in such cases. Without throwing so much light on the undertaking as a shaft, by means of which we can *see* and *touch* the deposit, it furnishes, none the less, a proof of its actual existence, and may, in certain cases, enable the administrative authority to pronounce affirmatively on its concessibility.

Thus it is, for example, that recently, in the Department of the Moselle, several concessions have been applied for and granted in consideration of the results obtained by applying this method in various places before a single shaft intended for the working of the coal had been sunk.

This summary method of prospecting is called *boring*.

It consists in drilling in the rocks a hole of small diameter, by means of suitable tools which act on the bottom by percussion or a rotatory grinding motion, at the extremity of a rod which is worked from the surface and lengthened in proportion as the hole deepens. The *débris* caused by the action of the tools accumulate at the bottom of the hole, and are removed from time to time, by means of suitable cleaning tools. By the alternate use of tools for chipping the rock and raising the *débris*, the hole advances in depth, while we are able to judge of the nature of the formations traversed, by examining the fragments obtained from it.

Such borings have of late been much employed in the Departments of the Pas-de-Calais and of the Moselle, to carry on the prospecting mentioned in the preceding chapter (N° 62). Depths of 100, 150, 200 yards, and more have been very easily reached; and, elsewhere, borings have been pushed to a depth of 981 yards (900 metres).

These deep borings are hardly at all applicable except to stratified deposits. The chance of failing to hit upon a mass limited in a horizontal direction is too great; and in the case of a vein, the variations in thickness and richness which characterize such deposits too often render the search useless, without our being perhaps sufficiently authorized to draw a negative conclusion from it.

(**76**). Searching for minerals is not the only purpose for which boring is employed; it is also, and perhaps more frequently, employed in searching for springs, or for sinking what are called *Artesian Wells*—so named from the province of Artois, where they had been known for centuries, before any one had ever thought of boring in search of minerals.

The water discovered by boring appears to proceed from subterranean sheets which exist in certain permeable strata, overlain by others relatively impermeable. We may meet, for example, with beds of sandstone or beds of limestone full of joints more or less disintegrated (as often happens in certain beds of the White Chalk) overlain by more or less compact beds of clay or marl. If we suppose the whole of the strata to have a basin-shaped or trough-like form (Fig. 47), the outcrops of the various beds will be exposed at the surface in a series of concentric curves. Rain falling on the surface of the ground and running water will filter down through the permeable strata, and the quantity will be occasionally increased from hollows having been formed at the outcrop of these strata on account of their softness and state of disintegration. These strata, therefore, will be entirely saturated with water.

If, however, as generally happens, there are points on the outcrop at different levels, it must be evident that water will penetrate downwards at the higher points such as A, and come to the surface at the lower points such as B. In this way it may give rise to springs; but more often it finds its way out into the bottom of river beds or under the sea. The water, therefore, which permeates the strata is not stagnant; it forms, on the contrary, a sort of great subterranean current, whose direction and velocity at each point depend on the position of that point, in plan and elevation, with respect to the outcrops, as well as on the greater or less permeability of the stratum in the neighbourhood of the point in question.

If we consider separately a small mass of water, from the time when it enters the watery stratum until it escapes, the envelope of its successive positions will resemble a pipe. The section of this pipe is to be regarded as irregular and abruptly variable from point to point, and the perimeter of the section as very great, relatively to the section itself; it is a pipe, in fact, in which the loss of head per yard of flow will be very much greater than in an ordinary pipe. This, however, does not imply any difference in the laws by which the flow is regulated, except in the value of the numerical coefficients. (Cours de machines, Nº 136).

Supposing then that a hole were bored to a given point in the subterranean current, and a pipe of sufficient vertical height were inserted, a sort of piezometer would be formed, in which the water would remain at a certain depth below its point of infiltration; this would express the total head employed in communicating its velocity at the point in question, besides overcoming friction, and in compensating for all losses of *vis viva* experienced since it left the point where it entered the stratum.

In other words, the level of the water in the tube would be one point in the curve of pressure; and the geometrical locus of those levels, considered with respect to the whole subterranean sheet of water, would form a more or less undulating surface, to which the name of *piezometric surface* or *surface of pressure* may be applied. From this definition it follows that, an artesian well piercing a stratum containing water at a certain point, will, or will not yield a jet of water, according as the piezometric surface at this point is above, as at M, or below, as at N, the corresponding point on the surface of the soil (Fig. 47). The above statement forms a sort of theorem defining the geometrical condition upon which depends the success of any boring undertaken at a given point, with a view to form an artesian well which will furnish a jet of water. We may state the same thing in a somewhat different manner.

If we were to suppose the water to be stagnant in the porous stratum, to be quite motionless as it would be if we were to stop all the orifices at which it might escape, the liquid mass would be at rest, and the piezometric surface would be identical with what may be called the hydrostatic surface, that is to say, with a horizontal plane passing through the point of infiltration.

Denoting by H the ordinate of the piezometric surface with respect to this horizontal plane measured downwards, and by H' the ordinate of the surface of the soil with respect to the same plane, the condition under which a jet of water may be obtained is expressed by the relation $H' > H$; if we suppose $H' = H$, the water will find its level exactly at the surface of the soil; if, finally, we put $H' < H$, the water will remain below the soil at the depth $H - H'$ in the piezometer. It can be raised from this point to the surface by means of pumps, if it is desired to procure water. On the other hand, the bore-hole may be employed to get rid of water which would otherwise lie upon the surface; for, since pouring water into the piezometer tends to raise the level there, the resulting excess of pressure gives rise to a downward current, in virtue of which water is discharged into the watery stratum below. A boring which is used for this purpose is called a well of absorption, or *boit-tout* in French.

(**77**). The above theory may be regarded as perfectly established, and in accordance with all the facts observed; it also explains, and may even predict them.

To quote a few instances :—

1° The piezometric level at a given point, that is, the level at which water stands *below* the surface in the case of a well of absorption, or that to which it *rises above it* in an artesian well to which a tube has been fitted of sufficient length to prevent any overflow, is independent of the diameter of the bore-hole, and is generally higher when the hole is lined with a tube than when it is not.

The first circumstance is due to the fact that the level in question depends solely upon the *head* of the subterranean water at the point where the bore-hole meets it, and this head has a perfectly determinate value independent of the bore-hole, so long as no water is permitted to escape.

The second point is to be explained by the circumstance that, before arriving at the subterranean water-sheet in which the boring terminates, other water-sheets are frequently pierced which have a lower piezometric level (in no case are the strata traversed absolutely impermeable), and, when placed in communication with the underlying water, they may play the part of a well of absorption. The sides of the well resemble a tube which has not been made water-tight, in which there are leakages causing a loss of water and a consequent lowering of the level of water in the tube. This principle is so reliable, that if, after a time the flow of water is observed to have diminished in the case of a bore-hole lined with tubing, we can discover the cause by seeing whether the piezometric level remains the same or not. In the former case, we conclude that the diminution of flow arises from some obstruction in the tube or at its lower end, and *it is necessary to clean it out;* in the latter case, we conclude that the tube itself is defective, and *that it must be replaced.*

2° The quantity of water furnished by an artesian well increases *with the section of the hole*, but in a ratio which it is impossible to predict by calculation; it is always lower than the ratio of the sections, and for a given ratio of sections it diminishes as the absolute size of these sections increases.

The first point is evident; and the second will not be less so, when we consider that the bottom of the well is not in communication with an indefinitely large reservoir whose head would continue the same whatever outflow might take place (a condition which is necessary, and implicitly taken for granted, when it is said that the flow from an orifice is proportional to its section). On the contrary, in this case as the outflow increases so must the velocity of the water increase in the fissures of the watery stratum which converge towards the lower orifice of the bore-hole, and consequently the pressure upon this orifice must diminish. It is, however, impossible to express this diminution by figures; for it depends essentially upon the section of the little channels through which the flow actually takes place, at the particular well under consideration. In short, it is no more possible to calculate the flow of water from a bore-hole, than it is to calculate the flow in a pipe in which we know *that there are obstructions*, but do not know their *magnitude*.

3° The supply of water is more abundant according as it is collected nearer to the surface of the soil, or further below the piezometric level. The increase cannot be calculated *à priori*, however. It is due to the fact that collecting the water at a lower level amounts to reducing the pressure upon the bottom of the bore-hole considered as an orifice of discharge, thus increasing the motive head; on the other hand, as the motive head is diminished by an unknown amount, owing to an increased velocity of flow in the little subterranean channels, it is impossible, as has just been said, to know what is the effective head remaining, and consequently it is impossible to calculate the discharge.

4° Again, after a well has been bored, the quantity of water yielded increases when the hole is tubed. This follows from what has been already said about the variations of the piezometric level. The flow through a well which has not been tubed is like the flow in a pipe from which leakages take place at various points in its length.

5° Two wells, sufficiently near, influence one another in such a manner that each of them reduces the quantity which the other by itself would yield; and the closer they are to each other the more does their joint discharge tend to reduce itself to the quantity which would be yielded by a single well with a section equal to the sum of their sections.

This last result will evidently be obtained in the limiting case, when we suppose the axes of the two wells to coincide. The further these axes are separated the greater is the total discharge, because the greater will then be the total number of little channels which contribute to it; and finally, if the distance become sufficiently great, those little channels form two independent systems: the two wells then cease to influence one another, and each of them has the same discharge as if it existed alone.

These two discharges will, moreover, be equal, if the two wells are of the same diameter and supplied with the same head of water, excepting, however, those contingencies which may result from a certain difference in the permeability or thickness of the bed containing the water, in the vicinity of the points where the wells pierce it. In the extreme case, those exceptions may become of such importance as to cut off the discharge of a well, if it happened to strike a point where the permeable stratum had thinned off to nothing, or even where the stratum, preserving its thickness, had entirely lost its permeability.

6° Lastly, we may further mention as a curious fact, exemplified in some of the wells of Artois near the sea, that although they overflow at *high water* they cease to do so at *low water*.

This fact is easily explained by the supposition that the stratum yielding the water crops out on the one side in high-lying parts of the country, and on the other side under the sea.

The high water increasing the pressure upon the orifices of escape lessens the outflow, and raises the piezometric surface of the entire subterranean water-sheet; and at certain points, not far from the sea and at a sufficiently low level, it may cause the water to pass up to the surface of the soil.

(**78**). All these facts viewed in conjunction can leave no doubt as to the theory of artesian wells. It is upon this theory that we must rely, whether in searching for localities where artesian wells may be established, or in estimating the chances of success which a given locality affords.

The investigation necessary, in order to resolve either of these two questions, is essentially geological and topographical. We naturally leave out of this investigation formations of igneous origin (although theoretically it is not absolutely impossible that a fault containing water might occur, and play the part of a permeable stratum). It is requisite that the sedimentary formation submitted to investigation should lie in the shape of a basin, with the outcrops of the strata forming a series of concentric curves.

It is requisite that amongst those beds there be some which are freely pervious to water, lying between others which are relatively impervious.

It is further requisite that the formation should not have been too much dislocated by faults, which might break the continuity of the sheets of water, and furnish points at which they might be able to discharge their water directly to the surface.

In addition to these geological conditions, the topographical condition which must be fulfilled, in order that an overflowing well may be obtained at a given point—a *condition which is necessary and sufficient* — is that at this point, as we have already said, *the piezometric surface of the subterranean water-sheet be above the surface of the soil.*

From this condition it follows :—

That failure will be inevitable, if the given point is above the points of infiltration;

That success will be certain, if it is below the points of outflow.

That a doubtful result may be obtained, when the point lies at an intermediate level, which *may* be higher as we get nearer to the points of infiltration, and *must* be lower the nearer we go to the points of outflow.

(**79**) *The Paris basin*, considered in all its geological features, is eminently suited for the production of artesian wells. An examination of the geological map shows that it is composed of a series of sedimentary formations arranged in the form of a basin, like so many saucers of decreasing size placed one within the other, the neighbourhood of Paris, occupying nearly the central position. These formations, which have escaped the metamorphic influence to which the older formations or those more adjacent to centres of eruption are generally subject, present alternations of permeable and impermeable beds which are but slightly dislocated.

In passing from the top to the bottom of these strata, we meet with several horizons which are capable of furnishing, and in fact do furnish, artesian wells.

At London, which stands on the basin in question, there are wells of this kind, supplied from water-sheets which occur in subordinate members of the Plastic Clay series.

Certain wells, in the vicinity of Paris derive their water from the chloritic sands between the Plastic Clay and the Calcaire grossier.

The wells of Artois are in the White Chalk covered over by Plastic Clay (The same permeable beds of White Chalk present great difficulties in sinking mine shafts in the Departments of the Nord and Pas-de-Calais).

The great wells of Grenelle and Passy are supplied from the Greensand lying below the White Chalk.

Lastly, those which are being sunk at present at La Butte aux Cailles and La Chapelle, to the South and North of Paris, will draw their supply from the Oolitic rocks still lower down. It has been decided to go thus far, from the expectation that, if those new wells were to terminate in the Greensand, the discharge from them would be made partly at the expense of that yielded by the wells of Grenelle and Passy.

In the case of these last named wells, it is easy to define the boundary of the water-sheet by an examination of the geological map. The Greensand crops out on one side in the vicinity of Troyes, say at an altitude of about 390 feet (125 metres) above the sea, and on the other side at Tours and to the North of it, at an altitude of about 200 feet (60 metres). It passes under Paris at a depth of from 1800 to 1950 feet (550 to 600 metres). For all points situated on a zone passing through these three cities, the piezometric level will be comprised between 390 and 200 feet (125 and 60 metres), and will diminish from east to west (At Paris it is more than 260 feet (80 metres).

We may then affirm, after what has been said in the preceding N°, that at any point of this zone, (excepting the accidental and hardly probable case of the sand having become agglutinated and impermeable, or not being in existence at the point struck), a well sunk to the Greensand *will be certain to yield a jet of water*, if its surface level is less than 200 feet (60 metres) above the level of the sea, *and will certainly not yield it*, if its surface level is more than 390 feet (125 metres), the limit between these two cases being about 260 feet (80 metres) in the vicinity of Paris, and approximating towards the first or the second of those numbers, according as we proceed from Paris towards the West or towards the East.

(**80**). It appears, in summing up the preceding N^os (75 to 78), that *deep boring* may be required, firstly, for the purpose of prospecting a single bed or a series of beds, and more especially a series which is known in one locality and is suspected to be present in another under more recent formations; secondly, for the purpose of searching for springs of water which rise above the surface, or near enough to the surface to be pumped up, or lastly, and less frequently, for the formation of absorbing wells.

These are not the only possible applications. Borings of great diameter are executed in the working of rock salt or of salt marls. A hole is bored down to the floor of the bed, and a pump is lowered in the interior, with a certain clear space round about it for the passage of pure water. On working the pump saturated water is extracted, the degree of saturation varying inversely as the speed at which the pump is driven.

This method dispenses with the cost of subterranean working, and may be recommended in the case of a bed which would only yield to the miner an impure material, that would necessarily require to be dissolved and refined before being delivered in the market.

Bore-holes of large diameter are sometimes further employed for the purpose of establishing communication for ventilation, and even, as will be explained hereafter in detail, for the purpose of establishing mine-shafts of large section, in some cases where sinking by the usual methods would involve too heavy an expenditure for pumping, or might even become impossible in consequence of a superabundance of water.

(**81**). Lastly, boring may be made use of by the miner *on a small scale* under various circumstances.

By means of small bore-holes he can penetrate to water, when the faces are approaching old inundated workings, the position of which is only imperfectly known; he can give the line of a shaft if a *rise* is being put up to meet it; he can explore beds near the surface, such as peat or the mineral called bog iron ore; he can study the nature of ground in which he has to make a deep cutting or put in foundations for important buildings.

To sum up, it is clear that the engineer in general, and particularly the mining engineer, ought to be acquainted with the details of these systems of boring, and be able, in each case that may occur, to choose his tools and suit his mode of procedure to the result to be obtained. Generally, however, it will be found suitable when a great work is under consideration, demanding apparatus of importance and an experienced staff, to apply to contractors who give their special attention to this kind of work.

In the next sections we shall consider the tools properly so called, and then the apparatus; we shall next describe the various operations which the execution of this work demands at its different stages, and, finally, we shall conclude with some practical data relative to these operations.

§ 2. — Boring tools.

(**82**) The instrument employed for making a bore-hole consists of two parts : *the rod* with its fittings at the surface, by which the tool at the bottom of the bore-hole is manipulated ; and *the tool*, which varies according to the kind of work that is being done.

The rod proper is composed of a number of simple bars 1 to 2 inches (27 to 54 millimetres) square, joined together end to end ; their length is 16, 20 or even 33 feet (5, 6 and 10 metres), and, in general, it is an exact submultiple of the quantity by which the arrangements at the surface permit the rod to be lengthened or shortened at a time. Besides these, there are some shorter bars which are used while the hole is being deepened, for the purpose of maintaining the top of the rod at a constant height above the level of the surface. All the bars should be free from flaws and perfectly straight. They are joined together either by fork joints, (fig. 48), or by screw joints, (fig. 49). The former have the advantage of allowing the rod to be turned round in either direction, which is sometimes very desirable; but they require a number of small pieces (bolts and nuts) which are troublesome to handle, and are apt to be damaged by the repeated concussions of long continued boring. Screw joints with simple triangular threads are usually to be preferred; each bar is terminated at one end by a male screw, having a section at least as great as the bar, with a seat at its base whose section is a little greater, and at the other end by a socket, having the same section as the seat, with a female screw. The depth of the socket is rather greater than the length of the screw, in order that when the joint is made the seat and the ledge of the socket may come together exactly. The swelling formed by this joint has a section rather greater than double that of the rod. All the joints are identical, so that any two bars may be joined together. The socket is always kept downwards. A small shoulder *a* below the joints serves to hold the rod suspended on a key, when necessary, while pieces are being screwed on or off.

In deep bore-holes iron rods have a great disadvantage on account of their weight; they weigh 3·3 pounds per square inch per foot (0^k·78 per square centimetre per metre) of length, and 2·94 pounds (0^k·68) in water which always fills the bore-hole, say in round numbers 3 pounds (0^k·7), taking into account the extra weight of the swellings at the joints. A rod of 1·06 inches (27 millimetres) square, by 1640 feet (500 metres) long, weighs say 5621 pounds (2550 kilogrammes), and one 2·12 inches (54 millimetres) weighs 22,484 pounds (10,200 kilogrammes), or four times as much, so that serious difficulties have to be coped with, and these increase rapidly with the depth, when the tool is worked by percussion. A weight like this, spread over such a length of rod, cannot be suddenly arrested by the blow at its lower extremity without straining the rod greatly, especially near the bottom, and making it lash against the side of the bore-hole. From this cause rods are frequently broken, the sides of the bore-hole give way, and serious consequences often ensue. These inconveniences are so great that boring by impact becomes impossible at great depths, and it is necessary to have recourse to rotary motion, as in the case of the Grenelle bore, one of the first deep undertakings of this kind. In this case it was possible, owing to the marly nature of the strata; but in hard siliceous rock it could not be done.

At first sight then, boring would seem to become *impossible*, when the two circumstances, *great depth* and *very hard strata*, present themselves at the same time. The question has been solved, however, in two ways:—

1. A wooden rod with iron joints is substituted for the iron rod, and the greater part of the weight is supported by the water which fills the bore-hole.

2. The rod is made in two distincts parts: a lower short massive part which carries the boring tool and is alone exposed to the concussion, and another part serving to lift the former for the purpose of making the blow, but not solidly joined to it, and so escaping the effect of the shock at the bottom of the bore-hole.

Wooden rods are generally made of pine with very straight grain; they are $2\frac{1}{2}$, 3 or 4 inches (6, 8 or 10 centimetres) square, have their edges chamfered, and are 33 to 39 feet (10 to 12 metres) in length. The joints are made in exactly the same way as those of iron rods, with a socket at the bottom and a male screw at the top. These iron pieces are fixed to the rods by means of forks which embrace their ends and are fastened with bolts (fig. 50).

In the case of deep bores there is a tendency to prefer wooden to ron rods; but, when the second contrivance is employed, the substitution of wood for iron becomes a matter of minor importance. This contrivance is a most important improvement, and it may be said *that a deep bore cannot be undertaken nowadays* without having recourse to it in one form or another.

(**83**) The first form that was tried is the *sliding joint* of Œynhausen, represented in figure 51. At the upper end of the part that carries the tool, there is a head *n* which is lifted on the seat A B of the sliding joint, and becomes free at the instant the tool strikes the bottom. The upper portion of the rod must have its motion arrested at the same time, however, by coming in contact with a spring or counterbalance at the surface, arranged so as to deaden its velocity, before it has descended a distance equal to the length of the joint. In this manner we prevent the rod from being bent and from lashing against the sides of the bore-hole, which would be the case, as we have said, if this part of it were arrested with a sudden shock at the same time as the cutting tool. The sliding joint was a great improvement at the time it was first adopted; it allowed of the upper rod being much reduced in thickness, since its only use was to transmit motion to the part carrying the cutting tool.

The elastic stop may be either a counterbalance or a well bent spring. The counterbalance can be placed on the boring lever. If we make P equal to the weight of the rod below the sliding joint, P′ the weight of the upper rod, P″ the counterbalance, R and r the arms of the lever corresponding respectively to the counterbalance and the rods, H the distance through which the counterbalance is lowered in order to lift the rods through a height $H\frac{R}{r}$, then the work to be done by the motive power at the surface can be easily calculated.

When the rod and its appendages descend under the action of gravity, the counterbalance is raised at the same time. If we designate the velocity of the cutting tool, at the instant it strikes the bottom, by V, then half the *vis viva*, which is numerically equal to the work done in lifting the system, is given by the expression: —

$$\left(P + P' + P''\frac{R^2}{r^2}\right)\frac{V^2}{2g}.$$

On the other hand, the effect produced by percussion on the bottom of the bore-hole, may be considered equal to half the *vis viva* of the striking mass, or: —

$$P\frac{V^2}{2g}.$$

and its relation to the whole work done is: —

$$\frac{P\frac{V^2}{2g}}{\left(P + P' + P''\frac{R^2}{r^2}\right)\frac{V^2}{2g}} = \frac{P}{P + P' + P''\frac{R^2}{r^2}}.$$

It will be seen from this expression that, by diminishing the counter-balance as well as its arm of the lever, an advantage is gained as far as the amount of work to be done is concerned. These quantities, however, cannot be diminished indefinitely, because one condition must always be fulfilled, namely, to arrest the motion of the rod, before it has traversed a distance equal to the length of the sliding joint.

Let H' be this length; then the equation will require to fulfil the condition :—

$$\left(P' + P'' \frac{R^2}{r^2}\right) \frac{V^2}{2g} \leqq \left(P'' \frac{R}{r} - P'\right) H'$$

an equation which supposes that $P'' \frac{R}{r} - P' > 0$, or $P'' R > P' r$, that is to say, the moment of the counterbalance P'' should be greater than that of the weight P', and this difference should increase directly as V and inversely as H'.

If we put $P'' R = \mu P' r$ (μ being greater than unity) then the useful effect is : —

$$\frac{P}{P + P' + P'' \frac{R^2}{r^2}} = \frac{P}{P + P' \left(1 + \mu \frac{R}{r}\right)}$$

and it will be seen that, if P and μ are given, it will be necessary to diminish R, that is to say, to prefer a heavy counterbalance placed near the fulcrum of the lever, to a lighter one acting at the end of a longer arm.

Another arrangement is to place the counterbalance on a special lever which does not comes into play until the cutting tool strikes the bottom of the bore-hole; at that instant, a shoulder, forged at a suitable height on the rods, comes into contact with the lever and raises the counter-balance for an instant; but as soon as the motion is arrested it returns to its former position. With this system the *vis viva* at the instant of percussion is only $(P + P') \frac{V^2}{2g}$; the *vis viva* utilized in the blow is always $P \frac{V^2}{2g}$; and the useful effect is $\frac{P}{P+P'}$: the last quantity is greater than we had formerly, so that, from a mechanical point of view, the second system is preferable. The same result would be obtained if we replaced the counterbalance by a spring whose initial tension was equal to P′; it would come into action in the same way as the special lever, and would have a play of which the amplitude was rather less than the length of the free part of the sliding joint.

(**84**) Some of the principal boring engineers have designed other arrangements to take the place of the sliding joint of Œynhausen: each of these has its own special merits.

Kind's *free-fall instrument* is represented in figure 52. The lower rod, carrying the tool, terminates in a head which is seized and lifted by a system of two movable arms B B′ which form a kind of grapple similar to that used for lifting the battering block of a pile-driver. The two arms separate or approach each other as the disc D moves upwards or downwards. The disc is formed of three sheets of leather held between two plates of sheet iron; its diameter is nearly the same as that of the bore-hole and it works like a piston, being subjected to an upward pressure from the water as it descends, and to a downward pressure as it ascends. The jaws of the grapple are thus held together when the rod is raised, and they open as soon as it begins to descend under the accelerating force of gravity. The upper rod remains behind, retained partly by the resistance of the water on the disc, but principally by a spring or counterbalance, while the lower rod with the cutting tool falls freely to the bottom of the bore-hole. The work is performed in the following way:—The upper rod is made to descend until the grapple bites the head of the lower rod; the whole system is then raised to a certain height and let go suddenly; it begins to fall; the grapple opens; the tool and lower rod fall with an accelerated motion until they strike the bottom, but the upper rod remains behind, and gradually comes to rest without shock or lashing against the sides.

This arrangement operates perfectly, when the diameter of the bore is large enough to contain the small mechanism described above, without requiring to have the dimensions of the pieces and their joints made too small.

Figure 52 *bis* may be considered to be a variation of Kind's instrument, and operates also by the play of a parachute. It is different, however, in this respect, that the weight of the tool itself opens the grapple as soon as the latter ceases to be held by the catches, from which it is relieved by the falling behind of the parachute. This instrument was introduced by M. Esche.

The system employed by Degousée and Laurent, which is equally inapplicable with too small a diameter, consists in adding to the tool a piece which descends with it to the bottom, and remains there during the continuation of a boring. This piece, called the dead weight, is so arranged that the branches of the grapple are forced open by it when the tool has been raised to a given height. This may be done in different ways: for example, the top of the dead weight may be provided with a sheet iron cap whose position can be regulated at will; the cap is suitably widened downwards, and the claws of the grapple, coming in contact with it near the upper limit of the stroke, are forced together; the lower rod is disengaged and falls freely, while the upper rod remains behind. This contrivance is similar to one sometimes employed for disengaging the battering block of a pile-driver.

Degousée and Laurent employed a rather more complex arrangement than the above, at the deep bore of La Chapelle. It is represented in figure 53. The disengaging action of the cap is produced by means of two striking bars; when they touch the bottom of the hole, the jaws of the grapple open as they are relieved from the action of two tappets which kept them shut. Special measures are taken to prevent the jaws from opening during the descent, in order to avoid a premature fall of the tool.

Lastly, M. Dru, the successor of M. Mulot, the contractor for the Grenelle boring, is employing an arrangement which has the same object in view as the foregoing—viz: to withdraw the upper rod from the reaction when the lower part is striking the blow; but it effects the disengagement in a different way. The pin on which the arms of the grapple turn, is placed in an eye which is oblong in the vertical direction, thus permitting a slight movement of the grapple relatively to the upper rod. The whole system is raised with a free rapid movement until its upward course is suddenly arrested by a stop placed at the surface; the grapple continues the upward motion for a short distance, however, and by this subsequent movement its jaws are opened, and the tool immediately falls.

We cannot see any reason for giving a decided preference to one of these systems over the others; the same essential peculiarities are possessed by them all. These are:—

1. The possibility of reducing that part of the rod immediately connected with the tool, to a mass as thick and short as may be desired, and consequently well adapted for boring by percussion.

2. The possibility of greatly reducing the weight of the upper part of the rod, which does not suffer from concussion, and has to bear no strain except that of lifting the tool or descending again to raise it.

It may, however, be considered that Degousée's arrangement, although somewhat complicated, has a certain advantage over the others in a mechanical point of view. The lever may be worked by a crank and connecting rod, and this continuous movement avoids shocks and nullifies the work corresponding to lifting the upper part of the rod. It follows that the quantity $\frac{P V^2}{2g}$ is equal to the work done, as well as proportional to the useful effect.

(**85**) When a rod is complete in other respects, it may be made still more perfect in its action, by fitting a system of *guides* and *parachutes* to it.

The *guides* are distributed on the rod, for the purpose of keeping it in the axis of the bore-hole and preventing any lashing against the sides. They may be made either like a kind of cage (fig. 55), which offers no resistance to the passage of water, or in the form of cylinders of wood or cast iron provided with openings so that they may not act like pistons. Otherwise, they may be allowed a certain play on the rod, longer than the longest stroke.

The *parachute*, which is a guide at the same time, is fitted to the lower end of the rod. It is a kind of cap (fig. 56) made of thick leather fixed on a long tube which is moveable on a turned part of the rod. Four straps join the edges of it to the tube, and strips of iron are fastened to its exterior to prevent it from being worn away by friction on the sides of the bore-hole. If we suppose that, part of the rod, fitted with a parachute, becomes detached by mistake or accident, then the resistance of the leather cap, passing through the water, will curb the velocity so much as to prevent any breakage from taking place. This parachute may also be employed in bore-holes with loose sides, as it does not hinder the passage of small stones that may be detached accidentally.

(**86**) At the surface, the rod terminates in a head which serves to suspend it to a lever, or to the rope of the windlass by means of which it is raised and lowered. The head should be constructed in such a way that the rod may be turned round indefinitely in one sense without twisting the cord or chain to which it hangs. Figure 57 represents a simple head with swivel joint, and with two eyes at right angles, into which one or two tillers or levers can be inserted for turning the rod. Figures 58 and 59 represent more complex arrangements; when heads of this construction are employed the brace-head can be maintained at exactly the same height above the surface, notwithstanding the progressive deepening of the bore-hole; and this is necessary for convenience, but more especially if springs or levers with counterbalances are used. The progress can also be measured by observing the successive positions of the lengthening screw.

(**87**) The *chisel* is the principal cutting tool used; its action is *essentially* percussive. The rod is turned slightly when it is raised after each blow, so that the blade may descend on a different part of the bottom at each stroke, and in this way form a hole of regular calibre. This tool is suitable for most kinds of ground and works without any rotatory scraping action; its cutting edge is made *sharper* and the length of stroke *shorter* as the ground in which it is working becomes *less hard*. It should be returned to the forge after each operation, and every time it is repaired should be carefully gauged in an iron ring of the same diameter as the bore-hole, so that the same dimensions may be preserved throughout.

The different kinds of chisels are: the simple chisel (fig. 60), with one straight cutting edge suitable for bores of small diameter — 9·8 inches (0·25 metre) and less; the chisel with step-cutter (fig. 61) less easily repaired, but suitable for larger bores and for very hard ground; the double T chisel (fig. 62), still more difficult to repair than the foregoing, and intended to help in keeping the hole round; lastly, the composite chisel, applicable to bore-holes of large diameter. The last mentioned tool is employed when the dimensions of the bore-hole are not compatible with the use of a chisel made in one piece; it consists of several pieces fitted together, and for facility of construction and repair, the ears and cutting edge are composed of a number of pieces. Several spare pieces of each kind are kept on hand, and when any of those in the chisel become blunted they are taken out separately and sent to the forge. Figure 63 represents a tool of this kind which is indispensable for holes that are begun with a diameter of 20 inches to 2 feet (50 or 60 centimetres), and they are of course all the more necessary in boring shafts, (see N° 79).

(**88**) Besides the ordinary cutting tool we may mention also: —

1. *Broaching bits*, or tools used for restoring the dimensions of a bore-hole in case it has become contracted, in consequence of a swelling out of beds of marl or clay. Figures 64 and 65 represent examples of these tools; they are made to act at the point required, by giving them an up and down as well as a rotary movement. The first tool has this advantage over the second, that it can be taken to pieces and each piece repaired separately.

2. *Enlarging tools*, intended for enlarging the diameter below tubes in order to let them down still lower. These tools must be constructed so that they can pass through the tubes already in the

borehole, and then expand their cutting edges to the required extent, either for the purpose of cutting away the little shelf on which the tubes rest, or to continue the enlargement further down. Figures 66 and 67 represent two enlarging tools designed by Kind, one for enlarging downwards, the other for cutting away the shelf of which we have spoken.

3. The *screw-borer*, or *auger* (fig. 68), is a blade of iron with steel edges, terminated by two tongues, and twisted so that its edges describe three or four successive spirals of a longer or shorter helix. This tool acts by being turned round and receiving slight vertical jolts at the same time; it is used for the purpose of loosening sand that has become somewhat solid, and preparing it for being cleaned out.

4. The *breaking-up-bar*, (fig. 69), is a prism with four faces terminating in an obtuse pyramid; it is used for breaking, or pushing aside into the walls, any small pieces of iron or other hard substances that may have fallen to the bottom of the bore.

(**89**)) After any of the cutting tools described above have been used, it becomes necessary to clean out the mud or rubbish that has accumulated in the bore-hole, so as to bare the rock and recommence boring with greater effect.

Two distinct classes of tools are used for this purpose: those which act by a rotatory motion, and those which act by an up and down movement. The type of the former class is the *shell-auger*, or *wimble*, represented in figure 70. This instrument, which is similar to the carpenter's auger, also acts like that tool, and penetrates little by little into the mass of *débris*, by means of a slightly inclined blade at its lower extremity. Its steel edge cuts the mass vertically, and the stuff is retained in the instrument by a horizontal guard at the bottom. It is considered advisable to make this tool somewhat conical towards the top, so as to compress the core of rubbish; it is also made more or less open, according as the mass on which it has to act is more or less plastic. The wimble acts very well, and cleans out the bore properly when the *débris* have a pasty consistence and can be formed into a compact core; it may even be employed *for cutting* soft ground. Figure 71 represents a *wimble-scoop*, suitable for boring very plastic clay; (fig. 72), a *wimble with screw cutter*, suitable for somewhat sandy masses.

Although these tools effect a good cleaning out of the bore-hole, they have the disadvantage of consuming much time in screwing and unscrewing the rods, when they are let down into and withdrawn from the bore-hole. Those of the second class avoid this inconvenience, since a rope serves to lower and raise them, so that they can be manipulated rapidly.

The *sludger*, or *shell-pump*, with an ordinary clack or ball valve, is the type of instruments of the second class. It may be said to have the same general application in cleaning that the chisel has in boring. These two tools do the ordinary work, and the others are employed under special circumstances. The shell-auger may be preferable for cleansing quickly when the materials are plastic, but the sludger is best when they are granular.

Tools possessing the advantages of both may be constructed, when the sludger is provided with a screw at its lower end (fig. 75). With this tool, the rubbish is cut by a rotary motion, and passing upwards through the valve, is retained in the cylinder till it is drawn to the surface.

When wimbles are drawn up, they are emptied of their contents by means of scrapers; sludgers are inverted, or, when they are very large, a small side door is opened and the sludge runs out.

In order to obtain an exact section of the strata passed through, the *débris* must be carefully examined. A handful is washed in a little water, on a shovel or in a pan, to determine whether the components can be separated; these may be afterwards studied separately under a lens, or submitted to chemical analysis. A case with pigeon holes should be provided for receiving a sample of each core that is brought to the surface.

(**90**) The information furnished by the samples can be verified afterwards, by taking another sample of the ground at any depth in the bore-hole. A tool called a *verifier* (fig. 76) is used for this purpose. It is provided with claws which open and scrape the sides when it is turned in one direction, or close into recesses when it is turned in the opposite sense; it has also a receiver for collecting the fragments broken off by the scrapers.

Even during the operation of boring, however, we may obtain solid cores from the bottom of the bore-hole, and these are evidently more satisfactory than the confused mixture of the cuttings with *débris* accidentally detached from the sides higher up. Moreover, these cores may be placed parallel to their original position after they come to the surface, so that, if they bear traces of stratification or are fossiliferous, the character of the beds traversed, their strike, dip, and the nature of their fossils may be exactly ascertained. For this purpose the following course is adopted: —The bore is cleaned out to the bottom with a wimble; a cutting tool with an eccentric cutter is then let down to mark the piece that is to be taken as a sample. For the purpose of keeping the cutter in a certain determined position, a plumb-line is hung on each side of the rod, so that the plane passing through the two plumb-lines coincides with the axis of the bore-hole. When a new bar has been added and the rod has to be lowered, a wooden straight-edge, coinciding with the plane of the plumb-lines, is screwed to its upper end; the rod is then let down, and when the process of lowering has been completed, care is taken to have the straight-edge exactly in the same vertical plane as it was before. In this way the tool may be let down with a certainty that the direction of its cutter has not been changed. After it has reached the bottom, a few light blows are made with it, without turning it, and then it is brought back to the surface.

A special tool called a *saw*, or *shearer* (fig. 77 and 78) is then attached to the rods and let down; it is formed of a number of longer or shorter cutting chisels arranged in a circle; it is turned round, making light blows at the same time, until a circular groove has been made round about the marked piece. Lastly, a tool is used for the purpose of breaking off the core; it is a kind of bell (fig. 79) which fits over the core, and exerts a strong lateral pressure against it, by means of a wedge pushed in by the weight of the rod. The specimen, having been detached, is retained in the bell by the pressure of the wedge, and by the lower extremities, bent inwards, of one or two springs fixed on the outside of the bell; it is brought to the surface and placed parallel to its original position, with the aid of the mark made at the beginning of the operation.

This series of operations may be repeated again and again when important strata are being passed through, and in this way an exact section of the ground can be obtained, as a series of consecutive cores, by the aid of which the strata may then be studied almost as well as in a cutting.

This result is very important, and gives the most complete information possible as to the nature of the strata. In ordinary boring, for example, when a seam of coal has been reached, grains of the mineral, although much broken up, may be distinguished from the earthy matters with which they are mixed, picked out and, submitted to a chemical analysis; but the ordinary core gives no clue, or almost none, as to the *purity* and *degree of solidity* of the seam: two essential qualities that can be well ascertained when specimens of a certain size are obtained.

(**91**) When a search is made for rock salt or salt marls, an ordinary core can scarcely give precise information, on account of the solubility of the mineral; so that it may be important to ascertain the degree of saltness of the water at the bottom of the bore.

The mode of obtaining a sample of the water is to let down a small cylinder closed at the top and bottom by valves opening upwards. The valves open when the cylinder is lowered rapidly; and several rapid strokes are made before the cylinder is raised again to the surface by means of the cord used in lowering it.

(**92**) Besides ordinary tools and the special ones already mentioned, it is necessary to take notice of some others which are employed *in cases of accident*. For, since boring is an operation carried on at a distance of, it may be, several hundred yards from the eye and hand of the workman, it is to be expected that accidents will frequently happen; and these should be provided for by having a good knowledge of all the circumstances under which they are likely to occur, and of the resources that are available to remedy them.

The instruments employed in the case of breakages of the rod, should be included among the common tools of the borer. These are, the *claw* and the *bell-screw*.

The claw (fig. 80) is an iron hook, with its upper ledge slightly inclined to the horizon, and wide enough to embrace the square part of the rod, but not a joint swelling. It is used when the rod is broken at a short distance *above* a joint, being let down at the end of a length of rod until it passes below the swelling; a slight turn is then given to it and it is drawn up, until the hook is arrested at the swelling.

When there is a considerable length of rod above a joint, the broken end may rest against the side of the bore-hole, and render the use of the claw ineffectual. In this case, the break having taken place a little *below* a joint, the bell-screw (fig. 81) is employed. It is a truncated cone, screwed internally; its larger base is rather greater than the section of a joint swelling, and its smaller base has a less diameter than the diagonal of the square part of the rod. It is continued downwards by a kind of hat or funnel of sheet iron having nearly the diameter of the bore-hole; and this contrivance, passing over the end of the rod, brings it back into the axis, so as to make certain that it will enter the bell. The bell is filled with grease before it is let down, and after it has passed over the end of the rod, it is turned gently until the screw bites (the direction being such as to tighten the joints); and it is drawn up when the bite is supposed to be sufficiently tight to raise the lost part of the rod.

These two instruments have the same importance, in regard to breakages, that the chisel and sludger have, in regard to ordinary boring. Among other less important tools of this kind, however, we may mention the *coil-drag* (fig. 82). It serves for lifting pebbles or bits of iron from the bottom, or for picking up the sludger line when it happens to break. Its inner edges are of steel.

Extracting a pebble, or part of a tool stuck in the mud, is not always an easy matter. In the case of iron, it has been proposed to dissolve it by an acid, letting down the solvent in a closed vessel and opening it at the bottom; and in the case of any other hard body, to crush it by the explosion of nitro-glycerine. The first method supposes the rock to be insoluble in the acid; and it appears that the second has been tried successfully; we should, however, fear the effects of the explosion on the sides of the bore-hole.

Among the special tools we should also mention the *pinching hook*, a kind of grapple, which is represented in figure 83. This instrument consists of a sheet iron bell for guiding the top of the broken rod; after the broken rod has been engaged, it passes freely upwards between the toothed branches, and when the instrument is raised, the teeth seize it firmly. The branches, which have steel teeth, are at first held apart by a small wooden block which is driven out when the rod enters; they then jam the rod and begin to bite it as soon as the instrument is drawn upwards, in consequence of their shape which tightens the grip as they pass into the bell mouth for a little way. This instrument should be used when the claw cannot be employed, on account of the length of rod above a joint, and when the bell-screw is inapplicable, as, for instance, when the tool is not jammed at the bottom, and the rod turns easily.

(**93**) A bore has often to be lined with tubes, as, for instance, when a considerable thickness of running sand has to be passed through; and this precaution is almost necessary when the bore is intended to be kept open for an indefinite period, like an artesian well.

A *retaining* tube is used in temporary bore-holes, and a *permanent* tube in those intended to remain open for a length of time.

Sheet iron is used in making retaining tubes; it should be of very soft iron so as to be able to withstand the various strains to which it will be exposed, both while the tube is being let down and afterwards. These tubes are from 0·078 to 0·2 inch (2 to 5 millimetres) thick according to their diameter, in bore-holes of ordinary dimensions, that is to say, varying from 4 to 20 inches ($0^{m}\cdot10$ to $0^{m}\cdot50$) in diameter. They are brought to the bore-hole ready for use, having a connecting socket at one end for the joint. All the rivets used in making them should have well rounded heads outside and inside, projecting very slightly, so as to offer as little resistance as possible against the sides of the hole during the lowering, or to the up and down movements of the rod and tools. The iron is generally too thin to admit of the heads being counter-sunk. The connecting socket is kept uppermost when a tube is lowered into the bore-hole; the bottom end of the next tube is let down into the connecting socket until it touches the top edge of the tube below it, and then it is turned round until the bolt-holes of the socket are opposite those in the tube. Small bolts are then let down from the top by means of a thread which is seized with a small wire hook passed through one of the holes; the bolt is drawn into its place, a nut is screwed on and the projecting end is cut off and filed smooth, (fig. 84). Although the length of the tubes, 5 to $6\frac{1}{2}$ feet ($1^{m}\cdot50$ to 2 metres), and their vertical position, render riveting inconvenient, this method of joining them may be employed; the riveting has, however, to be done cold. Figure 85 represents a tool for letting down all the rivets at once, and pressing a mass of metal tightly against their heads, by means of a lever, when they are put into the holes.

(**94**) Permanent tubes, like retaining tubes, may also be made of sheet iron, but they are apt to rust, and become pierced with holes here and there. These inconveniences are avoided by making them $\frac{1}{8}$, $\frac{3}{16}$ or even $\frac{3}{8}$ inch (4, 5 or 10 millimetres) thick for large diameters, whereas a thickness of $\frac{3}{32}$, $\frac{1}{8}$ and at most $\frac{3}{16}$ inch (2, 3 and 5 millimetres) is sufficient for retaining tubes. Some have been made even as thick as $\frac{3}{4}$ inch ($0^{m}\cdot02$), and in this case they are formed of two tubes each $\frac{3}{8}$ inch ($0^{m}\cdot01$) with their joints overlapping, both horizontally and vertically. With tubes of this kind, a connecting socket is not required, the rivet heads can be countersunk, and a perfectly smooth tube is thus obtained, both inside and outside. Sheet zinc and sheet copper, especially the latter, have also been used, and sometimes cast iron. The cast iron tubes are screwed into each other, every tube having a male screw at one end and a female screw at the other.

Lastly, wooden tubes have been employed, and found to answer the purpose well; their thickness, compared with metal tubes, is, however, an objection, as they occupy the space in a bore-hole, contracting its useful diameter. In old artesian wells of small diameter, they were formed of trunks of trees bored from end to end, and inserted one in the other. In wells of large diameter they are made of straight staves held together with hoops, and constitute, as it were, a long cask.

The kinds of wood employed in making them are oak, elm, and alder, all of which last for a practically indefinite period, when kept constantly wet. There are some in Artois which have lasted for more thân seven hundred years.

(**95**) When bore-holes have to be lined, several additionals tools are necessary for lowering the tubes or drawing them out, if the hole is to be abandoned or re-tubed.

If the tube is only required to support a thin bed of loose running ground, which has been found below a considerable thickness of solid ground, the arrangements represented in figures 86 and 87 may be employed. The first has a bayonet joint, by means of which the tube can be let down to the required position, and left there, by giving a slight turn to the rod. The second has two branches which are kept apart during the descent, whilst the pins which project on their external faces, fit into corresponding holes in the tube; when the proper place has been reached, the small bent lever which keeps the arms apart, is drawn upwards by means of a cord, and the arms, which are elastic, come closer together and pull out the pins. In both cases, the tube is made slightly conical at the top, to avoid projections on which the edges of the chisels might rest during the descent. A similar conical mouth should be made at the bottom, but it does not require to be so pronounced as that at the top; it is for the purpose of allowing the rods and tools to pass upwards without the risk of lifting the tube at the same time. The lower edge should be of steel and blunt.

These local tubes are seldom employed. In most cases the tube reaches all the way from the surface and is manipulated from this position. When the column does not descend freely, in virtue of its own or of an additional weight that has been added, it is driven down by the blows of a ramming block or *monkey*. A wooden cap, strengthened with hoops, is placed on the top to receive the blows; it has a hole in the centre, large enough for the swellings of the rod to pass through. The battering block may be a simple cast iron disc, or a wooden block hooped like the cap and fixed to the top of the rod; its weight can be regulated according to the length of rod that hangs below it. The effect of the blows is increased by turning the tube backwards and forwards, by means of a collar with handles which clasps the column firmly, (see figs. 88 and 89).

When a long column has to be forced down in this way, the blows are not very efficacious, as their energy is to a great extent expended in vibrations of the tube itself, and of the ground in contact with it. There is also a risk of damaging the tube, and the loosened materials, shaken from the walls of the bore-hole, get jammed on its exterior and give rise to much friction. Figure 90 represents a better arrangement in which the continuous pressure of screws is substituted for blows. The two beams of wood which serve as fulcrums are fixed solidly to the surface; they pass under the boring engine, and, if necessary, are loaded with additional weights.

We have supposed hitherto that there is a resistance to the descent of the column, but this is not always the case, especially when a permanent column is being put in. A tube of this kind, 39·4 inches (1 metre) in diameter, and ·78 inch ($0^{m}\cdot02$) in thickness, weighs 302 pounds per foot (450 kilogr. per metre) in water, and so long as it does not rub against the walls there is an enormous weight to be supported. In this case arrangements must be made for preventing, and not for facilitating the descent of the the column. It may be suspended by means of wooden yokes tightly pressed against it and resting on a retaining key, or by iron tie-rods whose application will be mentioned more particularly when we refer to the Kind and Chaudron method of sinking shafts, (Chap. IX).

(**96**) *Tube-drawers* and *tube-cutters* are used for withdrawing tubes from a bore-hole. The tube-drawer or Kind's shuttle (fig. 91) is a block of wood swelled in the middle ; it is joined to the boring rod and passes down the tube with a little play ; a short open tube, which rests on its upper surface, is filled with gritty sand ; when the desired position has been reached, this short tube is lifted by means of a cord, the sand spreads over the wooden block and gets wedged between it and the tube, so that, when the rod is drawn upwards, the tube is forced to ascend with it.

Alberti's tube-drawer (fig. 92) acts in a similar manner, only, the sand is replaced by a cylinder of thin wooden staves hooped at the top, but free at the bottom. The staves are made wedge-shaped and jam themselves between the tube and the wooden block.

It is necessary to cut the column and lift it in successive pieces when it cannot be drawn out whole. This is often the case if it has remained in the ground for a long period, or if the friction of the walls is excessive. Many different kinds of tools have been proposed and used for this purpose. The one represented in figure 93 acts well, even on the thickest tubes. It cuts the tube on being turned round continuously for a time in one direction ; it can then be disengaged easily, and the cut pieces are afterwards drawn to the surface by means of one of the tube-drawers already described.

3. — Machines employed in boring.

In the preceding paragraph, we have described, not only the different kinds of tools used in the ordinary processes of cutting a bore-hole and lining it with tubes, but also some of the special tools that are required when unusual circumstances present themselves.

Only essentially typical tools have been described; and it is obvious that when unforeseen accidents take place, the sagacity and experience of the master-borer are called into requisition to suggest the best mode of action to be adopted.

At the commencement of a bore, only simple tools, etc., are necessary. These are : the rod with its accessories; a boring tool which is more or less complex according to the diameter of the bore-hole; a sludger and cord for letting it down; a simple hooking tool like the claw, and, lastly, some retaining tubes. As soon as it has been ascertained that tubes are necessary they should be put in, so as to prevent any considerable falling in of the walls. These are the special instruments of the borer.

The machines by means of which the foregoing tools, etc. are manipulated, have not the same special character, and may, therefore, be more summarily described.

(**98**) The *jack roll*, or *windlass*, is the principal machine; it may vary in its construction, according to the importance of the boring, from the simple mason's windlass and triangles stayed with ropes so as to be approximately vertical, to a substantial pulley-frame like that of a winding shaft and often surpassing the latter in height. A high fulcrum is essential. The windlass and the pulleys fixed at the top of the frame, or derrick, serve for raising and lowering the rod in the bore-hole while the bars of which it is composed are being joined or separated. A high pulley-frame naturally permits long lengths to be unscrewed at once, and so tends to shorten the process considerably. The height of the pulley-frame and the proposed depth of the bore-hole should be to some extent, proportional; and care should be taken to make the useful height a multiple of the length adopted for the single rods.

In addition to height the frame should have stability. It will be remarked that when the rod is raised by a rope, which passes over the pulley and returns to the windlass near the ground, the top of the frame supports a pressure which is equal to twice the resistance offered by the weight and friction of the rods; and when the tool becomes jammed at the bottom by any accident this pressure may be much increased.

The rod is raised by winding one end of the rope, which passes over the pulley, on the windlass the other end being attached to the top of the rod. The windlass may be made to revolve intermittently by means of hand-spikes (but this method is only suitable for bores of little depth); or continuously by means of cranks or a tread-wheel; or, if its axis is vertical, by capstan bars when men are employed and by the arms of a gin when horses are preferred: in fine, any of the known arrangements for utilizing animal power may be applied (Cours de machines, Chap. II). It is evident, however, that animals are unsuitable in the case of deep bores, because of the amount of power required, and since their number must increase proportionally with the weight of the rod or depth of the bore; moreover, all these individuals would be unemployed during the greater part of the day. Under such circumstances, therefore, steam power is preferable.

The arrangements may be made in the following manner: A stationary horizontal engine with two cylinders may be used, or a portable engine of several horse power; it is made to drive a shaft, on which there is a drum or two bobbins, by means of a belt, or preferably, by gearing like a winding engine; two round ropes are wound upon the drum in opposite directions, or two flat ropes on the bobbins, their free ends pass over two pullies at the top of the frame. The length of these ropes is such that their extremities arrive simultaneously one at the top and the other at the bottom of the frame, so that the rod and its parts may be hooked and unhooked, at the mouth of the bore-hole and at the top of the frame at the same time. Loss of time is thus avoided.

The pulley-frame serves the purpose of letting down the boring tool and drawing it up again when the boring is completed. When this has to be done, the top of the rod is attached either directly to the rope, or, if its weight is considerable, to a system of pullies. Portions of the rod, of as great length as the height of the frame will permit, are screwed on or unscrewed successively. The rods in the bore-hole are supported by a *key* (fig. 94) which rests on the boring-floor at the mouth of the hole, and catches the shoulder under each male screw. A joint is screwed or unscrewed by means of an ordinary spanner or wrench with a long handle which grips the square part of the rod (fig. 95). Each length of rod which is joined or disjoined is attached to one of the ropes either by a *drawing cap* or *topit* (fig. 96), or by a *grip* or *liftings dogs* (fig. 97), which is fastened to the rope and serves the purpose of seizing the different lengths successively; or there may be as many drawing caps or grips as there are lengths of rod, and then they are only attached to the rope by a hook. In the latter case the lengths of rod can be suspended when they are out of the bore-hole, and this arrangement is better for keeping them straight than if they were allowed to stand on their ends; the caps or grips are then provided with hooks by means of which they are hung to a strong bar of iron fastened to the frame.

(**99**) The *boring beam*, *brake* or *lever* is employed in the actual process of boring; the top of the rod is attached to it by means of a chain when the drawing rope has been removed. This machine is worked by means of a number of cords attached to the end furthest from the bore like the hand pile-driver; or by horizontal handles fixed in it like those of a fire-engine; or by a continuously revolving windlass. In the last case, one end of a rope is fastened to the lever while the other end, after being taken round the windlass barrel two or three times, is held by a workman who produces the beating motion by pulling and letting out alternately. A cam may also be employed, and in this case the rope is attached to the lever at a suitable point, while the cam is fixed to a shaft turned by cranks.

The best method, however,—and it accords with the employment of a steam windlass—is to employ steam power, both for producing the beating action, and for raising and lowering the tools. The type of engine most suitable for this purpose is a single acting engine with one cylinder, worked by hand like a steam hammer. It is *direct acting* when the steam is admitted below the piston and lifts the rods directly; or it is a *beam engine* when the steam is admitted above the piston which draws down one end of a lever, while the rod is raised by the other end. This work could also be done by the same machine that works the windlass for raising and lowering the rod; and an arrangement of this kind is of considerable advantage in a mechanical point of view (see N° 84).

Besides the up and down movement given to the rod in the process of boring it must also be revolved slowly in order to make the hole cylindrical. This is done by the master-borer, or by one or two reliable workmen, by means of the *bracehead* which is fixed at the required height by a set screw (fig. 98). When the rod is lifted, it is turned through a tenth or fifteenth of a circle; the operation must be attentively and carefully performed, in order that no circumstance that could lead to an accident may escape notice.

(**100**) *For cleaning* the bore there is usually a special windlass, on which the necessary quantity of rope is wound, to be used with the sludger without the rod. The rope passes over a pulley which is fixed perpendicularly over the bore-hole when required for use. The descent of the sludger is regulated by means of a break on the windlass. It is raised by cranks on the axle of the drum, and by the same means the up and down movement, necessary to fill it, is given. This movement could also be produced by means of a rocking lever, and then the instrument may be raised by means of the steam engine, the lifting drum being put out of gear for this purpose.

§ 4. — On general boring operations.

(**101**) The choice of a suitable place is the first thing that has to be settled before a bore is commenced. The district in which the bore should be put down is indicated by the geological considerations which induce the undertaking; but considerations of another kind determine, to some extent, the *exact locality*. A place with easy access to a railway is chosen; or if steam is to be employed it is necessary to have feed water convenient; those places where there are thick beds of water-bearing alluvium are avoided, etc.

When the exact spot has been at length fixed upon, a shallow pit or *staple* is sunk through the surface deposits and either timbered or walled; then the guiding tube of wood or sheet iron of the initial diameter of the bore is fixed vertically in its axis. The top of this tube terminates at a short distance below the level of the floor on which the workmen are to stand, and it has no solid connection with this floor, so as to avoid shaking which might alter its position.

The boring floor, on which the different operations of turning the rod, joining and disjoining the pieces, etc. are performed, is kept as far as possible below the natural level of the surface; this arrangement gives more freedom at the surface, at the same time that it is equivalent to raising the height of the pulley-frame.

These first arrangements having been completed, boring is commenced by hand and carried to a depth of several yards below the bottom of the guide tube, the wimble being employed for cleaning. In the mean while, the other materials and the machinery are brought forward and set up; a shed is built large enough to shelter, not only the space in which the work of boring is to be carried on, but also the forge with its tools, a store, an office with its usual furniture and some pigeon-hole cases for samples of borings, a room for a watchman or master-borer, etc.

The work may then fall into its usual course. When all is in working order, the daily operations will be executed in a methodical manner, as far as possible according to the following programme.

The cutting tool is let down by means of the engine;

Boring is carried on for several hours;

The tool is then raised by the same engine;

Lastly, the bottom of the bore-hole is cleaned by means of the sludger.

Operations which are performed during the *usual course of work*, but not *daily*, are: using broaching bits (rounders), cleaning with the wimble, putting in and taking out tubes, taking samples, etc.

Lastly, *accidental operations* are: searching for pieces of rod that have fallen to the bottom of the bore or have become jammed by a fall of side; straightening the hole when it tends to deviate from the vertical; lifting a fragment of tool or other hard body which hinders the work of the chisel, etc.

Among the details concerning tools and machinery we have already given a general idea of how these different operations are performed, we have still to make some further observations, however, in regard to them.

Usual daily operations.—An examination of the daily journal of operations will show that the usual work of a shift consists, as we have already said, in letting down the chisel (this may occupy a couple of hours when a depth of several hundred yards has been reached), boring with the lever, lifting the tool to the surface again, (this operation does not require sensibly more time than letting it down), letting down the sludger, filling and raising it to be emptied, and, lastly, placing the chisel in position above the hole to be ready for letting down at the beginning of the next shift.

Accessory operations.—The normal, but not daily operations, which we have also mentioned above, interfere from time to time with this regularity; and, even when of comparatively small importance, they may occupy almost an entire shift, and not leave time for lowering the tool, boring with it and then again lifting it to the surface. It is natural to suppose, however, that there is a tendency to put off these operations, and to wait until they become urgently or absolutely necessary before proceeding with them; but surely this is a practice to be avoided. The very opposite principle should prevail; operations of this kind should be undertaken *as soon as there is a suspicion they would be of advantage*, and in this way accidents are to be avoided which might lead to the most troublesome consequences. Such mishaps may stop the work for days or weeks or whole months, and may sometimes even lead to an abandonment of the undertaking.

Accidental operations.—From the very nature of these operations it is impossible to describe them systematically, for they may vary, and ought to vary almost indefinitely according to the particular circumstances of the accident. In a general way, however, we should say, that the whole attention of a boring-master should be directed to the prevention of accidents, and if unfortunately they should sometimes happen, all his ability and perseverance will be required before he can hope to overcome the difficulty. At the moment when many accidents occur, it would be thought that the disaster cannot be remedied, and all that can be done is to abandon the bore. For instance, if the rod has been broken in attempting to draw out a tool wedged in by a fall of side, is it not natural to fear that it would simply break at some other point if a new attempt were made to dislodge it with the claw? This is not always the consequence, however, and what cannot be done the first time, may be managed by repeating the efforts with caution, and combining them in different ways. For example, besides simply drawing at the rod with the engine, it may be twisted in one or both directions alternately, with or without jerks; or a series of upward jerks may be substituted for continuous traction, and, little by little, these may produce a gradually increasing amount of movement, until the desired loosening is effected.

If it is desired to exert an energetic tug at the rod, or at a column of tubes, it is jammed firmly betwixt two wooden yokes, having had its surface previously roughened to make it hold better; long elastic levers are then placed each with one end under the yokes, and strong pressures are produced by jolting down the other ends. A very efficacious arrangement is to have one of Kind's sliding joints (fig. 85) in the rod that is introduced for the purpose of making manœuvres of this kind; by this means a series of jerks can be made at the rod below, either upwards or downwards according to circumstances, and these often lead to a disengagement. This artifice has to be employed not only in the case of an accident, but also as an indispensable addition to the use of certain tools. For example, with the enlargers (fig. 66 and 67) it is necessary for the purpose of disengaging the wedge by which their branches have been expanded before they can be brought to the surface. For this reason the wedge is not attached directly to the cord which serves to draw it into position, but a small sliding joint is introduced, the upper part of which, acting on the lower part like a kind of hammer, causes the wedge to fall down again.

A deviation of the bore from the perpendicular is a serious accident and one very difficult to avoid in highly inclined strata with alternations of hard and soft beds, or when the face of a steep fault is encountered. It is advisable, in a case of this kind, to fill up the bore, to the point from which it has deviated, with hard pebbles such as flints, to ram them down firmly and then to begin boring across this mass. When a thin bed of running sand is met with, it is better to throw in lumps of clay, ram it firmly down with a wooden rammer so as to drive part of it into the sand bed, then to cut a hole through the clay in the bore with a clay auger, rather than to let down a short tube which would cause the bore below it to be somewhat contracted. This claying-out may succeed when the sand bed is thin and the diameter of the bore small, or it may be employed with advantage in a large bore, to keep back the sand until a tube has been placed.

These examples might be multiplied, but it is plain that we cannot describe all the incidents that may occur in practice. Natural sagacity and experience ought to suggest special means and even with every care these are not always sufficient.

(**102**) The preceding account relates to the most commonly practised method of boring, called *boring with rods*. It will be of use, however, to give some information about another process which has been recommended for some undertakings; it is called *boring with a rope* or *the Chinese method of boring*.

The first name indicates the method of working: the second has been given to it because it appears to be, or to have been, practised in China, according to some short accounts given by missionaries.

The principle of the system consists in the employment of a rope, analogous to that which is used with the sludger, *for boring as well as cleaning*. The rod may be considered as reduced to the part under the sliding joint, that is to say to a *short thick part* which is heavy enough to make the tool act properly and at the same time *long enough*, and sufficiently well guided, to keep the bore vertical. It is of advantage, however, for the reasons given in the preceding number, to introduce a sliding joint between the rope and the tool.

The advantage supposed to be gained by the employment of this method, is a saving of the time spent in joining and disjoining the rods, which admits of the cutting tool being raised and lowered as quickly as the sludger. This advantage is self evident and becomes all the greater when the bore has arrived at considerable depths. Unfortunately, however, the rope is least applicable in the case of deep bores, partly on account of its extensibility and flexibility even when a wire one is used, partly because the system offers few resources in case of accident, or when, from any cause, it becomes desirable to rotate the tool; and it is very rare that these circumstances do not often occur in cutting a deep bore-hole. Of course it is always necessary to have a certain length of rigid rod attached to the rope, for reasons already specified.

Two other advantages have been claimed for this method: the first is, that there is less weight to handle; the second, that the pulley-frame need not be high; hence, fewer men are required to carry on the work, and the first cost is less than by the ordinary method.

It may be replied, that, in boring with the rod, good arrangements and the use of steam engines reduce the number of men, so that it becomes, as it were, independent of the depth; and, further, that if the first erection is made suitable only for boring with a rope, it would be insufficient if at any moment it became necessary to use a rod.

We are of opinion, that when a bore is commenced, it is better to arrange for the use of a rod from the first and to use the rope method in suitable ground where there is not much chance of accident, rather than to arrange solely for the rope method, not considering the possible necessity for employing a rod as more than a remote contingency. For bores of large diameter, however, this mixed system is not very practicable since the weight to be handled amounts to many tons.

In our opinion, these are the limits between which it is advisable to have recourse to rope boring; indeed, the method was much lauded at one time, and after undergoing some improvements in its details was employed with some success, but it was not much adopted and is now almost altogether abandoned (*).

An attempt was made to perfect it by a special arrangement called, by its inventor the French method; it was distinguished by the employment of a retaining tube which descended as the hole was deepened; the column of tubes received a slowly revolving motion which was imparted to the tool as it was in the act of boring. In this way it was possible to form a round hole and to prevent the rope from being worn away by rubbing against the sides; but the system does not seem to have survived its inventor.

(**103**) Another system consists in the employment of hollow boring rods. Theoretically, a hollow rod has the same resistance to tension as a solid rod of the same section while its resistance to crushing, and especially to torsion, is greater. In reality, however, hollow rods will have a much greater section, than the solid rods which they replace, before their thickness is pratically sufficient; and they will always be heavier and more expensive, partly on account of their greater weight, partly because their cost is greater per unit of weight. The advantage to be gained by employing them, consists in making them act as cleaning instruments, at the same time that the tool at their extremity acts as a boring tool. For this purpose a jet of water is made to flow down inside the tube; it escapes by an opening at the bottom and determines an upward current of water in the bore-hole, which raises the pounded materials to the surface. This system is still employed and appears to offer some advantages, it is well, however, not to exaggerate their importance. The time gained is not what is required for taking up and letting down the rod; for, if this work were not done for the purpose of cleaning, it would require to be done in order to examine and repair the tool. In reality, the time gained is what

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(*) Messrs. Mather and Platt, of Manchester, have adopted a system of boring with a flat hempen rope, and have used it with success in many parts of England and in various other countries. (See *Min. Proc. Inst. Mech. Engineers* 1869, p. 278) *Translators.*

would be taken up in cleaning; that is to say, when one tool is taken off and a fresh one put on, the rod can be put in again immediately. Indeed, the gain of time is a very small matter; nevertheless, it should be mentioned at the same time, that the cutting tool does somewhat more work, as the bottom of the bore-hole is always clean.

(**104**). The details given in the preceding pages (N^{os} 81 to 103) refer to important borings for minerals or for artesian wells. The borings of small importance, mentioned in N° 80, require neither the same variety of tools nor the same extensive preparations. They resemble more the ordinary shot-holes drilled by the miner for blasting purposes than the bores of which we have been treating.

Exploratory bore-holes in underground workings, in search of old workings containing water or foul gases which are supposed to be in front, are made only one or two inches in diameter, in order to be more easily stopped up when the old workings are tapped. They are bored parallel to the stratification, in the face and at the sides of the exploring drift.

The face holes are bored in the axis, or parallel to the axis of the gallery, and kept at a distance of 7 to 10 feet (2 to 3 metres) sometimes 30 to 40 feet (10 to 12 metres) in advance. These distances are dependent on the solidity of the substance in which the bores are made, on the size of the gallery, and on the supposed head of water. The side holes are bored obliquely and new ones are begun as required. In this way a certain degree of assurance is given that the front and sides of the gallery are protected by a certain thickness of mineral.

If it were not known exactly where the old workings had been, it would be necessary to bore also in the roof and floor of the gallery; that is to say, if the gallery were in a thick bed of coal for instance.

These holes are drilled with jumpers and cleaned with scrapers like those used in making shot-holes. The bit of the jumper is made of steel, the separate pieces of the rod are joined with screws; and they are made round so as to be more easily handled.

In general the bore-hole is begun in the face without any particular preparation. If, however, the object be to tap and drain an old working containing a large accumulation of water, and if the deposit is of a friable and jointy nature, a cast iron pipe of the same internal diameter as the bore-hole, is fixed in the face; it is fitted into the rock, to a certain distance, and carefully packed behind the large flange with which it is provided. It is also furnished with a cock by means of which the flow of water can be regulated after the waste has been tapped.

When holes of this kind are bored downwards and are not more than $2\frac{1}{2}$ to $3\frac{1}{2}$ inches (5 or 6 centimetres) in diameter they can be easily drilled by hand. Horizontal holes, or those tending upwards, are more difficult to cut, as they cannot be kept filled with water like the others and the bits get fouled and blunted more rapidly.

This inconvenience can be avoided by directing a jet of water into the hole from time to time.

It is easy to design an apparatus to counterbalance the weight of the rod, but such a contrivance is not so easily set up in a gallery where the space is limited. In practice a guide is set up to bear the weight of part of the rod when it seems to be necessary; it consists of a roller fixed at the required height to two props between which the rod passes.

The method of boring just described, is quite sufficient for prospecting holes reaching from the surface to a depth of 35 to 45 feet (10 to 12 metres); but if a series of such bores were required, it would be better to have a three-legged shears and a horse supporting a small brake or lever for making the strokes.

In prospecting beds of peat, the cutting tool is replaced by a screw auger of small diameter which is worked by turning it round.

For superficial deposits of iron ore which exist in irregular pockets in the limestone districts of many parts of France—Périgord, Berry, Champagne, Franche-Comté, etc.—the search is made with a pointed rod which is forced into the ground driving back the earth. Above the point there is a swelling rather larger than those at the joints, and the character of the deposits is known by observing the characteristic colour of the deposit which remains on this swelling when the rod is withdrawn.

§ 5. — Various data relating to boring.

(**105**) In the preceding paragraphs we have described in detail the form and mode of employment of the various instruments which constitute the special tools of the borer; in a more summary manner we have described the machines by the aid of which they are manipulated, and lastly, we have given some information about the carrying on of the work itself. As a résumé and conclusion we will give an outline of the mode of starting and carrying on a boring which has to be pushed to a depth of 700 to 800 yards (500 to 600 metres) or more.

After the position of the bore-hole has been determined on—regard being had to the considerations of N° 101—the following questions have to be considered and solved:—

1. *The initial diameter to be given to the bore-hole.*—It is of great importance to start with a hole of large enough diameter, and this is all the more advisable when it is foreseen that difficult ground will have to be passed through. In easily traversed strata a diameter of 8 inches ($0^{m}\cdot2$) will be sufficient; but for difficult ground in which several series of tubes, which have to pass through each other, will be required, the initial diameter should be at least 12 inches ($0^{m}\cdot3$) since it might not be practicable to force down a single column of tubes to the necessary depth, on account of the friction. It may be estimated, on the one hand, that each series of tubes will cause $1\frac{1}{2}$ to 2 inches (4 to 5 centimètres) of the diameter to be lost, because of the thickness of the tube itself and of the play which the tools must necessarily have in passing through it; and, on the other hand, the final diameter of the bore may be fixed at 4 inches ($0^{m}\cdot10$). These dimensions apply to bores put down in search of minerals: for artesian wells, diameters as great as 1 foot

8 inches ($0^{m}\cdot5$), 3 feet 3 inches (1 metre), and even 5 feet 10 inches to $6\frac{1}{2}$ feet ($1^{m}\cdot80$ to 2 metres) have been taken.

2. *The machinery for raising the rod.* — Height is the essential element to be considered in connection with the shearlegs, since it enables the operations to be done rapidly; it should be at least 50 feet (15 mètres). The most simple kind of shears is a three-legged one properly braced. The useful height, as already mentioned, is increased by placing the boring floor as far as possible below the level of the surface. For example, if the bore were to be begun at the bottom of a shaft, the engine would be at the surface and the boring floor at the bottom of the shaft. The rod can then be drawn up or let down in lengths equal to the depth of the shaft *plus* the height of the shears, and great economy of time is the result.

3. *The kind of rod to be used.*—There may not be many grounds of preference in choosing between iron and wooden rods; at any rate, both kinds are used by the most skilful borers. The former seem to be more secure and to offer more resources in case of accident, where as the latter are lighter and, hence perhaps, more easily handled.

The joints should all be screwed, as this is the only system that permits of the separate pieces being taken indiscriminately, and also occupies the least time in joining and disjoining. The employment of a sliding joint and free falling tool may be said *to be indispensable.* A parachute, and guides at proper intervals, are useful and may prevent accidents that might lead to serious consequences. For instance, if a great length of rod accidentally slipped away from the workmen: without a parachute it would fall to the bottom with great velocity and be bent or broken into a number of pieces which might become entangled in the most complicated way.

4. *The tools.*—The ordinary work will be done with a simple easily repaired chisel and a sludger. A claw and bell-screw will be required as accessory tools. A certain number of retaining tubes will be kept at hand; their exterior diameter should be $\frac{3}{4}$ inch (2 centimetres) less than the diameter of the bore in order to facilitate their being put into place; the swelling out of the walls

after a time, causes then to be held fast. The other numerous tools which we have already mentioned will be obtained as they are required.

5. *The motive power.*—Steam is preferable in all cases (excep when no water can be obtained) if the depth is to exceed 250 to 300 yards (250 to 300 metres); it is economical in every respect, the number of men is reduced and does not required to be increased with the depth, so that only a few skilful workmen are necessary. This is a great guarantee against accidents which might be caused by unskilfulness. The engine can be employed in all the operations except turning the rod, that is to say, in letting down and taking up the rod, in boring, and if required, in manipulating the sludger; it will be about the same size as an ordinary winding engine and have the same general arrangements—a horizontal engine with two cylinders, fitted with reversing gear, a light flywheel and a strong break. It may be 8 or 10 horse-power or even 12 to 15 for a deep bore. To diminish the chance of accident in case of a sudden stoppage of the rod, the engine is connected with the drum or bobbin-shaft by means of a belt, the same kind of connection is also made with the drum for the rope of the sludger. Both belts are never in gear at the same time.

The employment of two distinct ropes for manipulating the rod, lessens the time consumed in lifting and letting it down, and in this way increases the daily duration of the boring process.

The boring engine may be distinct from the others, but connected with the same boilers; it should always be worked by hand, so that the length of the strokes and the number made in a given time, can be varied as the master-borer directs. It is arranged like a pumping engine, either direct acting or with a beam; the latter arrangement appears to be preferable although it is rather more complex.

The diameter of the cylinder is calculated in connection with the boiler pressure and should be such that the piston may be able to lift easily the greatest weight of rod that will be employed when the bore is nearly completed; during the earlier stages, therefore, the steam must be throttled. When the winding engine is arranged to bore also, a special engine is not required; this arrangement may be made in a similar way to that employed by Degousée and Laurent who obtained thereby the considerable mechanical advantage we have already referred to in No. 84.

(**106**) With plant arranged as described above, properly planned, and confided to intelligent and skilful workmen, it may be though that a boring could be carried out under as favourable conditions as the actual state of the art permitted.

Notwithstanding this, however, the nature of the work entails so many uncertainties that it is impossible to foresee at the outset how much time will be occupied before the work is completed, or what it will cost. It is, therefore, difficult to find reliable persons to contract for borings; or, if they can be induced to do so, they will probably demand a higher price than the boring would cost if done by day work, a reasonable number of unforeseen difficulties being allowed for.

It appears better to treat with them on certain conditions which do not expose them, as it were, to the possibility of unlimited losses, and yet, at the same time, interest them in having the work promptly and fairly carried out.

For instance, a fixed monthly sum might be paid to the contractors for the use of the materials furnished by them, a second sum for the salary of the special staff, whilst the wages of the labourers as well as all expenses for coal, etc. might be paid by the company for whom the work was being done; or else another larger sum might be allowed to them if they became responsible for all other remaining expenses.

Certain dates could be fixed when definite depths would have to be attained; the company, however, might have the option of stopping the boring at any desired point. When the boring was finished the contractors would receive a certain *fixed premium* depending on the depth attained, and a certain *variable premium* depending on the number of days less than the time fixed by the contract, within which the work was carried to this depth.

This combination, or one like it, appears to guard the interests of both parties equally, and to make it advantageous for both that the work be done quickly.

(**107**) In order to give some idea of the figures that would form the subject of debate between the parties discussing a contract of this kind, we shall give some examples of mean daily rates of progress that have been made under various circumstances. These rates of progress are for continuous work by day and night, and should be reduced by *a little less than one half* if one shift were carried on in the day time only.

1. Tertiary and Chalk formations which are difficult on account of the running nature of some of the beds.—Bores of 100 yards (100 metres) 3 ft. 5 in. ($1^{m}\cdot05$).

2. Chalk formation with few flints.—Bores of 218 to 328 yards (200 to 300 metres) 4 ft. 4 in. ($1^{m}\cdot33$).

3. Chalk formation with many flints. Same depths as in the last case, 2 ft. 9 in. ($0^{m}\cdot85$).

4. Hard siliceous rock.—Bunter sandstone and Vosges sandstone of the Eastern departments— Bores of 163 to 218 yards (150 to 200 metres), 3 ft. 9 in. ($1^{m}\cdot16$).

5. The same rock.—Bores of 708 yards (650 mètres), 2 ft. 10 in. ($0^{m}\cdot86$).

6. Coal measures, easy ground.—Shallow bores of various depths, 5 ft. 10 in. ($1^{m}\cdot78$).

The corresponding costs can be estimated from the above figures when the expense of bringing the materials to the ground has been ascertained, and when the daily expenses can be estimated according to local conditions.

Each of the above figures, with the exception of the last but one, is the mean of a considerable number of borings and may, therefore, be accepted as nearly exact; but the works were carried out at different times scattered over a number of years, and were executed according to various processes. It is our opinion that similar work, done with the tools and latest improvements of the present day, would occupy less time and be done more economically. We consider that for bores of 218 to 328 yards (200 to 300 metres) in soft ground like the Chalk, with an ordinary proportion of layers of flint, 4 ft. 11 in. ($1^{m}\cdot50$) should be cut per day of twenty four hours; and at least 2 ft. 7 in. ($0^{m}\cdot8$) if the work be carried on during the day time only; for bores of 218 yards (200 metres) in hard sandstone with the beds nearly flat, 4 ft. 3 in. ($1^{m}\cdot30$) per twenty-four hours, and at least 2 ft. 3 in. ($0^{m}\cdot70$) per twelve hours by day; and for bores of 654 yards (600 metres) and more, 3 ft. 3 in. (1 metre) in the first case, and 1 ft. 9 in. ($0^{m}\cdot55$) in the second case.

As a simple illustration, we give the cost of the bore of 708 yards (650 metres) in depth, referred to above. Many accidents happened during its execution and explain the small daily rate of advancement. It cost about 8000*l.* (200,000 francs), or in round numbers 11*l.* 8*s.* 6*d.* per running yard (300 francs per metre). The cost of sinking a shaft to the same depth would be at least twice as much as this, and generally, it will be more than double that of boring, so long as the bore-hole is only for prospecting for minerals. Bores of large diameter cost notably more, both for cutting and for the lining with a permanent tube.

A large bore-hole for an artesian well, 546 yards (500 metres) deep by 1 ft. 7 in. to 3 ft. 3 in. or 5 ft. 10 in. ($0^{m}\cdot50$ to 1 metre or $1^{m}\cdot80$) in diameter would cost 15*l.* 4*s.* 9*d.* to 19*l.* 1*s.* per running yard (400 to 500 francs per running metre) or even more.

A series of shallow bores of 33 to 66 feet (10 to 20 metres) on the other hand, would not cost more than a few shillings per yard.

It is as useless as it would also be impossible to try to establish a rational mean between such widely separate limits; and such a mean would evidently be inapplicable to any particular case.

(**108**) We shall conclude this chapter by giving some examples of boring plant of which some details are given in Nos. 81 *et seq.* and in the figures 48 to 98 which are there referred to. These examples are represented in figures 99 to 104: the two first are simple arrangements for borings of little importance—with the rod (fig. 99) and with the rope (fig. 100); the four figures which follow, refer, on the contrary, to very important undertakings and represent types created by the three principal firms who have devoted themselves to enterprises of this kind for the last thirty years.

Figure 101 is the arrangement designed by M. Kind for the well at Passy; figure 102 is by M. Dru for the well of the Boulevard de la Gare. The latter well was sunk with the expectation of intersecting the water-bearing bed of the Grenelle and Passy wells at a depth of 600 to 654 yards (550 to 600 metres).

Figures 103 and 104 are the arrangements at the wells of La Butte-aux-Cailles and La Chapelle, the former by M. Dru the latter by MM. Degousée and Laurent; these bores were put down in search of a water-bearing stratum which was supposed to exist below that which supplies the two foregoing wells, in the Oolitic rocks, at a depth of 981 yards (900 metres). We have already stated that the authorities of the town of Paris decided to bore for a water-bearing bed below the Lower Greensand, which supplies the Grenelle and Passy wells, in order not to diminish the quantity of water furnished by these two, which already influenced one another although several miles apart.

If the plant represented in figures 99 and 100, might perhaps be regarded as insufficient for a boring of some importance, the four others, on the contrary, and especially the two last, may, with some reservations as to the mechanical arrangements, be taken as presenting the last improvements of the art of boring; and they are on a scale which surpasses anything that could be required in searching for minerals, even for a very deep bore-hole.

We have thus given examples of the extremes between which an engineer would generally be confined, in planning and considering in detail the erection of plant for work of this kind.

CHAPTER V.

BREAKING GROUND

§ 1. — Preliminary observations.

(**109**) We have seen in the preceding chapter how the deposits of useful mineral substances found in the bosom of the earth have been formed, and how extremely they vary in their character and mode of occurrence; how their material existence *may first of all be proved* by prospecting; what exploratory workings should be carried out upon them before the question of their being finally worked *can be put;* and, lastly, what numerous and delicate conditions may be included in the study of this question either from a technical or commercial point of view.

Let us suppose the question answered in the affirmative; we propose, therefore, to work a deposit of which we know more or less exactly the general character.

Whether it be a question of *winning*, *i.e.* reaching the deposit by shafts or levels, or of the subsequent *working* for actually removing it, we have always to make excavations, either in the enclosing rocks (*country*) or in the deposit itself. These excavations are the work of the *miner* properly so-called. They are effected by means of processes and special tools, the employment of which constitutes what is called the work of *breaking ground*. It is with this subject that we have to deal at present.

(**110**) Taking as a basis the difficulty of excavating them, and adopting an old classification originated by Werner, we may arrange rocks as follows :—

Loose or running ground ;
Soft or *fair* ground ;
Semi-hard ground ;
Hard ground ;
Very hard or *tight* ground ;
Lastly soluble rocks.

In Werner's line of thought, each of the categories corresponds to the use of a tool, or a process of working, which is particularly appropriate to it.

Thus, to running ground would correspond work with *the shovel*, to soft ground work with *the pick*, semi-hard ground would be treated with the *Saxon gad*, and hard ground by means of *gunpowder*; very tight ground would be excavated *by means of fire*, and soluble rocks *by means of water*.

This classification is nowadays almost obsolete. In the regular course of mining the Saxon gad work and fire-setting are rarely employed and will be so less and less. Leaving out work by means of water, which is merely a very special case, there is reason to believe that work by powder, or blasting, is destined to encroach more and more on the domain of the other operations, in proportion as more advantage will be found in economising human power on account of the rise in the price of labour. It is thus in England that a given amount of progress in a certain rock is made with *fewer days' work* and a *greater expenditure of powder* than in Germany.

However, in order to give an idea of the relative difficulty presented by the different rocks in which the miner may have to work, we will reproduce the enumeration, according to Werner, given in the classical work of Héron de Villefosse on Mineral Wealth.

In the class of loose ground the author places : « Vegetable earth, sand, certain earthy deposits and many alluvia. »

In the class of soft ground : « Strongly agglutinated sands, most alluvia, hard clay, rotten deposits, which are generally penetrated by clay and rusty oxide of iron, greatly decomposed granite and gneiss, some gypsum, nearly all the kinds of coal, rock salt, some ores with a veinstone of heavy spar, cinnabar, ruby silver ore and in general all ores with a friable veinstone. »

He classes under the head of semi-hard ground : « Certain limestones, copper slate, alum shale, serpentine, marl, gypsum, sandstone, all rocks which are much impregnated with clay and rusty oxide of iron, those which exhibit large pieces of mica or small joints, all granite, gneiss, porphyry and mica-schist which has undergone a considerable decomposition; all the so-called spathose substances, except felspar which is hard and heavy spar which is soft; lastly, most metallic ores such as sulphide of lead, sulphide of zinc, copper pyrites and spathose iron. »

He classes under the head of hard ground attacked by boring and removed by blasting : « Most kinds of granite, gneiss, mica-schist, porphyry, clay-slate, grauwacke, basalt, and limestones, quartz covered with crystals or mixed with clay, nearly all hornblende rocks, nearly all varieties of magnetic or red hematite iron ores, iron pyrites, mispickel, the ores of cobalt, all ores much mixed with quartz. »

Lastly, among the very tight or refractory rocks which are partly detached by fire, whereby the remainder of the operation is rendered easy, he reckons : « Pure quartz, very quartzose varieties of granite, gneiss, mica-schist, porphyry with a base of petrosilex, porphyritic schist, compact garnet, very quartzose sandstone, some conglomerates, some ores which are an intimate mixture of iron, zinc, sulphur, arsenic and quartz; lastly, tin ore disseminated through a very tight rock. »

This list is not very satisfactory because, on the one hand, it contains substances which need not be taken into consideration, such as ruby silver, which never forms masses of sufficient size to make it worth while troubling oneself about the means of breaking them, on the other hand, it is incomplete as it does not mention explicitly the rocks of the Coal Measures; neverthless we can retain five degrees of hardness which we shall designate by the numbers 1 to 5, passing from the harder to the softer rocks.

(**111**) Applying this classification we shall say in a general manner:

Firstly, *for lodes*, the workings in the enclosing rocks (*country*) in the Palæozoic strata, such as those to which most metalliferous districts in Europe belong, will meet with rocks whose hardness may be denoted by the number 2; hardness of the 1st degree being a tolerably rare exception. The lodes themselves may be of the 2nd degree, passing over to the 1st when the veinstone consists essentially of quartz with a saccharine structure in which the ores are finely disseminated; they will pass over to the 3rd degree, when the veinstone consists of heavy spar and when their ores are concentrated into large masses.

Secondly, *for the Coal Measures*, the hardness of the rocks to be cut through in crosscutting or sinking through the strata, will usually be of the 2nd or 3rd degree, with this difference that in the coalfields of the centre and South of France, the 2nd degree is proportionately much more common than in the great coalfields of the North, and that occasionally rocks of the 1st degree occur, such as very quartzose and tightly cemented sandstones and conglomerates.

Coal, always remains a substance of the 4th degree, in spite of certain differences in compactness causing great variations in the quantity of *large* coal obtained in the getting, and consequently in the merchantable value of the product.

Thirdly and lastly, *for massive deposits*, every variety of hardness may be met with from the 1st degree which would characterize certain stockworks, or quartzose masses with ores finely disseminated though them, such as those of the Rammelsberg in the Hartz, down to the 5th degree, which would be presented, for instance by many alluvia.

§ 2. — Description of the operations.

(**112**) The removal of loose ground is effected by means of the pick and shovel and constitutes properly speaking navvies' work.

The navvy's pick serves to break up the ground into small pieces, to disintegrate it, so as to render it easy to fill the shovel. Large lumps, such as large boulders, will be loaded by hand and also pieces that are strongly cemented together which would not yield to the pick.

The head of the pick may have only one *shank* ending in a *point*, or in an *edge* at right angles to the *hilt*, according as the ground to be removed is *sandy* or *clayey;* on the opposite side it may have a square *poll*, which in case of need can be used as a sledge.

The head may also have two shanks or stems, one ending in a point and the other in an edge; these two parts should have their common centre of gravity in the axis of the hilt, so as to facilitate the use of the tool in planes other than vertical, without the hilt tending to turn in the hands of the workman. In the case of open workings, where the workman's movements are not confined, the hilt may be from 3ft.3in. to 3ft.7in. (1 metre to $1^{m}\cdot10$) in length; it is usually made of ash split in the direction of the grain. In order to make it suit the hand it is best to give it an oval section of $1\frac{1}{2}$ inch by 2 inches ($0^{m}\cdot04$ by $0^{m}\cdot05$), and to make the end very slightly swelled. A firm hold for the hilt is obtained by making the eye slightly conical, the small base being towards the hand. A wedge driven into the wood spreads out the fibres and prevents the hilt from coming off. The two stems of the head ought not to be in a straight line but should form the arc of a circle having its centre somewhere about the shoulder joint of the workman, so that the point may strike the ground fairly. The tool ought to be steeled at its edge and tip, or may be made entirely of steel.

The figures 105 exhibit the principal details mentioned above.

The tool for removing the rubbish formed by the pick is the shovel, the *plate* of which may be from 10 to 12 inches ($0^{m}\cdot25$ to $0^{m}\cdot30$) broad by 12 to 16 inches ($0^{m}\cdot30$ to $0^{m}\cdot40$) on the side.

To make it enter more easily into the stuff, the thin blade which forms the plate of the tool has a trapezoidal section of which the cutting edge or *mouth* is the smallest side; often also the two sides or edges join in a curve, or themselves form two curved lines which unite at a more or less acute angle (fig. 106). On the back of the plate there is a projecting rib which dies away towards the mouth, and spreads out on the opposite side to form the socket for the hilt or helve.

The hilt is about 4ft.5in. ($1^{m}\cdot30$) long and ought to be inclined at an angle of about 45° when the plate is horizontal, or, what comes to the same thing, it ought to make an angle of about 135° with the plate. This arrangement is suitable for open workings. In a low working place where a man cannot stand upright this angle of 135° ought to be increased, and the lower the working place the greater the angle. At the same time the handle or hilt would have to be made shorter. Many shovel plates are now made of soft cast steel, which permits them to be made lighter while at the same time they are more durable.

All these details, which may appear minute, are important, because each of them contributes its little share towards increasing the useful effect. We will say here, in a general manner, that for any work, no matter what it may be, the tool put into the workman's hands should always be studied with care as to its shape, its dimensions, the amount and distribution of its weight, etc., and it should always be kept in good condition.

I think it my duty to lay some stress upon this point because sufficient attention is not always paid to it in France, where people are too often disposed to think and say that *for a good workman there are no bad tools*, meaning that a skilful workman manages to do his work even if his tools are indifferent. They follow other plans in other countries, in England especially, where it is found on the contrary that *no tools are too good for a good workman.* This is certainly one of the causes which bring about this unquestionable result, that in many industries, all other circumstances being the same, the English workman produces a useful effect superior to that which is obtained in most other countries.

(**113**) In the case of deep excavations we must add to the stock of tools, consisting of pick and shovel, large wedges, formed of round wood shod with iron at the bottom or large end and ferruled at the top; they are 4 to 5 inches ($0^{m}\cdot10$ to $0^{m}\cdot12$) or more in diameter and vary in length from 1ft.8in. to 3ft.3in. or 4 feet ($0^{m}\cdot50$ to 1 metre or $1^{m}\cdot20$) (fig. 107).

These stakes are planted in lines parallel to the breast of the cutting, which is in the form of a series of steps or *stopes*, and are driven in by blows from a sledge. This brings down a prism, having for its length the width of the cutting and for the sides of its base the height of the stope and the distance from the line of stakes to the edge of this stope.

The dimensions of these prisms should be determined by the condition that in falling down they ought to break up into pieces small enough to render the subsequent pick work much easier.

The working place in a deep cutting in loose ground, will therefore present a straight breast of the width of the cutting, bounded to the right and left by slopes suited to the more or less loose nature of the ground.

The necessary roads for removing the rubbish are arranged on the sides of these slopes. The total height of the work will have to be divided into a series of straight *stopes*, like the steps of a great staircase, each of them being from 3 feet to 5 feet, or 6 feet or more high. (1 metre, $1^{m}\cdot30$ or 2 metres) (fig. 108).

Each of the stopes is sufficiently in the rear of the preceding one to let the men work without inconveniencing one another; or the width is at least double the height. They are carried on by *undercutting* the foot of stope with the pick and then driving in stakes about 1 or 2 yards apart (1 metre to 2 metres) at a distance of from 3 to 5 feet (1 metre to $1^{m}\cdot50$) from the edge. The undercutting must be performed cautiously by skilful and prudent workmen, who must take care not to be caught under any premature fall of the piece they are trying to detach. As a rule they ought not to continue their undercutting until the prism falls of itself; they ought only to prepare for the fall, and then complete it by driving in the stakes; during this operation the workmen not directly employed in wedging ought to withdraw behind the breast of the cutting.

(**114**). Rocks of the 2^{nd} class are broken down by the pick.

The miner's pick has the general shape of the pick just described, but differs from it in its dimensions and the manner in which it is used.

Instead of working in the whole of the mass with the double intention of making the excavation in question and of subdividing the rocks into pieces fit to be loaded at once by the shovel, the pick is employed on a harder substance and one less easy to break up, simply to make grooves or cuttings as deep and narrow as possible; the object is to reduce the quantity of matter to be broken up by the pick and obtain masses set free on several sides, which can then easily be made to *fall*, either by allowing them to *work* or by assisting the fall by means of wedges or blasting.

In breaking stuff in a working place the first operation generally consists in making a cut or *jud*, (*holing*, *benching*, *kirving*, *undergoing*) at the bottom of the level if the rock is uniformly hard; or else in the softest part best suited for the work. For instance in a seam of coal this will be a rib of friable coal or a parting of soft shale.

Holing is an operation of the same nature as the *undercutting* mentioned in the preceding number, but it is carried out in a clearer and better defined manner. The *jud* is made 8 to 10 inches ($0^{m}\cdot20$ to $0^{m}\cdot25$) high at most, sometimes only two or three inches, and it is carried to a depth of not less than 20 inches ($0^{m}\cdot50$) and generally 2ft.6in. to 3 feet ($0^{m}\cdot80$ to $0^{m}\cdot90$), occasionally even 4ft.3in. to 5 feet ($1^{m}\cdot30$ to $1^{m}\cdot50$).

After having been *holed*, the block to be removed has to be *sheared* or *cut*, that is to say, grooves or *side-cuts* are made on each side of it. They ought, as a rule, to be narrow and of the same depth as the holing.

When holed and sheared on each side a block adheres only by two faces, the upper or lower according as the jud was made above or below the block, and the back-face.

It may fall of itself on removing props or *sprags* which supported it temporarily during the work.

If it does not come down of itself, it is made to fall by a little blasting, performed as will be explained hereafter, or by wedges driven in by a sledge in the plane along which it is desired to make the block break off.

The whole prism is thus made to fall either in one piece, or in several consecutive pieces if there are planes along which it separates easily, or if these successive falls render the picking more easy and thorough.

The block in falling generally breaks into several pieces, which are broken up with the pick, but only so far as is strictly necessary in order to load by hand, whilst the resulting smalls are filled with the shovel. The work is done in this way to avoid the trouble of breaking up, which would not only be *useless* but also *disadvantageous*, as large lumps are generally more valuable than smalls.

Picks are made in different shapes as shown in fig. 109.

The head of the pick is made of iron 10 to 14 inches ($0^{\text{m}}\cdot25$ to $0^{\text{m}}\cdot35$) long, ending on one side in a square taper steel tip, the *acuteness* of which diminishes with the hardness of the rock, and on the other in an oval or trapezoidal eye which serves to receive the handle (*hilt* or *helve*). The head has a square section 1 inch ($0^{\text{m}}\cdot025$) on the side, or better is rectangular, 1 inch to $1\frac{1}{4}$ inch high by $\frac{1}{2}$ inch to $\frac{3}{4}$ inch wide (27 to 30 millimetres by 15 to 20 millimetres). Its weight generally varies from $1\frac{1}{2}$ to $4\frac{1}{2}$ lbs. ($0^{\text{k}}\cdot75$ to 2 kilos.) or even $5\frac{1}{2}$ lbs. ($2^{\text{k}}\cdot50$). The handle or hilt is from 2 feet to 2ft. 4in. ($0^{\text{m}}\cdot60$ to $0^{\text{m}}\cdot70$) long in low workings, and from 2ft. 8in. to 3ft. 3in. ($0^{\text{m}}\cdot80$ to 1 metre) in places where men can work at their ease and give good blows.

The oval or trapezoidal eye generally forms a symmetrical swelling on each side of a plane passing through the axis of the hilt and the head. In other cases the swelling is made entirely on one side. This may be done when a seam has to be holed at the very bottom, and the miner wishes to swing the pick as low as possible letting it slide along the floor.

The pick just described is the principal tool used by miners for breaking down a seam of coal; it admits of several variations.

Thus the so-called *poll-pick* differs from the ordinary picks by the dimensions of the head. It is from 14 to 16 inches ($0^{m}\cdot35$ to $0^{m}\cdot40$) long, and in section $1\frac{3}{8}$ inch (35 millimetres) by from $\frac{3}{4}$ inch to 1 in. (20 to 25 millimetres), it has a square poll at the end opposite the point. Its weight may be from $6\frac{1}{2}$ to 9lbs. (3 to 4 kilos.) and even more. It is used for breaking away thick hard partings which may be interstratified with a seam of coal, or in the case of working in rock for working down and breaking up the rocks already fissured and shaken by blasting. It is used in various ways according to circumstances : either as an ordinary pick, or else as a lever by putting the tip into a crack and *prizing* with the handle, which ought to be strengthened at the *feather*, or finally as a sledge striking with the poll. The poll is sometimes made so large that the handle passes through the centre of gravity of the head. It may thus be easily swung in any plane and is used for *hulking* a lode, *i. e.* removing a soft *dig* or *hulk*. The German name for this kind of pick is *Schrämhammer*.

The *double-pointed* or *English pick* differs from the ordinary one in having the helve or hilt in the middle of the head and not at one extremity. The tool does not require to be grasped tightly; for work it is equal to two ordinary picks; it requires a little more skill than these when it is necessary to make a deep and narrow jud.

The *rivelaine* is a pick with one or two points, formed of flat iron at most $\frac{3}{4}$ inch (2 centimetres) thick, welded to an iron handle of the same thickness, and ending either in a round part to be grasped by the hand or in a socket into which a wooden hilt is fixed. The total length of the two handles amounts to 5ft. 10in. ($1^{m}\cdot80$).

This tool is used for holing in layers of clay, often only $\frac{3}{4}$ to $1\frac{1}{4}$ inch (2 to 3 centimetres) thick, which frequently occur under a seam of coal.

The *rivelaine* does its work by a kind of scraping action rather than by percussion and serves to make a very narrow jud into which the swelling that forms the eye of an ordinary pick would not enter.

A thin and soft layer occurring at the floor of a seam or in the seam itself is called a holing, *havrit* in Belgium; and kirving in a bed of this kind is called in Belgium *havage*. The existence of a holing (*havrit*) facilitates and shortens very considerably the work of *getting* the coal, and from this point of view we ought to make a distinction between seams having *a holing* and those having none, that is to say those where the coal preserves its hardness to the very floor, to which it adheres more or less tightly.

The pick, of whatever kind it may be, generally ends in a point for attacking the rock, which scales off and splits into little fragments under the blows. In making a cut, a skilful miner first of all makes two little grooves very close to one another working his pick along two vertical lines; and he then breaks off the little prism between the two grooves by working his pick along a vertical line between the two first ones.

If the rock instead of being brittle and fragile has a pasty consistency, the point may be replaced by an edge or chisel tip at right angles to the handle. This is done with *rivelaines* when the *havrit* is soft and decidedly clayey.

If the rock is to certain extent tenacious, as in the case of lignite that has partially preserved the fibrous texture of the wood, the tip of the pick may very conveniently have a chisel edge parallel to the handle, like that of an axe.

Wedges (fig. 110) employed for producing the fall are either square-pointed $1\frac{1}{2}$ inch (4 centimetres) square at the head, or flat chisel-shaped $1\frac{1}{4}$ inch by $2\frac{1}{2}$ inches (3 centimetres by 6). They are from 8 to 20 inches long ($0^{\text{m}}\cdot 20$ to $0^{\text{m}}\cdot 50$). The longest are called *aiguilles* in French. A seat is made for them by a few blows with a pick and then the wedge held in the hand is driven in by heavy blows from a sledge, in the plane of the joint along which the severance is to be effected. The sledge is an iron prism 2 to 2 $\frac{1}{2}$ inches (5 to 6 centimetres) square and 7 to 8 inches (18 to 20 centimetres) long, furnished with a handle 20 inches to 2 feet (50 to 60 centimetres) or more long. It weighs from 6 $\frac{1}{2}$ to 11lbs. (3 to 5 kilos.) and sometimes the weight is as much as 22lbs. (10 kilos.), the handle is then 3 feet to 3ft. 3in. (0^{m}·90 to 1 metre) long and the sledge is swung with two hands. It is sometimes necessary to use two wedges, one above the other, when the rock yields sensibly before breaking.

Wedges are sometimes replaced by the arrangement called *plug and feathers*. Two half-round pieces of iron (fig. 111) are placed with their flat surfaces against each other in a bore hole, allowing a certain amount of play; a very flat wedge, or *plug*, which is not quite so wide as the hole, is pushed in between them, and the three pieces are arranged together in the hole so that the surfaces in contact are parallel to the plane of the intended crack. The wedge is then driven in by heavy blows from a sledge between the two side-pieces or feathers. A very powerful effect is thus produced which gives good results with rocks that will not yield without breaking.

At Liége this arrangement is employed instead of gunpowder in places where the possible presence of fire-damp forbids the use of blasting.

(**115**) The work of breaking ground with the *gad* (*) is, so to say, a sort of chiselling or chipping, which is performed on rocks which are so hard that the pick would actually have no effect on them, and on which the pick itself would be of little use on account of the want of precision of the successive blows of the tool. The hardness of the rock is such that, in order to detach a fragment, the series of heavy blows must be struck one after the other at perfectly definite points. The miner must have an assortment of gads

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(*) *Pick and gad work* in England is different from the German *hammer and gad work* (*Schlägel- und Eisenarbeit*) as here described. It consists in breaking away the easy ground with the point of the pick, wedging off pieces with the gad driven in by the mallet or the poll of the pick, or prising them off with the pick after they have been loosened by the gad. The Cornish gad is merely a pointed wedge. *Translators.*

from 3 inches to 12 inches long (75 to 300 millimetres). They are a species of chisel, with steel tips or made entirely of steel, $\frac{3}{4}$ inch to 1 inch (20 to 25 millimetres) square, terminated at one end by a square head and at the other by a more or less acute point (fig. 142). The workman holds the gad in the left hand, either directly or by means of a little wooden handle about 10 inches ($0^{m}\cdot25$) long put through an eye near its middle. In this latter case we have the true *Saxon gad*. When it is held directly in the hand like a carpenter's chisel the simple word *gad* is sufficient.

The Saxon gad is more convenient than the common one for placing the tool at the required point and in the proper direction. It is struck by a hammer held in the right hand weighing from 3 lbs. to 6 $\frac{1}{2}$ lbs. (1 $\frac{1}{2}$ kil. to 3 kilos.) and fixed to a handle 14 inches ($0^{m}\cdot35$) long.

The miner proceeds by making a first groove, the depth of which depends on the hardness of the rock, and he then enlarges this groove by splitting off fragments on its two sides in succession; when he has thus made the point of the tool go over the whole of the face of the working, an advance will have been made equal to the depth which the hardness of the rock allowed him to give to the first groove (*).

It is easy to understand the tediousness of such a process of notching which renders it necessary to chip into pieces all the rock which has to be removed. Such, however, before the application of powder, was the only means at the disposal of the miner for breaking this kind of ground. The work was excessively slow in very hard rocks. Thus, in old adit levels where the dates are marked on the walls, the rate of progress is seen to have been very small in hard ground, only 11 to 14 fathoms (20 to 25 metres), for instance, in a year.

The use of the Saxon gad is abandoned as a regular process of breaking ground; it only serves now as an accessory, in order to

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(*) The Saxon gad is used for wedging off pieces of rock in jointy ground, as well as for the chipping process described. *Translators.*

break off rocks cracked by blasting, to give excavations exactly determined dimensions, if it is a question of putting in the foundations of a machine, or when ground has to be removed without shaking by blasting the foundations of a machine already erected, etc. It may be considered that, as a regular process for breaking ground, its place is taken in the case of the softer rocks by pick work of which we have just spoken, and in the case of the harder rocks by the process of blasting which we shall now describe, or by a combination, as far as may appear suitable for the ground, of the use of the pick and blasting.

(**116**) This last method of working may be considered as the principal improvement that the art of mining had received for many centuries. It may be safely said that without its aid it would have been necessary long ago to have abandoned many metal mines, as the price of labour has not ceased to increase relatively to that of the metals. The greater production obtained in a day's work by a miner through the use of gunpowder has served to compensate to a certain extent for the increased rate of pay.

The economy produced by the use of blasting is usually considerable, and the harder the rock the greater is the saving.

We do not mean by this that, as a rule, the actual work done by gunpowder should be regarded as more economical than that effected by human labour. The relation would evidently vary according to the mode of employing these two forces, and a numerical determination of it would not be easy.

It will be remarked, however, that the work done by the powder in blasting is effected, mechanically speaking, under very unfavourable conditions. Firstly, much of the rock is often projected; this means a useless expenditure of force, for the object is to *break off* the rock and not to *project* its fragments.

Secondly, the enormous heat which is developed at the moment of the explosion, and is rapidly lost by diffusion, corresponds to an internal or vibratory force, which is of no more use than the external force employed in projecting the fragments.

Lastly, the expansion of the gases is badly utilized, because the fracture is produced as soon as the molecules have moved a finite distance, however small, at right angles to a given surface, and consequently without there having been any appreciable increase in the volume of the gases.

As a set off, however, against this, the enormous initial pressure resulting from the combustion overcomes immediately molecular resistances, against which human power would have no effect unless they were considerably subdivided.

In other words powder gives large blocks, whilst the Saxon gad subdivides the mass into a much greater number of smaller fragments; powder is therefore economical compared with the use of the Saxon gad, not so much *because the foot-pound would be produced more cheaply by it*, but *because it requires the expenditure of far fewer foot-pounds* to excavate a cubic yard.

It is easy to see what the above consideration would lead to, taking a cursory view, if we supposed that the fragments obtained in the two cases of using powder and the gad were similar in shape. Supposing m equal pieces obtained by powder and m' obtained by the gad for a given volume of excavation produced, denoting by A and a the homologous sides of these pieces, we shall have firstly, as the volume is the same

$$mA^3 = m'a^3.$$

The quantities of work produced would be respectively proportional to mA^2 and $m'a^2$ and their relation would be :

$$\frac{mA^2}{m'a^2} = \frac{a}{A} = \sqrt[3]{\frac{m}{m'}}.$$

Thus the work of powder would be to the work of the gad in the inverse ratio of the homologous dimensions of the pieces, or what is the same thing, in the direct ratio of the cube roots of the number of these pieces.

(**117**) The *stone miner*, that is to say the miner working in blasting ground (so-called in the collieries to distinguish him from the miner working on coal, called the *hewer* or *collier*) has the following tools for his ordinary work : — a set of *borers* or *drills* of various lengths, a *hammer*, a *scraper*, a *pricker* or *needle* and a *tamping bar* or *stemmer* (fig. 115).

The borers are rods of iron tipped with steel at one end, or rods of steel, round in section so as to be easily handled, and having an edge at one end rather wider than their diameter, which generally varies between 1 and 2 inches ($0^{m}\cdot025$ to $0^{m}\cdot050$). The workman holds the borer in the left hand, the edge set against the bottom of the hole, and strikes it on the head with the hammer, turning it a little after each blow, so as to make the hole round.

The hammer weighs from $4\frac{1}{2}$ to $6\frac{1}{2}$ lbs. (2 to 3 kilos.) ; it is fixed on a handle 1 foot or 14 inches ($0^{m}\cdot30$ to $0^{m}\cdot35$) long.

The scraper is an iron rod with a small round plate at one end made by flattening the rod and turning it up at a right angle. This part is used for scraping out the sludge or dust from a hole. The other end has an oblong eye into which some tow or rag is put for drying the hole.

The tamping bar, or stemmer, is a rod of metal, swelled out towards the bottom ; it is used for ramming in the substances with which the hole is filled after the cartridge has been placed at the bottom.

The needle is a slender tapering rod which is inserted into the powder and kept in its place during the tamping in order to preserve a little channel through which to set fire to the explosive. The swelling of the tamping bar is grooved so as to fit over the needle.

(**118**) The work is performed in the following manner : —

After having taken down with the crowbar (fig. 114), pick or gad, all the ground that the previous blast had sufficiently shaken or cracked, the miner examines the nature of the rock and the shape of the place and thereby decides upon the position, direction and depth for the new hole. The conditions to be fulfilled are, firstly, that the rock should be as free as possible on one side, that is to say that there should be *a line of least resistance*, at right angles to which the principal cracks will be formed; and, secondly, that neither too much nor too little rock should be taken to be broken off at one line. In the first case there is a risk of seeing the hole go off like a gun, or *blow out its tamping*; in the second, there is a useless expenditure of powder.

A place for the hole being chosen, the miner gives it a few blows with the poll of the pick or the gad if the surface is slippery; he then takes the shortest borer, and holding it in position, strikes it with the hammer and turns it an eighth or tenth of a circle after each blow in order to make the hole quite round.

If the hole is made downwards, which is usually preferred, it is kept partly full of water to dilute the sludge produced by the boring and prevent the tool from sticking and getting hot. A little ring of straw, or a piece of leather with a hole in it, through which the borer passes may be put over the hole to diminish the spurting out of the water.

The borer is changed when its edge has become blunt and it is replaced by another of a length suitable to the depth of the hole.

The hole is cleaned out from time to time by putting in the scraper and withdrawing the sludge formed by the borer. If the sludge is too liquid it may be brought to the proper degree of thickness by putting in a pellet of clay, or quicklime or baked plaster, and mixing it with the water.

When the hole has reached its proper depth which varies from 16 inches at the least to 2ft., 2ft. 8in., 3ft. 3in. ($0^m{\cdot}60$, $0^m{\cdot}80$, 1 metre) or more according to circumstances, it is carefully scraped out for the last time and is dried by tow or rags held in the loop of the scraper, forming a sort of plug which sucks up the water as it is moved up and down.

If the rock is jointy and watery the hole is clayed out, by ramming in several lumps of clay and re-boring it with the borer (*).

If there is any water coming *round the orifice of the hole* a little ring of clay is made round it, which keeps back the water.

(*) In England holes are clayed out by means of a special tool, the *claying bar* or *clay-iron*. *Translators.*

The next thing is to put in the powder. It ought to be brought by the miner in cartridges prepared beforehand and *should always be put into the hole with the cartridge.* One or more cartridges are put in according to the quantity of powder which it is desired to employ. The powder usually fills up one third or one half of the length of the hole.

The needle ought to reach to about the middle of the charge.

Holding the needle against the side of the hole the miner then puts in on the top of the cartridge the tamping made of dried clay, pounded brick, soft slate, etc. These substances are put in by small quantities at a time which are rammed in successively, the hole being tamped *harder and harder* as the distance from the powder increases. During the tamping the miner turns the needle from time to time to prevent its sticking in too tightly.

When the tamping is finished, the needle is drawn out by putting the tamping bar through the ring and pulling it or striking it lightly. A match which may be made in various ways is introduced into the small channel thus left.

Sometimes a straw is taken and is cut off just below two knots; it is filled with fine powder and fixed with a little clay at the entrance of the hole, the knot towards the inside. When lighted it recoils like a little rocket and carries the fire into the cartridge.

Sometimes the match is made of a series of *squibs* stuck one into the other, and occupies the whole length of the needle hole; squibs are elongated cones of paper coated with powder.

They may be made by mixing powder with a gummy solution and dipping into it strips of paper which are rolled round a needle and allowed to dry.

When the squibs have been put in, a sulphur match, made by dipping cotton in melted sulphur, is applied. The miner must be careful to draw it quickly through the flame of his lamp before putting it in its place. It is fixed by means of a little clay or tallow to the last squib which projects beyond the hole (*).

(*) In Germany the miner softens the end of his sulphur match in the flame of the lamp and presses it on to the squib; it adheres on cooling. *Translators.*

If there is a draught in a certain direction the miner takes care to turn the match away from it; he then looks about to see if everything is ready for effecting his retreat. If, for instance, he is working at the bottom of a shaft he ought to give the signal agreed upon that his comrades may be ready to draw up the kibble and he ought to have received the answer to this signal. He should also call out and warn all the miners working close by.

When all these precautions have been taken, he lights the end of the match and goes away at once. It is prudent to retreat to some distance, as there are instances of fragments being thrown a long way.

When the report of the explosion has been heard, the miner goes back to see how *the hole has torn*, he examines the cracks that have been formed, sounds the ground with the hammer and breaks down with the pick or crowbars all the pieces that have been sufficiently shaken by the explosion.

When the explosion does not happen within the usual time, one or two minutes, the miner should wait *at least ten or twelve minutes* before going back to the place, because various circumstances, easy to be understood, may delay the combustion of the match and squibs. There are even instances of holes having gone off after a longer time than we have just mentioned.

On his return to the hole which has missed fire, the miner removes the match and squibs, puts in others, after having made sure that there is no obstruction in the needle hole, and attempts to fire the shot once more.

If, after one or two similar attempts, the charge does not go off, it must be supposed that the powder has got wet; the best thing to do under these circumstances is to give up the hole and bore another by its side. At all events it ought not to be untamped save with great precautions, and never unless the powder was introduced in a cartridge and when the hole inclines downwards, so that it may be kept thoroughly wet during the removal of the tamping.

(119) Such is the ordinary work of the miner.

This work frequently occasions accidents, and it is important to state their causes precisely.

They may happen :—

Whilst the cartridge stuck on the needle is being put in, if the needle is pushed in too suddenly, and happens to rub hard against some rough piece of quartz.

Sometimes, it is thought, from the first *layer*, or *laying*, of tamping being driven in too suddenly, compressing the air between it and the powder and thereby producing an evolution of heat sufficient to ignite the charge, just as tinder may be kindled by a condensing syringe.

In turning the needle during the tamping, or in drawing it out at the end of the operation, or if the miner is clumsy enough to strike it with the hammer and drive the point down to the bottom of the hole.

If the shot goes off prematurely, from the match having been badly placed or not made long enough.

If, on the contrary, the hole goes off too slowly, just as the miner is returning to it to ascertain the cause of the supposed missfire;

Lastly in untamping or *picking out* a hole, after a missfire.

A large number of these accidents are avoided by using needles made of copper, bronze, brass, or even wood, instead of iron ones, and by making the tips of the tamping bars or the tamping bars themselves entirely of bronze. These arrangements have been considered sufficiently important in some countries to be made obligatory; they are, nevertheless, not much liked by the miners, because these needles get bent or break too easily. The bronze or wooden tamping bar seems, moreover, to be without any real use, if the powder is not put in naked, but introduced in a cartridge as should always be done.

A better plan is to do away with the needle altogether, and employ what is called *safety fuse*, or *Bickford's fuse*.

This system, which is much used at the present day, perhaps *more than the needle*, consists in replacing the squibs by a cord in the axis of which fine powder has been introduced during the manufacture. The powder forms a continuous train tightly squeezed by the threads that surround it. The miner cuts off a sufficient length just before using it, and puts one end into the cartridge, tying the edges on to the fuse with a small piece of cord, or with threads of the fuse which have been unravelled for a short distance (fig. 115).

The cartridge is then pushed down to the bottom of the hole, the fuse lies on one side, and takes the place of the needle which is now unnecessary.

The tamping having been accomplished, the end of the fuse may be lighted directly, or else by allowing the flame of a candle-end, fixed by a bit of clay, to burn through it gradually.

It burns slowly — at the rate of 20 inches to 2 feet ($0^{m}\cdot50$ to $0^{m}\cdot60$) per minute — which gives the miner time to get out of the way.

The combustion of the train of powder in the fuse is not instantaneous, but gradual, by an effect analogous to that which occurs in an ordinary fuse. In consequence of the compression, the gases disengaged by the combustion of the first grains of powder cannot make their way forwards, and the succeeding grains only take fire in consequence of the conductibility of the fuse in proportion, as its different components reach a sufficiently high temperature.

This system, which was invented some forty years ago in Cornwall, has spread extensively since that time. In fact, it offers numerous advantages with regard to convenience in use, increase of the useful effect, *which should result from the suppression of the needle hole*, and, lastly, greater safety resulting from the abolition of the needle, directly on account of the dangers in handling this instrument and indirectly by reducing the number of miss-fires.

It possesses another important advantage, when holes are wet or have to be blasted under water. In the latter case, a tube of thin sheet iron provided with a bottom is usually employed. It is placed in the hole, which is charged in the usual manner; but it is simpler to employ cartridges prepared beforehand in little bags, which are made waterproof by being dipped in pitch, and to replace the ordinary fuse, or white fuse, by one also waterproofed by pitch.

Contrasting with these different advantages, these fuses have the inconvenience of cost, which is all the more marked when powder and labour are cheap. They are therefore almost universally used in England, and more in France than in Belgium and Germany.

(**120**) The work described above is what is called *single handed boring*. In some mining districts, often in England, for instance, and in most open workings, *two-handed boring* or even *three-handed boring* is employed; it differs from the preceding kind by two or three men working at the same hole. One holds the borer with both hands whilst the other one or two strike, or *beat*, it with a great mallet or sledge held with both hands weighing 11 to 13 or even 22lbs. (5, 6 or 10 kilos.), and furnished with a handle 2ft. 3in. to 2ft. 8in. ($0^{m}\cdot70$ to $0^{m}\cdot80$) long.

In open workings, when single handed boring is used, the hammer is sometimes dispensed with, and the ordinary borer replaced by what is called a *jumper*, which is merely a large borer swelled in the middle so as to be conveniently held, and terminated at the two extremities by cutting edges. This tool is used like a common earth borer.

It is important to give an explanation of these two kinds of work: boring by several men, and boring with the jumper.

Theoretically, denoting by M the mass of the borer, by M′ that of the sledge, by V the velocity which it possesses on reaching the head of the borer, by U the velocity, supposed to be the same, of these two bodies after the blow, we have according to the principle of the motion of the centre of gravity :—

$$M'V = (M + M')\,U$$

$$U = \frac{M'}{M + M'}\,V$$

The effect of the percussion will be proportional to

$$(M + M')\,U^2 = \frac{M'}{M + M'} \times M'V^2,$$

the work developed by the miner in handling the sledge being equal to $\frac{1}{2}M'V^2$.

The effect produced is therefore proportional to the fraction $\frac{2M'}{M+M'}$, that it is to say it increases if M' increases or if M diminishes.

We will now pass to the case of the jumper, supposing that the striking body acts directly on the rock, in other words making $M = 0$.

Thus, *in the first place*, double-hand boring may be preferable because it allows heavier mallets to be used. At first sight the contrary might be thought to be the case considering that the power of the man who turns the borer is not properly utilized; but as the men relieve each other, and as such hard work as beating cannot be kept up and requires the alleviation of frequent rests, the men utilize these rests in succession by turning the borer, and at the end of the shift their time has been better employed than in single hand boring.

In the second place, with the jumper the useful effect is greater than in boring with a mallet, because we avoid injurious vibrations, or the loss of the *vis viva* of transmission, which accompanies the blow of the mallet in the borer.

However, in a confined place, like many levels, the position of the hole ought to be decided above all by considering how the hole can be made to do the most work; it would not, therefore, always be convenient to use the jumper or double-hand boring and consequently single-hand boring is commonly resorted to. However, the fact that people are glad to return to the other methods when there is plenty of room for working, tends to give the impression that these methods present some advantage (although this must not be exaggerated); instances of this may be seen in open workings as already stated (Nos. 118 to 120).

(**121**) In the preceding five Nos. we have described the mode of blasting as it is generally carried out.

Numerous attempts have been made to improve it, and it, is advisable to give a list of them and at the same time to point out briefly their objects and results.

In order to *diminish the consumption of gunpowder for a given effect*, or, what comes to the same thing, to increase the effect of a given quantity of powder it has been attempted to make the powder act on a greater surface; the basis of the idea being that at the instant an explosion forms a fissure along a certain plane, the two equal and directly opposite forces which produce it are obtained by taking the pressure of the gases on the unit of surface, and multiplying it by the area comprised within the apparent outline on this plane of the volume occupied by the gases.

If d is diameter of the hole and h the height occupied by the gases *and if the plane of the fissure passes through the axis of the hole*, this apparent outline is equal to hd.

The height h is increased by reserving a little space above and below the cartridge by means of a little wooden stopper of the same diameter as the hole, and cut out in the middle like the groove of a pulley or else terminated in a little tail (fig. 116).

This stopper is put at the bottom of the hole, tail downwards and the cartridge is placed above it; a few cuts round the body of the stopper allow the gases at the instant of the explosion to spread into the vacant space left around the tail. If h' is the length of the stopper the active surface for a cartridge of the length h, is $(h+h')d$ and *it is supposed* that the action will be greater than if only exerted on a surface hd.

This argument is only admissible *if the volume* occupied by the gases for the height h' can be neglected, that is to say if the tail occupies the greater part of the hole. If, on the contrary, the tail were thin enough to be neglected, Mariotte's law shows that the pressures being in the inverse ratio of the volumes there would be the same total pressure with or without the stopper; and Laplace's law shows that a smaller total pressure would correspond to the greater volume on account of the reduction of temperature due to expansion (*Cours de Machines*. Chap. X), without counting the cooling due to contact with a larger surface.

A different argument has been used by supposing that the empty space left by the stopper would produce a phenomenon analogous to what happens when the end of the barrel of a gun is stopped up even pretty lightly. It is well known that it is easy in this way to burst the barrel at the breech.

The reason of the gun not bursting at every shot is that the mass of the charge is small enough to take a very high velocity almost instantaneously, and thus to allow a rapidly increasing space for the gases evolved by the explosion of the powder. If the extremity of the barrel is closed by an obstruction, this can only be expelled by the compression of the air in the barrel between it and the charge. This compression delays the motion of the charge and gives time for the explosion to take place more completely; and as the gas is developed, though not absolutely instantaneously, at all events extremely rapidly, the least retardation of the velocity of the charge, due to an external cause, may increase very considerably the pressure which corresponds to a given position of the charge in the barrel. The same effect of bursting may be produced, and for a similar reason, when the charge has not been tightly rammed on to the powder, or the powder not thoroughly driven down to the bottom of the barrel.

From these facts some persons have concluded that the stopper underneath, arranged as has just been said, increased the pressure on the rock.

The analogy and the conclusion do not appear to be perfectly exact.

If it is wished to compare a bore hole to the barrel of a gun, it must be to a barrel whose charge does not, or at least *ought not to go off*, because it is rammed very tightly and has a great mass filling the whole length of the barrel. It is in no wise proved that, under these conditions, the barrel would burst more easily with a given charge if there were a space left under the cartridge than if there were none. Experience has not decided, and reasoning would seem rather to indicate the contrary.

We do not think, therefore, that the method of blasting with *the stopper underneath* offers the advantages which have been assigned to it, and, indeed, its use has not spread.

Another means of increasing the height taken up by the cartridge is to mix the gunpowder with an inert substance, such as sand or sawdust. At first sight it seems as if there were the *same initial volume* of gas and, consequently the *same theoretical pressure* exerted *on a greater surface*, and consequently a greater effect upon the rock; the advantage appears to be evident.

It must be remarked, however, that there is not the *same temperature* and that, consequently, this hypothesis of the *same pressure* is not exact. The temperature is in fact reduced by the substance mixed with the powder, and by reason of the greater extent of cooling surface; it is also reduced from combustion taking place in a less instantaneous manner, and thus allowing the cooling influence of the foreign substances to exert itself all the longer.

This system, although not irrational, cannot have all the advantages which at first sight it seems to present. The question must be decided by actual practice, and the experiments made at various times have not been favourable, at least as far as concerns ordinary powder.

Another plan consists in replacing the sawdust *mixed with powder* by a wooden stopper placed side by side with the powder and occupying the whole length of the cartridge. It is either made in the shape of a half-cylinder with a section equal to half that of the cartridge, or of a round rod placed in its axis. The powder then takes the shape either of a half-cylinder or a hollow cylinder (fig. 117).

In the first case, the diametrical plane separating the stopper from the powder ought to be placed along the plane where *it is supposed* that the fissure ought to be formed, and this is a difficulty and a constraint; in the second case, the cooling surfaces are too great.

This plan, although also tolerably rational, more rational in fact than using sawdust, has not been much adopted.

(**122**) Attempts have been made *to lessen the work of boring*, by diminishing the diameter of the hole for the greater part of its length, and enlarging it only at the base, in the part which is to receive the powder.

M. Courbebaisse, engineer of bridges and roads, effects this enlarging in calcareous rocks by means of hydrochloric acid, which dissolves the rock and leaves a more or less spherical chamber; M. Trouillet, a contractor, uses appropriate enlarging tools which form a cylindrical cavity (fig. 118).

The advantage with regard to labour is evident, with less labour expended in crushing the rock by the borer a greater acting surface is obtained, with its centre of gravity at a given distance from the orifice of the hole.

M. Courbebaisse's process, however, is only applicable to a particular case, that of calcareous rocks (although as has been pointed out it would be suitable for iron ores); and M. Trouillet's plan requires a set of somewhat complicated tools, which would not perhaps be of much service in very hard rocks and could not be made small enough for ordinary shot holes.

These two processes, although very rational, do not seem to become much adopted in the ordinary course of mining. It appears that M. Courbebaisse's process is employed in some quarries of the department of the Isère,

(123) In order to *diminish the labour of tamping, and at the same time its dangers*, a thick mortar can be put into the hole, made of plaster of Paris or hydraulic lime prepared immediately before use. These substances set quickly enough to offer a sufficient resistance when the shot is fired.

It is even sufficient to pour in *dry* sand and settle it down gently. The pressure exerted by the powder at the base of the column of sand causes a lateral thrust against the sides of the hole, and consequently a friction which increases with this pressure and prevents the column from being blown out; it is an effect analogous to that which takes place above Kind's shuttle when the rope is drawn for pulling it up (*see* No. 96).

This system is never employed in mining work, where the holes are not deep, and are often bored nearly horizontally or even upwards; but it may be very well applied to holes that are nearly vertical and sufficiently deep.

(**124**) The question may be asked, whether it is theoretically better for a given amount of work, to increase or to diminish the individual importance of the blasts.

The question does not present itself in the same way *for an underground gallery of small section* and *for workings of large section.* In the former most of the holes have their dimensions determined by the necessity of acting on a given surface from a given centre; in the latter it is possible to proceed by a series of slopes, of any desired height and of a width which may be practically looked upon as indefinite, neglecting the influence exerted by the lateral walls upon a small part only of this width.

In the first case let us designate always by d the diameter and by h the total depth of the hole; let us call μh the depth of the centre of the cartridge, or $2h\,(1-\mu)$ the length of the cartridge (fig. 119).

The work of boring is evidently proportional to d^2h, the expenditure of powder to $2d^2h\,(1-\mu)$; lastly the surface acted on is proportional to $2dh\,(1-\mu)$.

The useful effect is therefore in the form

$$\frac{2dh\,(1-\mu)}{d^2h}=2\,\frac{1-\mu}{d},\ \text{or else}\ \frac{2dh\,(1-\mu)}{2d^2h\,(1-\mu)}=\frac{1}{d},$$

according as we compare it with the work of boring or with the expenditure of gunpowder. In both cases it is inversely proportional to the diameter; it is better therefore to aim at *the diminution of diameter* and *increase of depth* than at the reverse of this.

This is the advantage, or more correctly *one of the advantages*, of replacing iron borers by borers made entirely of steel, which may be made more slender and will work in narrower holes. The reduction of their diameter involves a reduction in weight and is another favourable circumstance, as we have seen above (No. 120).

In the second case, the slopes may be more or less high and may be pushed forward with more or less important blasts. If, in order to examine a simple case, we suppose that the two figures are similar in every thing, it may be said :—

That the *work of boring*, the *expenditure of gunpowder* and the *volume broken off*, vary as the cubes of the homologous dimensions, and that the *useful surface* on which the pressure is exerted, and the *surface* of the blocks *broken off*, vary as the squares of these dimensions. From this we may draw the conclusion, that the scale on which the stopes are made is theoretically a matter of indifference if we employ holes which are similarly placed and whose diameters, depths, and lengths of charge are proportional. Practically, however, it seems that there ought to be most advantage in working with large blasts, as the mass of the powder cools all the less easily, and the needle hole, which varies but little in size, becomes of less and less importance, as the diameter of the holes increases.

(**125**) Endeavours have been made to *increase the effect of the powder* by firing a certain number of blasts simultaneously.

Care is always taken to do this in places where a large number of men are employed, so as not to multiply, in the course of the day's work, the intervals of lost time whilst the men are obliged to seek shelter. It is known in such cases how many holes have been charged, and the men go back to their work when they have heard a corresponding number of reports.

We mean, however, here to speak of a *complete simultaneousness*, such as must be imagined in order to make the shocks produced by each hole synchronous.

It is easy to understand that in the case of two adjoining holes this synchronism ought to increase the effect of each. Suppose, for instance, that two shots are fired simultaneously at A and B, along a line parallel to a face CD along which the rock is free (fig. 120); an intermediate point *m*, to which the cracks produced at A or at B would not reach in consequence of the insufficient tension produced at this point by *either explosion separately*, might be fissured if these effects were added to one another — were *superposed* so to say — and produced a sufficiently powerful resultant in consequence of their simultaneousness.

This result would not be attained if we contented ourselves with using fuses of the same length lighted at the same time; for they do not burn with perfect regularity, especially if they are compressed differently, and the most compressed will generally burn the most slowly.

The only practicable means of realizing the simultaneousness spoken of is to employ electricity. This method, besides having the above-stated advantage of rendering the simultaneousness complete, possesses another important one with regard to the safety of the workmen; for it prevents the numerous causes to which both premature and slow explosions are due. By this means, in fact, the powder is fired at a perfectly definite moment, from a distance, and when it has been ascertained that all the workmen are safely sheltered.

This process has another important advantage, that of rendering blasting in wet ground, or under water, very much more easy and simple.

No doubt, therefore, the use of electricity is destined to spread more and more in all works where it is *possible*, and consequently *expedient*, to blast several holes at the same time.

We may employ, either static electricity, produced by ordinary electrical machines, or galvanic electricity, produced either by means of batteries with a sufficient number of cells, or by induction currents from a Ruhmkorff's coil.

Without entering into details regarding these different ways of employing electricity, which in fact belong to the domain of physics, we shall confine ourselves to a few remarks on the arrangements to be made for the special application under consideration.

The powder must always be ignited either by means of an electric spark, or by a metallic wire heated red-hot by the passage of a current.

In the first case, a small cap of wood or cardboard is half filled with a fulminating mixture, made in various ways — very often of equal parts of chlorate of potash and sulphide of antimony. Two brass wires, insulated by a covering of rosin or pitch applied hot, are bent inside the cap so as to leave their points almost touching. The cap is then stopped up and wrapped round with a little cotton wool. To the end of the cap is fixed a thin rod which has two longitudinal grooves *outside* in which the two wires can lie ; or a better plan is to make the rod of two halves each of which is grooved, and when the two halves are glued to one another *two little internal channels* are left to receive the wires.

The cap is inserted into the cartridge or into the powder which has been already put into the hole, and the rod lies on one side, like a needle; if it is thought more convenient for tamping, the rod can be dispensed with and the two wires simply held against the side of the hole. The end of one of these wires is fixed to the conducting wire coming from the machine, and the other to a wire which goes to a second hole, and so on to the last hole, the second wire of which comes back to the other pole of the machine, or is in free communication with the ground and so closes the circuit.

The spark is produced by an ordinary electrical machine provided with a suitable condenser.

Such an apparatus can be made small, is very portable and is perhaps more easily handled and kept in order than a galvanic battery. From ten to twelve holes may be fired by it at a distance of half a mile or more; which is more than is required in practical mining.

In experiments which were made with a view of determining the limits at which this process could be applied, it was found possible to fire fifty holes placed along a line of 220 yards at a distance of more than six miles.

In the case of a galvanic current produced by a battery, the two above-mentioned wires are joined in the interior of the cartridge by platinum wire made fine enough to become incandescent, in consequence of the resistance it opposes to the current when the circuit is closed. This system may be employed for a small number of shots at a distance of a few hundred yards.

For greater distances the number of cells would require to be increased.

A convenient substitute for this apparatus is Ruhmkorff's coil, which produces effects of electric tension greater than those of any other process, and effects, by means of the spark, as complete a simultaneousness in the explosions of the separate holes as an electrical machine.

(**126**) It is well known that the composition of the ordinary blasting powder used in France is as follows : —

Nitrate of potash, or saltpetre.	65 parts.
Sulphur.	20 »
Charcoal.	15 »
Total.	100

Of late years numerous trials have been made with other explosive compounds, and it is important that we should give an account of the results obtained.

Theoretically, the properties of any given explosive will depend essentially upon its specific volume, the corresponding volume of the gases produced by its explosion, the temperature of these gases, and, lastly, the rapidity with which they are produced.

The volume and temperature of the gases are the two elements on which the theoretical initial pressure depends, and the greater or less intensity of which causes an explosive to be *strong* or *weak*.

The greater or less rapidity in the development of the gases constitutes the difference between a *quick*, or *shattering*, explosive and a *slow* explosive.

We must also take into consideration the *nature of the gases* developed, because the phenomena of *dissociation*, due to the very high temperature produced, vary according to their nature. The dissociation tends to reduce the initial temperature; then, when the temperature and the pressure have diminished sufficiently to allow the final combinations to be reformed and maintained, heat is once more produced, and consequently the pressure decreases less rapidly, with the time or with the increase of volume, than is pointed out by theory.

Thus a pre-eminently good *shattering* explosive would be one that exploded rapidly and produced gases at a very high pressure and temperature, which were *final* products, not capable of being decomposed immediately after their formation by a phenomenon of dissociation.

Such for instance would be the case with chloride of nitrogen, because its explosion produces two simple substances chlorine and nitrogen, which have no tendency to combine together again, no matter what the temperature and pressure are. This substance produces instantaneously *as great a pressure* and *as high a temperature* as are possible; then this temperature is very rapidly lowered by contact with the sides and the expansion due to their being separated.

With ordinary powder, on the contrary, the combustion is slower, and it may happen that the sides yield quickly enough to allow the increase of volume to take place before the combustion is complete; this, indeed, is what is pointed out by the most simple observation, which shows that the evolution of the gas is generally accompanied by smoke, a proof of an incomplete combustion. The result of this is that the initial pressure is *smaller*, but it is kept up *longer*, both by the continuation of the combustion and by the reconstruction of the final products of this combustion which had been at first destroyed by dissociation.

In short, the amount of the initial force is less, but its impulse (product of the force by the time) and its work (product of the force by the space described) are greater; and, consequently, the same may be said of the quantity of motion or of the *vis viva* imparted to the walls which yield to the action of the force.

The first of these two bodies will therefore be essentially a *shattering explosive;* the second will be in preference a *projecting powder.*

It is seen by this theory, borrowed from M. Berthelot (Compte rendu des séances de l'Académie des Sciences, vol. LXXI), how it will be possible, if we know the composition of any explosive mixture and the nature of the products of the explosion, and have determined by direct experiment the rapidity with which the deflagration is propagated through the entire mass, to decide beforehand to what category the mixture belongs: either to that of shattering explosives, or of explosives fit for throwing projectiles.

(**127**) From a mining point of view, the following question presents itself: To which of the two kinds of explosives ought the miner to give the preference?

n most cases, the answer is not doubtful, for it is a question of *aking* and not *projecting* the rock. This opinion, however, is far from being generally admitted, and indeed, artillery powder and sporting powder are quicker than those employed by the miner. Many persons suppose that with a slow combustion the force is better utilized; in other words, that the rock, is better broken up by a somewhat prolonged pressure than by a sudden shock.

With these ideas, and also for the sake of economy or of trying to avoid the Government monopoly, numerous attempts have been made during the last few years to substitute nitrate of soda for nitrate of potash; the former is cheaper, but has the inconvenience of being deliquescent, and this property renders it difficult to prevent the gunpowder from becoming damp. Then again, charcoal has been replaced entirely by coal, or partially by some other organic substance, such as powdered sugar, flour, residues of tan, etc.; the proportion of sulphur has been reduced, etc.

All these mixtures, recommended by their inventors under the various names of lithofracteur, yellow gunpowder, white gunpowder, etc., have had a temporary success. However, since most of them act slowly as compared with ordinary blasting powder, they have not succeeded in becoming regularly employed in mining; indeed, it may be said, that *in most cases* where they would be made use of in mining — that is to say for *hard and brittle* rocks — their employment does not seem desirable.

They seem to be applicable only in these two cases:—

In the first place, where the explosion would take place in a substance of little consistency, such as earth embankments, where the pressure can only be communicated to the mass by means of a finite motion of the molecules which form the sides of the chamber; this motion cannot be effected instantaneously, nor without a considerable increase in the volume of the chamber (but this case interests military rather than mining engineers).

Secondly, when it is desired to tear out the rock without shaking the walls of the excavation, or else to get out pieces of a definite size and shape, making as little small stuff as possible; for very quick powders, besides producing the general effect required of tear-ing in a given direction, always crush the rock more or less round about the hole.

Excepting in those cases, where the desired result is to *make an excavation*, and not to *utilize the substance broken down* — that is to say in the case of all work in the enclosing rocks (*country*) – *strong and shattering* powders should be preferred *as a rule;* since they *tear* well in hard rocks, their action is so quick that the labour of tamping may be considerably reduced, and their useful effect is only slightly lessened by the presence of *joints* or *vugs* communicating with the hole.

Next in order come *strong and slow* powders (which are the most suitable for fire arms).

They act without crushing the rock so much round about the chamber, and they require a good well rammed tamping of sufficient dimensions.

Joints and cavities (*vugs*) are extremely unfavourable, causing an escape of gas when powders of this kind are exploded. They are besides apt to throw fragments a long way.

The action of *weak and slow* powder, such as ordinary blasting powder is the least favourable of all; so that if the question of cost were not so deeply involved, military, or, better still, sporting gunpowder ought to be preferred by the miner to ordinary blasting powder; or those powders themselves ought to give precedence to more shattering explosives.

(**128**) In accordance with these ideas, which are the reverse of those that led to trials with slow powders, people have of late years tried gun-cotton, or pyroxylin, employed in a suitable state of compression, the substitution of the chlorate of potash for the nitrate, nitro-glycerine, and lastly *dynamite*, a preparation the active principle of which is nothing else but nitro-glycerine.

Nitro-glycerine is a liquid, which, from its density and composition, can produce at the instant of its explosion a *theoretical* initial pressure eight or ten times greater than that produced by the same volume of gunpowder; on the other hand, during the expansion due to the dilatation of the charge, a certain quantity of heat may be taken up again to re-form the compounds which had at first been dissociated. It participates thus both in the properties pointed out above for chloride of nitrogen and common powder.

It is less thoroughly shattering than chloride of nitrogen; but can produce greater projecting effects than that substance.

M. Nobel was the first who manufactured it on a large scale for mining purposes, and the first who stated precisely the apparently strange and paradoxical conditions under which its explosive properties may be developed.

Although infinitely more explosive than powder, it does not take fire when touched with an incandescent body, or if it does take fire, it burns quietly and without smoke.

If placed in a *non-resisting* case and into the fire, it breaks its case and burns quietly; if the case resists, it explodes after having been heated sufficiently long.

If a thin layer is subjected to a violent blow between two hard bodies, such as an anvil and a hammer, it explodes at the point struck, without this explosion being communicated laterally to the rest of the layer.

Lastly, a mass of nitro-glycerine always explodes if fulminating bodies are exploded in it or near it. (This is equivalent to a violent shock.)

These different circumstances are explained by the liquid state of the substance, by the weak conductibility, which is a consequence of this state, by its very great specific heat, and, lastly, by its property of decomposing slowly under the influence of a gradually increasing heat, and, on the contrary, of decomposing with explosion if suddenly brought to a certain temperature (190 to 200°C. — 374° to 392°F.).

The explosion due to a sharp blow struck at a point in the mass must be conceived, by imagining that this blow transforms the *vis viva* of the striking body into vibrations of the mass struck and of the striking body itself. If the pressures resulting from the blow are too sudden to have the time to distribute themselves through the mass, the first layers may assume vibrations equivalent to those which would be produced by the instantaneous application of a temperature above 200°C. (392°F.). This first layer is decomposed suddenly, and the gases evolved may, in their turn, produce the equivalent of a blow upon a second layer surrounding the first and so on. The explosion is, therefore, propagated through the whole mass, each layer receiving, from the shock of the gases developed in the preceding layer, a vibratory motion or a temperature, which causes its decomposition, and makes it act, in its turn, on the next layer.

A certain mode of producing the explosion of nitro-glycerine having once been found, the employment of this substance was not long in spreading over the greater part of Europe and America, and also in France, although on a smaller scale.

It was everywhere found that its use diminished the expense and increased the speed of the work.

However, this substance remained inconvenient for use, on account of its liquid state, which rendered its carriage difficult and dangerous, and because the destruction produced in cases of accidents, was exceptionally violent. These dangers were considered so great, that even in England, where, as a rule, much liberty of action is allowed in trade, the importation of nitro-glycerine was forbidden by Act of Parliament, and no persons were permitted to make, store, carry, sell or use it without a Government license.

In order to avoid these various inconveniences, M. Nobel proposed to substitute *dynamite* for nitro-glycerine, or rather, to speak more correctly, the *dynamites*, the use of which seems to be gaining ground nowadays to the more or less complete exclusion of guncotton and liquid nitro-glycerine.

(**129**) Under the generic name of dynamite are designated more or less intimate mixtures of nitro-glycerine with a solid substance of *any chemical nature*, sufficiently porous to absorb a suitable proportion of nitro-glycerine and to retain it, without there being any fear of its exuding during carriage or whilst kept in barrels or cartridges, even if a certain pressure should be exerted on its surface.

It is easy to conceive that nitro-glycerine *stored up*, so to say, in the pores of an inert substance, is preserved from shocks of a certain intensity, and may be transported and handled with a certain degree of security.

The work done by dynamite is in proportion to the weight of nitro-glycerine which it contains in a given volume, and consequently the inert substance should be as absorbent as possible. It is advisable also that it should have as low a density and as small a capacity for heat as possible, so that for a given volume the substance should offer the least possible empty space, and that the inert body should not diminish the temperature of the gases too much at the moment of explosion. Numerous substances have been suggested for the mixtures; some are inert, as porous silex, easily reduced to powder, with a floury appearance, resembling the millstone (*meulière*) of the neighbourhood of Paris, tripoli, alumina, kaolin, etc.; others, such as powdered coke or coal, sugar, and other substances rich in carbon, play a certain active part in utilizing the small quantity of oxygen in excess which results from the explosion of the nitro-glycerine, besides the ordinary products of the complete combustion of an organic body (water, carbonic acid and nitrogen).

Lastly, a certain proportion of another explosive substance may be added, such as ordinary powder or gun-cotton, so as to obtain a mixture of the two substances which partakes, more or less, of the characteristic properties of both; such, for instance, is *dualine*, where the absorbent substance is sawdust, saturated with nitrate of potash and transformed into pyroxylin by treatment with nitric acid.

As a rule nothing but silex is used, and two or three kinds are manufactured: No. 1 contains as much as 72 or 75 per cent of nitro-glycerine, the two others a smaller proportion. The latter can be used with advantage instead of ordinary powder. In France, these three kinds are sold by the Excise at the respective prices of 3s. 5d., 2s. 4d. and 1s. $7\frac{1}{2}$d. per lb. (9 fr. 50 c., 6 fr. 50 c. and 4 fr. 50 c. per kilogramme), whilst blasting powder costs only $9\frac{3}{4}$d. per lb. (2 fr. 25 c. per kilogramme).

Dynamite has been subjected to all sorts of trials, which have shown that so long as there is no excess of nitro-glycerine, causing an exudation, there is nothing in the transport or handling that can make it explode. It should be considered *free from all danger* as long as it is not heated to 200°C. (392°F.) in a resisting envelope, or exposed to a shock as sharp and violent as that which might be produced by the fall of a hammer on an anvil, or a bullet or cannon-ball penetrating into the mass, or the explosion of a fulminating cap in the midst or in the neighbourhood of the mass. In a word, it is *less dangerous to handle* than ordinary powder, and, consequently, there is no reason for prohibiting its free circulation and its application to mining, to which it may render very great services.

As it is much stronger than the powder generally employed, it lessens in a very marked degree the labour of the miner; for he can use smaller holes, 1 inch ($0^{m}\cdot025$) in diameter for instance, instead of $1\frac{5}{8}$ inch ($0^{m}\cdot035$), which reduces the work of boring in the proportion of 25 to 49, or of 50 per cent, for a hole of a given depth, besides which the operation of tamping can performed much be more rapidly. The only inconvenience is that of ignition, which cannot be effected by squibs or ordinary safety fuse. The end of the safety fuse must have a long fulminating cap fixed on it, just before it is inserted into the cartridge.

In cases where it is found desirable to combine the use of dynamite with simultaneous firing, the advantages of which we have already pointed out (No. **119**), the place of the safety fuse will be taken by two metal wires ending in a fulminating cap placed in a small cartridge filled with dynamite, which will be introduced into the principal cartridge; any of the arrangements described above may be employed for exploding it.

(**130**) For the future, therefore, all miners *should be accustomed* to work with dynamite.

We may define the domain of this new agent in the simplest and most general way, by saying that it will be employed for *work in the enclosing rocks*, and that its advantages will be felt more and more as the rocks are harder to bore and more brittle, as they present more joints and *vugs*, and as the section of the workings increases. Gunpowder may continue to be employed for *breaking down mineral*, and the greater the interest in reducing the proportion of smalls, the more advisable will its use become (such would be the case in working slate, freestone, or coal, or parts of a lode very rich in massive ore).

In fact, it is admitted that even in the countries where dynamite is extensively used there appears to be no sensible decrease in the use of gunpowder.

(**131**) Nos. **112** *et seq.* contain a description of the processes employed for breaking ground, from the loosest rocks to the hardest that are usually met with. There are few, *if any*, rocks so hard that they cannot be successfully attacked *by boring small holes with steel borers and blasting them with charges of dynamite.*

If, however, such rocks should be encountered, there remains a last means of cutting through them; it consists in *surprising* the rock first of all by means of fire and then attacking it by the ordinary methods. The action of a strong fire on a wall of rock produces a kind of decrepitation; this is due to the volatilization of the water contained in the rock and also of certain substances, such as sulphur, derived from the decomposition of ores contained in the mass, and especially to the small conductibility of this mass; for it becomes cracked from the same cause which produces the fracture of a badly annealed lamp glass of unequal thickness or strength.

Fire-setting is only employed as an exceptional process in some localities in Germany where wood is still abundant and cheap. It is most certainly destined to disappear, and there is not a single locality in France where its use could be recommended, at all events in its ordinary form.

Figure 121, borrowed from an old work (that of Delius), shows how the fires may be arranged to heighten workings or widen them horizontally. A rise may also be made by putting the fire on the top of a pillar of rubbish in the axis of rise, and thus affording means of access to fresh air and an exit for the products of combustion (fig. 122).

The piles of firewood are generally made up on the Saturday morning, and those of the uppermost workings are lighted first. The mine is left to itself till the Monday, and then the miners go in to complete the work of removal begun by fire, to make the necessary repairs, and to prepare new piles of wood for the following Saturday.

We think that if there were any reason for applying fire-setting in some wholly exceptional case in France for making a tunnel, coal should be substituted for wood. A portable apparatus might be used analogous to that employed in M. de Lapparent's process for preserving wood, when no coal gas is at hand (*See* Chap. VII).

In this manner a kind of blowpipe action would be obtained, much more localized and also much more effective than the ordinary method, as seems to be shown by various experiments made on a small scale by M. Daubrée.

(**132**) The process of removing ground by water is employed in two cases : that of loose rocks, or rocks that can be undermined, and that of soluble rocks.

In the first case, when the localities offer facilities, that is to say when there are suitable differences of level and when water is abundant, it may be largely used to assist the work with the pick.

In New Grenada, for instance, large excavations are made in some decomposed auriferous porphyritic rocks. A stream is turned, brought to the top of a long escarpment and made to run along it; then men with crowbars assist in the work of loosening which has been initiated by the fall of water. The substances carried off pass into channels which are prepared with a view to catch as many as possible of the particles of gold.

Workings of somewhat the same kind have been established on a very large scale in the gold districts of California. They effect a great economy of labour, as a few hands can thus work over very large quantities of stuff.

Water may also be made to act in virtue of its expansion on freezing ; or by causing certain bodies, such as wood, to swell as they become impregnated with it. It appears that the first method is employed in the open granite quarries in the neighbourhood of Boston (Mass.), where bore holes are filled with water and then stopped up with a strong plug.

The second method may be used for splitting stones such as millstones, when it is desired to obtain them in regularly shaped pieces.

A groove is cut out, as many wedges of dry wood are driven in as possible, and when they are thoroughly tight water is poured over them.

Lastly, M. Guibal has proposed the use of water as a substitute for powder in blasting. For this purpose he employs the so-called *hydraulic cartridges*, which consist of an india rubber bag held between two collars; water is pressed into it by means of a screw (fig. 123), the cartridge expands, adapts itself to the sides of the hole, and exerts a very great pressure. This process, which does away with all danger to the workmen, may be applied in places where the presence of fire-damp prohibits the use of powder.

Compared with the use of powder, these systems are simply the substitution of *a pressure* for a shock; they act like a very slow powder (*see* No. **122**).

(**133**) The application of water to soluble rocks, that is to say rock salt, may be considered in two ways : either as preparatory to breaking the ground with the pick or powder by undercutting or holing, or for removing the whole mass by dissolving it.

The first method may be applied with advantage when the mass of the deposit is *pure enough* to be utilized in the crude state for agricultural purposes or in the manufacture of chemical products, but *so impure as* to require the part intended for domestic consumption to be refined. If the whole were worked away solid, a part of it would require to be dissolved at the surface; and it is simpler to dissolve it in place and lift it to the surface by pumps, because the removal of the remainder is thereby facilitated.

When the mass of the deposit is so mixed with clay that nothing can be utilized in the crude state, the whole may be dissolved in place, using various arrangements to which we shall have to return in speaking of the methods of working.

For the present we will confine ourselves to the remark that water may be used not only for removing the stuff, but also in excavating preparatory works, such as shafts or winzes that have to be sunk through the deposit.

A rise may be made by placing in its axis a vertical pipe that throws up a jet of water; of course the pipe will gradually have to be lengthened.

A winze may be sunk by means of a downward jet of water, which runs out by a bore hole previously put through to a lower level, whence the water can escape (fig. 124).

These works can be carried on more or less quickly, according as a greater or less quantity of water is made to act on a given point; but as it is generally advisable to get the water as nearly saturated as possible, the progress of the work is rather slow, compared with what it might be by the ordinary processes by hand; and the extent of the working area must consequently be increased, so as to make up by the number of working places, for the small production of each.

§ 3. — Applications and sundry numerical data.

(**134**) We must complete what has been said in a general way, in the preceding paragraph, by considering a few particular cases which permit certain special details to be given.

Example of an open working. — Although the working of a mine is generally carried on underground, there are also occasionally open workings, either when the deposit crops out to the surface or is merely covered over by a small thickness of earth. The object of the workings may be either to uncover the deposit or to work it away.

In all cases the working face should be as wide as possible and should exhibit a series of straight stopes, so that any mass of rock *in course of being broken down* should always be free on two sides.

With stratified rocks the top of each stope is a plane of stratification. The surface may therefore be horizontal or inclined up or down. The height of the stopes depends not only on the nature of the rocks, but also on the direction and amount of the dip. In most cases when the rocks are approximately horizontal, a vertical height of 5 to 10 feet is very suitable, whatever may be the hardness of the rock. However, larger stopes may be used, twice or three times as high as those mentioned — some have been made even 50 feet high.

These excessive dimensions are liable to be dangerous for the workmen employed; neither have they so many advantages as one might be led to believe. In the case of loose rocks, where great masses are thrown down, the facilities for filling are not increased, and as hard rocks will only fall in immense blocks, these will afterwards have to be broken up by blasting, and this could be done more easily at once if there were a series of smaller stopes.

It may be said, therefore, that these great stopes are only suitable for rocks which are sufficiently firm in place, and are at the same time so jointy, that if a large mass falls down the greater part of it will break up into lumps that can be easily handled.

Such, for instance, are rocks which exhibit a succession of small alternate hard and soft beds, as limestone and marl, sandstone and shale, etc.

In a case of this kind the undercutting might consist in a series of small galleries, 12 to 16 feet (4 to 5 metres) long, driven in at right angles to the working face and joined to one another by a gallery parallel to the face; pillars 6 to 10 feet square would thus be left sustaining a great block, having for its length the width of the workings, for thickness the length of the little galleries, and for height that of the stope. It will be removed by undercutting the pillars, as far as prudence will allow, and then finally throwing it down by blasting holes made in the axis of each pillar and a little above the ground.

The blasts may be fired in the ordinary way, or else simultaneously by means of electricity.

The system just described is represented in vertical and horizontal sections and in elevation in figures 125.

(**135**) **Example of a crosscut in hard rock.** — An ordinary level is made from 6 feet to 8 feet ($1^m \cdot 80$ to $2^m \cdot 50$) high and 4 to 8 feet ($1^m \cdot 30$ to $2^m \cdot 50$) wide, say for instance 6ft. 6in. (2 metres) wide, the pier being 3ft. 3in. (1 metre) high surmounted by a semicircular arch (fig. 126). This shape gives a section of about 1 square fathom (3·5 square metres) and an equal number of cubic fathoms per running fathom.

The *end*, or *forebreast*, usually exhibits an outline such as ABCD which is displaced parallelly to itself and becomes A′B′C′D′.

The line AB is carried to A′B′ by means of holes such as 1, 2, 3, fired in the order of the numbers.

The stope BCD, also called the bottom stope, is taken off behind, either by vertical holes in the direction C′D′ or horizontal ones in the direction DD′.

The object of making the outline in the form ABCD is to carry out the principle of always working on a rock as free as possible. It also allows the increased rapidity of driving, as men can work at the same time at the very end and on the bottom stope without inconvenience. It must be understood that the outline ABCD has been drawn under the supposition that it is a homogeneous mass without any joints in a definite direction; but we should not forget — and this remark applies to all work for breaking ground — that the miner should take into consideration the presence of joints or cleavages, and place his holes so as to take full advantage of them. When dynamite is employed less attention is often paid to the position of the holes.

The working face is then usually straight for its entire height, and in order to push it on, the miner merely blasts a series of holes *parallel to the axis* of the drivage; these become the axes of as many conical funnels, the bases of which placed side by side occupy the greater part of the section (fig. 127).

Supposing that the holes are bored to a depth equal to one third of the width of the level, say 2ft. 2in. ($0^m \cdot 67$), and that they are charged with cartridges of $4\frac{1}{2}$ to 6 inches ($0^m\cdot12$ to $0^m\cdot16$) long, the rock will be crushed behind the cartridges to a depth of 2ft. 7in. ($0^m\cdot80$), and by means of the pick and crowbar and, in case of need, a few small blasts, it will be possible to obtain a free working face 2ft. 7in. ($0^m\cdot80$) from the first.

If instead of being an ordinary mining crosscut the work to be carried out is a tunnel of large section, for a canal or railway for instance, a small gallery is first of all made at the top of the arch with a section of 50 to 60 square feet (5 to 6 square metres) and this drivage is pushed on as fast as possible.

Behind the *end*, the gallery is widened out on each side as far as necessary, and it is then brought to the desired height by two or three vertical stopes; in this manner the number of working places can be multiplied, and a tunnel of large section can be driven as fast as a mine level of small section. Fig. 128 shows in what order the different parts of the final section are removed.

(**136**) **Example of a shaft.** — Vertical shafts may be made in a variety of shapes, to which it will be necessary to return later on.

We will suppose the case of a large shaft intended for drawing and pumping, requiring no lining in the solid parts and masonry in the other parts,

It may be conveniently made circular in section, with *a useful diameter* of 13 feet (4 metres), or about 16 feet (5 metres) in the parts that have to be walled up, say 200 square feet in section (19 to 20 square metres).

The work is carried on by boring and blasting *sinking* holes near the centre of the shaft so as to form a *sink* or collecting place for the water; this sink is enlarged by successive holes which are made more and more vertical as the walls are approached. Care is taken to blast the sinking holes and side holes so as always to preserve a decided *sink* to receive the water.

The holes (1) of figure 129 might be replaced by a great central hole charged with dynamite.

(**137**) **Example of a large working place or long-wall work in a thin seam of coal.** — We suppose that it is a question of a thin seam analogous to those of Belgium and the North of France. The seam is not usually in contact with beds of hard sandstone, but most often lies between beds of shale or fine micaceous sandstone. Often also, touching the roof or more often the floor, there is a bed of stiff black clay which serves for the holing. The total thickness of the seam is subdivided into several distinct layers, varying in hardness and in the proportion of large coal that they furnish. These layers are superposed directly on one another or are separated by partings of shale or shaly sandstone; they form planes of easy division in the coal.

It also happens frequently that the seam is divided by planes perpendicular to it, which preserve a constant direction throughout the mine (*backs*, *faces*); sometimes also there are two systems of such planes (*cleat*) and each piece of coal exhibits the form of a peculiar parallelopiped, due to the planes of stratification and a sort of cleavage in two directions perpendicular to the bedding.

These different circumstances are utilized by the miner in working away the coal.

Theoretically, and considering things only from the point of view of the actual work, the working place or face of work should be made as wide as possible and should be parallel to the principal cleat of the coal,

There are faces of a length of 10, 15, 20, 30 yards and more; and in England some are several hundreds of yards long.

The colliers are distributed along the face each having a definite length to work away. They hole the coal, supporting it in the meantime by chocks of wood, or by inclined props, or by little pillars of coal which are only removed at the last minute. The colliers at the extremities of the face *shear* the coal, or make the vertical cuts; and, lastly, the falling is brought about by wedges or a few small shots, or — if the presence of fire-damp does not admit of blasting — by the plug and feathers described in No. 114 (fig. 111).

If circumstances render it necessary that the workings should advance in a direction oblique to the cleat, the working face may be kept parallel to the cleat and oblique to its direction (fig. 130).

There is an essential difference with regard to the facility of working away, and also, up to a certain point, in the proportion of large coal, between working places where the face is *parallel* to the cleat and those where it is *at right angles to the cleat.*

Thus, when a working area is cut up into pillars by two systems of drifts at right angles to one another, it often happens that a distinction is made between the two systems; the drifts that are most important in number or extent are driven across the cleat, and the others are simple cross drifts, or *headways*, for ventilation.

The appearance of the working face is very different in those two cases : in the first, the coal presents great flat shining surfaces; in the second, a granular structure.

(**138**) **Example of a working place in a thick seam of coal.** — It often happens in a *thick* seam (we mean a seam decidedly thicker than the usual height of a mine level which rarely exceeds 6ft. 6in. to 8 feet (2 metres to $2^{m}\cdot50$) that the levels are only driven in the lower part of the seam; the upper part is left as the roof and is taken away at the same time as the pillars that are first of all left between the drifts.

These levels are carried on like the working places just described, and only differ from them by their width which is less, and their height which is greater. They are made from 6ft. 6in. to 16ft. (2 to 5 metres) wide, according to the hardness of the coal and the firmness of the roof, and according to the duration assigned to them by the system of working adopted.

The height of *about* 6ft. 6in. (2 metres) will depend upon the thickness of the layers; because a plane of stratification between two layers will be taken as roof, and the height will be increased or diminished according to circumstances so as to leave off at a firm layer.

In other cases it is thought preferable to carry the level the whole height of the seam, and then one of two different methods may be adopted : the workings may be carried on by a series of *underhand stopes* (fig. 131) beginning with the layers near the roof, or else they may be carried on by *overhand stopes*, beginning with the layers near the floor and working away the upper layers in succession (fig. 132).

Of these two methods the first is decidedly preferable as far as the safety of the men is concerned. By beginning at the top any weak layers of shale, or false roof, which often occur directly above the seam, may be made to fall so as to procure at once a firm roof for the working place. The subdivision into underhand stopes may be made according to the position of the partings interstratified with the seam, so as to render the sorting or picking more easy. The width of the stopes may easily be increased in descending so as to give a sort of ogee section, which for a given mean width of the working place corresponds to a minimum strain on the roof.

In *overhand stopes* the miner is always working under the rocks *which he is trying to break down*, and which consequently are *threatening his safety at every instant*, in spite of the temporary props by which he keeps them up. These rocks fall down in immense blocks and break up, forming a confused mass from which the large lumps of coal are picked out, whilst a part of the smalls is left buried amidst a lot of sterile stuff derived from the partings in the coal and from the roof. This method is dangerous to the workmen, causes the coal to be much broken up, and wastes a more or less important part of the smalls.

The only advantage to be confronted with these inconveniences appears to be an economy of labour in getting the coal, referring the cost to the quantity of large coal obtained, and considering the smalls as valueless.

It seems to me, however, that the day is gone by, even in the countries richest in coal, for the smalls to be considered as of no value. Colliery proprietors will no longer be seen, as was so long the case at Newcastle, setting fire to their heaps of small coal (*slack*) in order to get rid of what was considered as a useless encumbrance. With the increasing value of fuel, and the various methods of utilizing all kinds of small coal, either as such, or in the form of coke or of patent fuel, with new means of transport created daily, any method of working which does not allow the whole mass broken down to be removed as completely as possible, should be looked upon as antiquated and inadmissible.

We shall return to this important point in speaking of the methods of working.

(**139**) **Example of a level driven in a lode.** — A level driven along a lode might be carried on like a crosscut if the lode possessed a hardness analogous to that of the surrounding rock, if it adhered to it tightly, and if the ore was sufficiently uniformly distributed in the veinstone for *any two small fragments* to be considered as *having the same average composition.*

This is not the mode of proceeding, however, which must usually be adopted, either to derive advantage from the circumstances which may facilitate the breaking of ground or to husband the ore. The existence of a *dig* or *hulk* should be turned to account by making the equivalent of a sort of *holing*, which is called *hulking* the lode; the lode thus stripped is broken down by means of the pick or crowbars, or by small blasts placed so as to throw down the parts rich in ore and injure them as little as possible. The precautions to be taken should be all the greater as the ore is more valuable and more friable. At the limit, the level is driven in some measure in the surrounding rock, or *outside* the deposit. The lode is thus left intact on one wall and can be broken up at leisure, in place so to say, behind the end or forebreast, using precautions analogous to those which have been pointed out in the preceding paragraph for getting coal.

(**140**) The different examples given above (Nos. 134 to 139) will be sufficient to furnish a general idea of the manner in which the work of breaking ground is performed under the various conditions which may occur. The first general principle to be observed consists in always keeping the mass to be removed as much detached on as many sides as the shape and dimensions of the workings will allow. Another very important principle is to carry on the work so as to husband the substance as much as possible; for, as already stated, it usually has a greater market value or is dressed with greater advantage in the state of lumps than in the state of smalls.

The first principle is applied in order to facilitate the miners' work and thus increase the progress or the *quantity* of substance broken away. The second principle takes into consideration essentially the *quality* of this substance. Moreover, in both cases, the miners should have an interest in the result obtained, and *daywork* is not admissible for workings of this kind. The workmen therefore will have a fixed price either per running fathom driven, per cubic fathom of ground taken away, or per bushel or ton of useful substance obtained, one price being fixed for the large and a lower one for the smalls. If it is wished to stimulate them still further, a price will be fixed for *a certain* minimum quantity *obtained in a fortnight*, with a much higher and rapidly increasing price for any surplus.

In cases of urgency the work will be continued day and night, the workmen relieving each other at their working places, or, as it is called, *tools in hand*. They may have two shifts of 12 hours or three shifts of 8 hours. Sometimes, especially in very wet shafts, the duration of the shift is only 6 or even 4 hours.

It may be considered that, with good miners, working with eight-hour shifts is not dearer than working with twelve-hour shifts, as a miner who employs his eight hours well will give out in that time all the useful effect he is able to produce in a day. Therefore, without extra expense, the rate of progress with twelve-hour shifts may be increased 50 per cent.

In workings in rock, the measurements from which the fortnightly or monthly payments are calculated should be made starting from a fixed point, and should only include the distances *squared up*, that is to say brought to their final shape and dimensions and having the floor at its proper level.

Care in fact should be taken to make the workings retain exactly their dimensions, direction, and inclination; nevertheless this requires constant superintendence, on account of the tendency of workmen to contract their working places, to rise too much, or to turn off in the direction where they meet with the fewest obstacles. The dimensions are at once ascertained by measurement. The perpendicularity of a shaft is ascertained by plumb-lines placed around the top of the shaft at suitable points. The direction of a level is given by means of two plumb-lines fixed to plugs driven into the *back* (or *roof*) in the axis of the level. A lamp placed in the middle of the end ought always to be in the plane of these two lines. In order to keep the proper inclination, the level is determined at a given point by a plug at a given height, and the miners have to regulate their workings by this and go on level till another one is fixed.

In all kinds of work endeavours should be made to simplify the subject of the contract price, by giving, for instance, only the actual *driving* to one set of men, leaving others to remove the stuff, to put in timber behind, to lay down rails, etc.

This plan may be *less convenient*, from the fact of more superintendence being necessary to make the different works go on in proper accord; but it gives the advantages to be derived from the division of labour, and skilled workmen who can command higher wages are not put to mere labourer's work.

We shall return to this general question of the organization of the work in a mine.

(**141**) We shall only now add, by way of concluding the chapter, a little information in figures, by means of which persons will be able to form, *à priori*, a rough estimate of the cost of different works that may have to be carried out in given rocks.

We will suppose, first of all, that it is a question of a crosscut, about $37\frac{1}{2}$ square feet (3.5 square metres) in section, the daily wages of a miner being 3s. 2d. (4 francs) and the pound of powder costing 11d. (2 fr. 50 c. the kilogramme).

The following table gives for different kinds of rock the number of shifts worked, the quantity of powder required, and the net cost per running fathom of drivage, that of the cubic fathom excavated and the monthly progress obtained, working in two shifts and counting 25 working days to the month.

NATURE OF THE ROCKS	NUMBER OF SHIFTS WORKED	WEIGHT OF POWDER lbs.	NET COST		MONTHLY PROGRESS Ft. ins.
			PER RUNNING FATHOM £ s. d.	PER CUBIC FATHOM £ s. d.	
Exceptionally refractory rocks, or of the 1st degree of hardness.	91	48	16 12 2	15 19 0	6 6
Rocks of the 1st degree, hard and quartzose granite.	46 to 55	32 to 40	8 15 0 to 10 10 10	8 8 0 to 10 2 5	11 0 to 16 4
Rocks of the 1st degree, drivages in very hard and very quartzose lodes.	44	14	7 12 2	7 6 1	13 0
Rocks of the 2nd degree, hard Coal Measures, sandstone and conglomerate.	27 to 36	16 to 32	5 0 2 to 7 3 4	4 16 0 to 6 17 8	16 0 to 22 0
Rocks of the 2nd degree, tolerably hard Coal Measures, ordinary granite.	18 to 27	12 to 16	3 8 0 to 5 0 2	3 5 4 to 4 16 0	22 0 to 33 0
Rocks of the 3rd degree, ordinary Coal Measures, clay-slate or soft mica-slate.	13 to 18	6 to 12	2 6 8 to 3 8 0	2 4 10 to 3 5 4	33 0 to 46 0
Rocks of the 3rd degree, easy Coal Measures.	7 to 11	4 to 6	1 5 10 to 2 0 4	1 4 10 to 1 18 9	49 0 to 82 0
Rocks of the 4th degree, working place at the face of the coal, 64½ square feet in section.	3½ to 7	0 to 2	» 11 1 to 1 4 0	» 10 8 to 1 3 1	82 0 to 164 0

(**142**) On examining carefully the above table, it may be seen that if we wished to characterise each of the four first degrees of hardness by average values, the results in round numbers might be stated as follows, saying that the average cost of driving and average monthly progress would be :—

	£.	s.	d.		Ft.
For rocks of the first degree of hardness.	10	5	0	and	13
For rocks of the second degree of hardness. . . .	5	2	6	and	26
For rocks of the third degree of hardness.	2	11	3	and	52
For rocks of the fourth degree of hardness. . . .	0	17	7	and	132

Such are the figures which might serve as a *first starting point* in discussing a contract price with the workmen. With a section of $37\frac{1}{2}$ square feet (3.5 square metres) in the first three cases, and $64\frac{1}{2}$ sq. ft. (6 square metres) in the fourth, the prices of the cubic fathom would be respectively £ 9 16s. 10d., £ 4 18s. 5d., £ 2 9s. 3d. and 9s. $9\frac{3}{4}$d.

It is quite natural that the above results should be included between very wide limits. Experience teaches the engineer to appreciate by attentive examination of the ground and by having it worked before him, into what category it may be placed; but it is only after practice *with the men and the conditions of the locality*, that he is able to introduce a certain amount of precision into his estimate.

(**143**) Knowing, or estimating the price per running fathom of a level of small section in given ground, the price per cubic fathom excavated may be deduced from it, and from this last price we can derive the price of another excavation of given shape and dimensions employing the following coefficients, or *moduli of transition* :—

For a section of 100 to 200 square feet (10 to 20 square metres) instead of $37\frac{1}{2}$ square feet (3.5 square metres). . .	$\frac{1}{2}$ to $\frac{3}{4}$
For a very large section of 387 square feet (36 square metres), of which 129 (12 square metres) for the drift and widening, and 258 (24 square metres) in the bottom stope, for the drift.	$\frac{1}{2}$ to $\frac{3}{4}$
ditto for the bottom stopes.	$\frac{1}{3}$
For large open workings in stopes.	$\frac{1}{4}$
For a rise.	$1\frac{1}{2}$

For sinking a shaft according as there is more or less difficulty from water	$1\frac{1}{2}$ to 2
For stoping a narrow lode	$\frac{2}{3}$ to $\frac{3}{4}$
ditto an average lode	$\frac{1}{2}$
ditto a wide lode	$\frac{1}{3}$ to $\frac{1}{2}$

Suppose, for instance, the case of a shaft in ground consisting sometimes of rocks of the second degree and to be made 13 feet (4 metres) in diameter without masonry, and sometimes of rocks of the third degree with masonry, requiring to be excavated $16\frac{1}{2}$ feet (5 metres) in diameter. Suppose the price of the first to be £ 5 per cubic fathom and of the second £ 2 10s. per cubic fathom in narrow levels.

A shaft of 13 feet (3 metres) in diameter has an area of 3·68 square fathoms ($12^{m}{\cdot}57$); using the highest values of the above coefficients, the price *per* fathom sunk will be firstly $5 \times 3{\cdot}68 \times \frac{3}{4}$, *on account of the large section* and it will become $5 \times 3{\cdot}68 \times \frac{3}{4} \times 2 =$ £ 27 12s. *on account of the difficulties arising from the sinking and the presence of water.*

In the parts requiring masonry the section will be about 6 square fathoms (20 metres) and the price per fathom sunk, calculating as above, will be $2{\cdot}5 \times 6 \times \frac{3}{4} \times 2 =$ £ 22 10s.

These figures £ 27 12s. and £ 22 10s. represent *the work of the miners only*, the haulage of the stuff is supposed to be paid for by the mine owner. They would be reduced $\frac{1}{4}$, and would become respectively, £ 20 14s. and £ 16 17s. 6d., if there were very little inconvenience from water during the sinking.

Suppose as a second example a large tunnel with a section of 387 square feet or 10·75 square fathoms (36 metres) in rocks of the second degree of hardness, or at £ 5 per cubic fathom in small levels.

We shall have :—

For the drift and widening	$5 \times 3{\cdot}58 \times \frac{3}{4} =$ £ 13 8s. 6d.
And for the bottom stope	$5 \times 7{\cdot}17 \times \frac{1}{3} =$ £ 11 19s. 0d.

Numerous other examples might be given, but is is only by practice that *the true figure* suitable for a *given case* can be fixed; the values given above, either for the different kinds of rock or for the coefficients, are only *means of arriving at a first approximation*, which should be put right by a subsequent special examination.

(**144**) What has just been said relates specially to crosscuts and levels.

For working places in a given deposit it would be idle to endeavour to lay down, *à priori*, a general average of the net cost of breaking stuff.

The work depends essentially on peculiarities of the deposit, on the period of working (whether preparatory workings or actual removal of the deposit), lastly on the organization of the work, according as the miners have simply to break ground, or have also to perform in part or wholly the accessory work of picking, loading, hauling, filling up, timbering, etc.

In the case of coal, instances of mines may be cited where the produce of one day's work of a hewer does not exceed half a ton, and others where it reaches 8 tons.

The average is generally nearer the lower than the higher limit, and an output of $2\frac{1}{2}$ to 3 tons is a good average — if anything a *high* average rather than a *low* one. Fixing the day's wages of a hewer at 3s. 2d., including lighting, powder, and tools, the net cost of getting a ton of coal would amount, everything included, at the working place to from 1s. $0\frac{1}{2}$d. to 1s. $3\frac{1}{4}$d.

These amounts should be remembered, not forgetting that examples of figures *lower than the first* will pretty often be met with in favourable cases, such as occur in England, in spite of the high price of labour in that country, and that figures *very much higher than the second* may also be met with, as is often the case in certain thin seams, dipping at high angles, without any soft layers to hole in and with a bad roof, such as occur in Belgium and the North of France.

CHAPTER VI.

APPLICATION OF MACHINERY TO BREAKING GROUND.

(**145**) The processes described in the preceding chapter constitute the regular work of the *working miner*, properly so-called, whether he be employed in breaking mineral or making excavations in the enclosing rocks (*country*).

They are processes which have been sanctioned by an almost universal usage. When the working places where they are applied are *well organized*, that is to say, when the sets of workmen who succeed each other are responsible for the result aimed at, when they are directly interested in this result — which according to circumstances is a certain distance to be driven, or a certain quantity of a substance to be produced, of a size and in state of purity agreed upon — and, lastly, when they are furnished with tools and explosives suitable to the nature of the rock, then it may be said that their work is performed under the most favourable conditions that the present state of the art of mining allows.

Must we on that account consider this art to have reached its culminating point? Is it capable of no further improvements in the branch which we are discussing, save in matters of detail, such as might result, for instance, from other substances being substituted for the steel of the tools and the powder or dynamite used in blasting?

May we not hope, as has been the case with so many other industries, to be able eventually to economize human power applied to a laborious work, which represents a great part of the labour expended underground?

These are very important questions and they require special consideration.

(**146**) Their importance is due, in the first place, to the fact that as mining increases, in order to keep pace with the growing wants of consumption, it becomes more difficult to get the proper supply of workmen. With the unheard of development of material riches and general well-being for the last half century, it is impossible to conceal the fact that the mass of the working classes are gradually losing their laborious habits, are seeking less fatiguing occupations, even if not quite so well paid, and are thus tending to withdraw from the occupation of mining. This occupation, in fact, has few attractions and is somewhat laborious; in reality, however, it is less hard than it appears, and it has the great advantage of being more regular and of having less *dead season* than most other kinds of employment.

However this may be, this disposition on the part of the working classes, which must not be left out of our calculations, has as its natural economic consequence the increase of wages, and, at the same time, as an almost inevitable corollary, a certain tendency of the workmen to restrict their useful daily effect, and too often to reduce the number of working days, either individually, or collectively by seeking pretexts for strikes. In this manner, when the time comes for increasing the output, it becomes difficult to increase the working population in an equal proportion, and even simply to keep up the old rate of production with the same number of workmen.

In this state of things, the first duty of mine owners ought to be to take up seriously the question of recruiting their workpeople. The general means at their disposal are these: Firstly, to accept a rate of wages corresponding to that of the locality; secondly, to endeavour to make the workpeople attached to them by offering, by means of a system of suitable institutions, moral and material advantages to them and even to their families; and, finally, by organizing the underground operations, so that there may be places for the boys as soon as they are able to work. This is a means of improving the position of the families and training workmen for this special mining industry — for miners should be accustomed to their work from an early age, almost as much as sailors.

(**147**) In the second place, it may be remarked that the usual methods of breaking ground are by no means satisfactory, *from a mechanical point of view.* They consist in the detaching of fragments of rock by the workmen, either directly by means of blows from certain tools, or indirectly with the aid of gunpowder, acting in certain cavities made by special tools.

It has long been observed that powder, even when acting expansively as it does in fire-arms, is a very expensive agent from a mechanical point of view.

Suppose, for example, that the explosion of a quantity of gunpowder, equal to one third of the weight of the projectile, imparts a velocity of 1640 feet (500 metres) per second to the latter; then we can estimate the amount of work done in foot-pounds by 2·2 lbs (1 kilogramme) of powder, costing 2 shillings, by the following relation :—

$$T_m = \frac{3\times 2\cdot 2}{2g} \times 1640^2 = \frac{3\times 2\cdot 2\times 2{,}689{,}600}{2\times 32\cdot 19} = 275{,}727 \text{ foot-pounds.}$$

This is not a quarter of the work which would be produced for about the same sum by a mere labourer working all day at a winch (*Cours de machines*, No. 39). This useful effect of 275,727 foot-pounds, however, is *assuredly very much greater* than that produced in blasting, where the work of projection is *nil*, or at all events useless, as has been said in No. **116**.

It is also easy to see that the miner, working with his ordinary tools, is under *very unfavourable conditions for labour.*

He soon becomes exhausted, in fact, from having to work in an inconvenient or very uncomfortable posture; furthermore because, as a rule, he has to sustain the weight of the tools whilst using them, without thereby increasing the useful effect; and lastly, because these tools are usually light, and have consequently to be wielded with great velocity in order to do the work. The miner is fatigued uselessly by the weight he has to sustain, and by the rapid manner he has to move his arms, in order that the tool he is handling, shall arrive at the end of its course with sufficient *vis viva.* He is, in some measure, in the same conditions as if he were loaded with a weight, and set to work at a crank-handle going at too great a speed; it may be affirmed, without stating the precise figure, that his work at the end of the day would really correspond only to a few thousand foot-pounds.

It is seen, therefore, that these methods of breaking ground are barbarous *from a purely mechanical point of view*, and that a great advance would be attained, both with regard to output and cost price, if we could succeed in employing human power more advantageously in this work, or in substituting for it some other natural motive power.

It will be further perceived that if this last result is important, it is at the same time difficult of attainment. In fact, it is not merely a question of arranging an apparatus which should receive the action of a motive power under conditions favourable to the employment of this power, and execute, in as automatic a manner as possible, the very simple operation of dividing a mass of rock into several blocks. It is very clear that a number of machines employed in manufactures perform much more delicate and complicated operations than this.

However, there can be no comparison between the task of erecting a fixed machine with its motive power in a workshop, and overcoming the thousand restraints which are met with in arranging a machine for breaking ground in a mine. It should be possible to put the machine up in a very cramped space, to set it to work quickly and easily; to put it away rapidly when men come to break down, pick, and fill the stuff, put in the tramway and timbering, carry on the stowage, etc.; these are operations which it seems impossible to do mechanically, and which altogether often take up as much of the workmen's time as they employ in handling the pick and borer, or even more. Lastly, the apparatus ought to be sufficiently simple to enable as many to be set at work at one time, as there are working places to be kept in activity.

It seems, therefore, very difficult to substitute mechanical means for manual labour, or rather *for part of the manual labour*, in all cases. Up to the present time at least, the employment of machines has been confined to cases of driving some great crosscut, which it was important to finish as quickly as possible (*Cours de machines*, No. 390), or else in cases where the mode of working allowed very wide working places, whilst the nature of the seam, especially its thickness and firmness of roof, rendered it possible to keep the working faces easily accessible to mechanical apparatus.

All these conditions are necessary, and it is on account of this necessity that machines of this kind, which for some years have begun to be much employed in the collieries of Yorkshire, Lancashire and Wales, have not been able to spread in other coalfields, for instance, in the mines of the Anzin Company where they have been tried without success.

(**148**) However this may be, and without being able to state how these trials will end, it is certain that the question is put, that its importance is understood, and that the engineer should be acquainted with the principal trials that have been made with varying success during the last twenty years.

We may distinguish trials which have in view a better utilization of the motive power of man, and the more thorough ones where endeavours have been made to substitute another motive power for that of man.

Following the first set of ideas, two kinds of arrangements may be mentioned; firstly, those in which rotatory work is substituted for percussive work, approaching more or less the mode of action of a man working a handle or a beam, which draws and pushes alternately; secondly, those in which an effort is made to remedy the inconveniences in the ordinary percussive work pointed out above (No. **147**).

(**149**) It has always been customary in soft rocks to bore holes for blasting by means of augers acting by rotation, instead of the borer and sledge. The auger is the tool especially employed in the numerous gypsum quarries in the neighbourhood of Paris (fig. 153).

M. Lisbet has endeavoured to extend the use of this tool to harder rocks. His apparatus is shown in figure 154. It consists of a frame, or stand, placed in front of the working place, and stayed against the roof and floor by two points, one of which is furnished with a screw, so that the apparatus can be firmly fixed. The frame can be lengthened, or shortened to suit the height of the working place; a sliding block, which can be moved up or down, carries a nut the direction of which may by altered with regard to the axis of the frame. Through this nut passes a long screw with a square thread, at the extremity of which is a screw-auger made of steel. This auger when rotated acts by its point and last spire; the other spires do not touch the rock and only serve to remove the debris, acting like an Archimedean screw. As the progress of the auger ought to vary according to the hardness of the rock, whilst that of the advance screw when rotated is constant, the screw is made hollow and the shank of the auger goes quite through it, up to the place where the handle or lever of the ratchet brace, which imparts a rotatory motion to it, is fixed. The handle or lever can be moved a little along the axis of the shank and made to grip the advance screw, and so rotate screw and auger at the same time, or else the auger can be rotated independently. In the first case, the auger turns and advances the space of one thread at each turn, and in the second case turns without advancing. When the auger and screw are both rotated, the tool tends to penetrate into the ground, which offers *an increasing resistance.* When this resistance has become so great that the workman can no longer turn the handle, and the stand begins to bend, he sets the screw free and the tool rotated alone continues to penetrate under the pressure of the elastic stand; but, at the same time, *the resistance decreases.* When it has become *nil*, or nearly so, he works the advance screw again once more, and so on.

In soft rocks the advance screw may be worked with the auger nearly all the time, and as a rule the periods during which the two are worked conjointly, increase in length with the softness of the rock. With very hard rock the changes are repeated very rapidly; it may be necessary even to bore a hole two or three times with augers of increasing diameters. The instrument, however, is not suited for hard rocks.

Lisbet's perforator succeeds fairly well in the Coal Measures of the North of France and Belgium, where, as we have already said, shale is more common than sandstone.

In rocks suitable for the use of this instrument two men, who set it up and take turns at working it, bore a sufficient number of holes to keep a third man constantly employed in charging and tamping.

(**150**) M. Leschot has invented an apparatus for boring holes for blasting, in which the boring tool acts by rotation, but in a different manner to that of Lisbet. The tool is a hollow cylinder of iron with a screw chased at one end for a certain length, and carrying, at the other end, a sort of crown, ring, or thimble, in which black diamonds are set. The setting is performed by making little cavities in the ring into which the ends of pieces of diamond are inserted, and the sides of the cavities carefully hammered up. The points of some of the diamonds are turned outwards, those of others inwards so as just to project beyond the edges of the ring. The ring is made to revolve rapidly, and at the same time to advance in the direction of its axis.

A circular groove is thus cut in the ground, leaving a central core adhering to the rock by its base. It is easy to detach the core when it has reached a certain length, by exerting a lateral pressure on it.

A jet of water, thrown forcibly to the bottom of the hole along the axis of the hollow cylinder, expels the detritus made, always keeps the rock well cleaned and prevents the tool from heating.

Fig. 155 represents a general view of the machine and the details of the ring, which is fixed to the end of the hollow cylinder by a bayonet joint.

Like Lisbet's apparatus this machine requires a stand with a carrier on which it can be raised or lowered, or turned in different directions; the rod is rotated rapidly by means of a handle and some rather complicated gearing, and at the same time is made to advance in the direction of its axis. The latter motion can be modified according to the hardness of the rock by means of various spare sets of gearing.

Leschot's apparatus differs from that of Lisbet in being particularly adapted for boring in very hard rocks, which would rapidly blunt steel tools, but have scarcely any action in the edges of the diamonds. Nevertheless the price of these diamonds, which are not abundant in nature, went up very much as soon as this new market was found for them. The scarcity of the diamonds will probably be a serious, and perhaps an insurmountable obstacle to the spread of this machine, which is very satisfactory in principle and the constructive details of which have been well elaborated by a clever engineer, M. Pihet.

(**151**) Another machine worked by manual labour by means of a handle is M. Gay's coal-cutter shown in figure 156. It acts like a kind of auger, and whilst kept pressed against one side of the holing by means of a suitable counterpoise, it is made to rotate and at the same time move in a longitudinal direction. A jud or holing is formed in this manner and is enlarged by the tool being passed through it several times. This machine, which has not yet come into general use, seems to be very well adapted for holing in sufficiently soft rocks, such as marl, certain iron ores, etc.

(**152**) The arrangements of the second class have been proposed by M. Delahaye and by M. Berreins.

M. Delahaye proposes by his system to do the work either of hewers or ordinary miners.

He has endeavoured to combine the following advantages:— A more comfortable posture for the workman, a more complete guidance of the point of the tool, an increase of the striking mass, which allows its velocity to be decreased, and a more direct connection between the striking mass and the point of the tool, thereby avoiding the loss of *vis viva* that results from the employment of a hammer (*see* No. **120**).

All these ideas seem perfectly rational.

Fig. 157 represents the machine intended for boring holes or for kirving nearly horizontally. It consists of two frames which can be lengthened and fixed somewhat like the frame of the Lisbet or Leschot machine. The frames carry two sliding pieces, the position of which is regulated by means of little winches placed at the top of the frame and furnished with ratchet wheels. The sliding pieces receive the ends of a fixed wooden guide, terminated on one side by an iron rod simply resting on the rollers of the hinder frame, and on the other side by a little cross head attached to the sliding piece of the front frame.

A tool carriage, formed of two cheeks of cast iron tied together by bolts is movable along the wooden guide. The cheeks are each provided with three corresponding holes which serve for fixing the tool; the lower ones are used in holing, those at the sides for shearing on the right hand and left hand.

A back and forward motion is imparted to the carriage and the tool thus acts by percussion. An elastic stop limits the recoil of the carriage, and so prepares for the forward movement without a useless expenditure of force on the part of the workman. When the machine is used for boring shot holes, and not for undercutting, the tool and carriage must allow the borer to be rotated; this rotation is effected, towards the end of the back stroke, by means of a *star wheel*, a contrivance well known in a variety of machine tools.

In the case of boring nearly vertical holes the frames would be given up , and the guide arranged so that it could be lengthened or shortened at pleasure. It would be fixed directly against the floor and roof by means of a screw. The boring would be performed by lifting the carriage by a little winch and then letting it drop, setting the winch free by means of a bolt arranged like that which fixes the position of the lever in the reversing gear of a locomotive.

The work would be executed under much the same conditions as beating down piles by means of a pile-driver working with a catch.

M. Berreins' machine, which was exhibited in full size at the *Exposition universelle* of 1867, but which does not seem to have been ever employed, was intended not only to utilize *human power* more fully, like the preceding one, but also to allow *the power of a tolerably large number of men* to be utilized in a drivage of the ordinary restricted dimensions, and thus double the rate of progress. It consisted of a large bell of sheet iron on the circumference of which steel cutters were fixed.

It was an arrangement like Leschot's crown of black diamonds, but on a larger scale, and was intended to work by percussion instead of by grinding. The bell was furnished with a long tail carried on rollers fixed in the axis of the level, and men arranged like rowers moved the machine backwards and forwards by means of cross arms fixed at right angles to the tail.

In this way a circular groove was cut, after which the cylinder of rock, attached only by its base, was broken off by blasting a large central hole or by driving wedges into the groove.

It would have been easy to complete this apparatus by adding an arrangement for giving a slight rotatory movement after each blow, and fixing a borer for making the central hole at the same time as the circular groove.

The fact to be remembered concerning the above-described apparatus, is the idea of applying *the power of a large number of men at one place*, where there is not usually room enough for more than two or three miners to work; in cases of urgency this may be of great importance.

It appears, therefore, that the principle of Delahaye's and Berreins' machines is that of applying human power, not to *small masses* which have *a great velocity* imparted to them, but to *large masses*, kinds of *rams*, whose *inertia* is brought into play, without giving them a great velocity and without the miners having to support their weight.

(**153**) The means of improving the use of human power have as yet appeared to be but an incomplete solution of the economic problem proposed, and endeavours have been made to substitute another motive power for it.

The question is no doubt important, as we have already said, but it is necessary to appreciate the limits of this importance, and it is not right to conclude from a comparison of the numbers of foot-pounds produced on the one hand by human power, and on the other by some different motive power, that there is a corresponding economy in the work of breaking ground. As has been already remarked, it is only to the work of *holing* or *boring* that a mechanical motive power can be applied; and the direct intervention of man will always be necessary, not only for setting up the machine and watching it, but also for carrying out all the accessory work which falls upon the miner in the course of his day's work, and which often takes up more than half of his time.

It is therefore less the economy of *money* than the economy *of time*, or, what is the same thing, *the increase in the work done daily by a given number of men*, that should be looked upon as the principal consequence of employing a motive power different from that of man. This economy of time is due to the fact that a power equal to that of a great number of men may be accumulated at the end of a level, as in Berreins' system, for example.

(**154**) Theoretically, and from a purely mechanical point of view, any motive power might be applied (*Cours de mécanique*, No. **34**); but the work to be done in a mine carries with it special restrictions, on account of the small space which is usually at one's disposal, the difficulty of ventilation, which usually makes its necessary to exclude all arrangements likely to heat the air much or vitiate it by abstracting its oxygen, or requiring furnaces inside the mine. In other words, the use of steam for producing power at the working places should as a rule be proscribed, save in special cases where there are facilities for its use, from the complete absence of fire-damp or the possibility of easily getting rid of the steam and products of combustion.

In England a considerable number of steam engines have been employed of late years in mines; the boilers are either placed in the mines near the ventilating furnaces, with proper precautions for keeping away any air charged with fire-damp, or else they are fixed at the surface and the steam is carried into the mine by long lines of pipes. These machines, however, are put up *immovably* at *fixed stations*, where arrangements are made for getting rid of the waste steam without interfering with the ventilation.

For *movable* machines, which have to work in various places and have to be moved along as the work progresses, either hydraulic power or compressed air will be employed. For the reasons given in the *Cours de machines* (Nos. **392** to **397**), it is easily seen that, from a mechanical point of view, it is generally preferable *to use compressed air*. The air is compressed at the surface by any motive power, and the compressed air is distributed to the different working places by a suitable system of pipes.

The loss of power from the length of the pipes is less than with steam, on account of the cooling to which steam is exposed, and less than with water on account of the smaller amount of friction. Besides, the employment of air helps to ventilate and at the same time to cool the working place.

The only inconvenience, and it is a somewhat serious one, is the necessity of providing *a special machine* for compressing the air; whereas, on the other hand, if water is made to act by its own pressure in a column extending down from the surface, the *pumping engine* employed for draining the mine, will easily do the slight amount of extra work thrown upon it by having to pump up the small quantity of water used in working the machines.

It would also be possible, as has sometimes been done, to make the working of the compressor *an accessory duty* of a machine *used principally for some other purpose*, such as pumping, winding, or even ventilating; but this superposition, in some measure, of two functions, which may have different requirements as to hours of use, variations of speed, etc., etc., is not without inconvenience.

All that will be done, as a rule, will be to take steam from the boilers of the principal machine and utilize it in a special engine for driving the compressor.

Whether it is a question of compressed air or water pressure, the machines may have the same general arrangement as would have been adopted for steam, save that in the case of water there will be some difference in the details of distribution (*Cours de machines*, Nos. **279** and **397**).

From what has just been said it is evident that everything points to compressed air as a fit agent for driving machines for breaking ground. It will be seen further on that it is equally fitted for other purposes in mines.

No doubt, therefore, it will play an important part in mining in the future, not only as a natural motive power properly so-called, but as *a convenient mode of transmitting power* from a machine placed *at the surface* and set in motion by a simple moving power, to any number of machines of all kinds distributed throughout *the underground workings*.

Machines for breaking ground may be classified as follows : — *coal-cutters*, used for holing and shearing, and *perforators*, *boring machines*, or *rock drills*, used for boring holes for blasting.

(**155**) All the coal-cutting machines are of English origin. The reason of this is that in England the seams are more fitted for their use and the output is increasing more rapidly than elswhere; besides which, English colliery proprietors are more liable than any others to suffer from a scarcity of workmen, and their increasing stipulations with regard to a diminution in the hours of work and an advance in the rate of wages.

A coal-cutter moving along the face of long-wall workings, in a tolerably thick seam and with a roof sufficiently firm not to require timber at the very face, will execute very rapidly an amount of holing which would require perhaps a couple of hours or even half a day from every one of the men distributed along the face. This is so much time gained, which can be utilized in the accessory work required, and the individual output of the miner and that of the whole working place are thus increased.

Until lately two machines have been preferred, viz : — that of Carrett and Marshall and that of Jones and Levick.

The first is worked by water pressure acting on a piston, and the holing is performed by means of several cutting tools or gouges, one behind the other, which successively enlarge the cut, taking off, so to say, series of contiguous chips. The machine is fixed to a carriage which moves on a tramway along the face; the rails have to be shifted each time after the coal has been broken down a distance equal to the depth of the cut. The reaction of the coal against the cutting tool would tend to throw the carriage off the rails; but, at the same time that the gouge is being pressed into the holing, a second piston, also acted upon by waterpressure, lifts up a " holder-on piece ", which presses against the roof and so stays the carriage.

The machine is entirely automatic, in the sense that it not only drives in the gouges and stays itself, but also moves itself along the rails a short distance on the return stroke of the cutter bar and " holder-on " as soon as the tool has made a full cut. This machine, although a little complicated on account of the number of functions which it has to perform, is pretty satisfactory in principle. The coal-cutter in question is shown in plan and elevation in fig. 158.

Jones and Levick's machine is more properly a coal-cutter in the sense that it really holes the coal in the same way as a pick or a *rivelaine*.

The machine is fixed to a carriage which moves along the working face; it is worked by compressed air and the carriage is shifted by the man who works the machine.

The piston acted on by compressed air sets a large pick in motion by means of a system of levers; the pick can be placed in any position, and can be moved parallelly to the bedding for holing and at right angles to it for shearing.

The machine is only automatic as far the back and forward movement of the pick is concerned.

A special contrivance reverses the stroke, even when the pick and consequently the piston do not finish their stroke. For this purpose the piston rod is hollow and carries a runner which participates in the motion of the piston and continues its course in virtue of the velocity acquired, if the pick happens to be prematurely stopped by too great a resistance of the rock; for instance, if too great a cut for one blow has been attempted, or if the point of the pick meets with some hard nodule of pyrites or clay ironstone in the holing.

Jones and Levick's machine has been tried at Anzin within the last few years, but without success, from reasons depending on peculiarities of the seams rather than from any fault of the machine itself.

The machine is shown, fig. 139, in elevation and section; the section shows the contrivance spoken of.

The two machines described above, were exhibited at the *Exposition Universelle* in 1867 and attracted the attention of inventors; since then numerous machines have been brought out in England, especially those of Messrs. W. Baird and Co., W. Benson, Kirkley, Birkenshaw, Simpson, and lastly that of Messrs. Winstanley and Barker, which at the present moment seems to be most in favour.

(**156**) The employment of compressed air has generally been found more convenient than that of water, adopted by Messrs. Carrett and Marshall, whilst the use of a tool with a percussive action like that of Jones and Levick has been attended with difficulties in keeping the machine in good repair.

There seems, therefore, to be a tendency, and in my mind a very reasonable one, to employ compressed air exclusively as a motive power, and to use tools acting either like circular or band saws, instead of tools acting like a gouge with a slow motion requiring very great force, or like a pick with the inconveniences accompanying percussive action. The idea of using a saw is not new, however, because a model of a coal-cutter with a circular saw, worked by hand, was shown in London at the 1851 Exhibition.

The new tools are arranged in series either on the circumference of a wheel or on the links of an endless chain. They are driven at great speed and gradually make cuts $2\frac{3}{4}$ to $3\frac{1}{4}$ inches (7 to 8 centimetres) high, reaching to a depth of from 2ft. 9in. to 3ft. 3in. ($0^{m}\cdot85$ to 1 metre).

This system is now being tried at the Blanzy mines.

In most of these machines, or at least in those which are coming most into use, a completely automatic action has very wisely been given up, because it would complicate them very much. The compressed air simply moves the tool which does the holing, and the advance along the face is effected by a winch moved by hand. This system seems preferable for a coal-cutter, because such a machine ought to be simple, easily set up, and fit to travel on a road which cannot be very carefully laid as it is shifted every day.

The following information has been published recently by M. Brüll concerning one of Winstanley and Barker's coal-cutters. It is driven by two small coupled engines worked by compressed air, making 80 revolutions a minute, and consuming at each revolution 1098 cubic inches of air of 3 atmospheres effective pressure, or 50 cubic feet per minute; in 8 or 10 hours work, in a hard coal where hand work is considered difficult, it makes a holing 3 inches (75 millimetres) high, 2ft. 9in. ($0^{m}\cdot85$) deep for a length of 120 yards (109 metres) along the face.

It requires 3 attendants, and does the work of twenty to twenty-five hewers. There is, therefore, a great economy of labour, and at the same time, with a given amount of ground opened out, the daily output may be increased.

A secondary advantage, which has a certain importance especially with thin seams, is the diminution of the proportion of small coal, or *slack*, in consequence of the smaller height of the holing.

Neglecting the small amount of expansion with which the compressed air is made to act, an expenditure of 50 cubic feet per minute with an effective pressure of 3 atmospheres corresponds to a work of

$$50 \times 144 \times 3 \times 15 = 324{,}000 \text{ foot-pounds}$$

or

$$\frac{324{,}000}{33{,}000} = \text{nearly } 10 \text{ HP}.$$

The power required would be less with a soft coal, and, therefore, either the pressure of the air or the quantity expended per minute might be reduced.

(**157**) If it is desired to form an idea of the *increase* in the daily output *with a given staff*, that may be expected to result from the employment of holing machines, we may suppose that the actual holing corresponds to a certain fraction of the day's work of a hewer. This fraction tends to approach unity when the coal is easily broken and the roof firm, and when the hewers do not fill up the excavations with refuse (*gob-stuff*); it may be only one-half or even less, if the hewers besides shearing and taking down the coal have much accessory work such as *putting*, filling the waggons, propping the roof, stowing, etc.

If the cutting is all done by hand, let us suppose that n hewers and m workmen of other sorts are employed and that T tons are produced daily.

With the coal-cutting machine employed at all the working places, these numbers become respectively n', m' and T'; and the question is to determine the quantity $\frac{T'-T}{T}$ or the relative increase in the daily output.

There are the following relations :

Firstly $m+n=m'+n'$ because the staff is supposed to be invariable;

Secondly $\frac{m'}{m}=\frac{T'}{T}$ if we suppose, what is approximately true, that the whole of the work other than cutting, requires a staff proportional to the output;

Lastly,

$$\frac{T}{n}=\frac{T'}{n'}(1-\alpha) \quad \text{or} \quad \frac{n'}{n(1-\alpha)}=\frac{T'}{T},$$

which means that the output of the hewer is increased in the proportion of $1-\alpha$ to 1, as soon as the fraction α of his time ceases to be employed in undercutting.

On the other hand, let β be the number of men employed in the mine for one hewer working under ordinary circumstances, β' what this number becomes when a coal-cutting machine is employed. We have, firstly, the relation :—

$$\beta'=\frac{1-\alpha}{\beta}$$

The equation $m + n = m' + n'$ becomes

$$n\beta + n = n'\beta' + n'$$

$$n(\beta + 1) = n'\left(1 + \frac{\beta}{1-\alpha}\right) = n'\frac{1+\beta-\alpha}{1-\alpha},$$

from this we deduce

$$\frac{n'}{n(1-\alpha)} = \frac{1+\beta}{1+\beta-\alpha} = \frac{T'}{T},$$

and consequently

$$\frac{T'-T}{T} = \frac{T'}{T} - 1 = \frac{1+\beta}{1+\beta-\alpha} - 1 = \frac{\alpha}{1+\beta-\alpha}.$$

If we suppose, and this is a fair average result, $\alpha = \frac{1}{2}$, $\beta = 3$ we should deduce

$$\frac{T'-T}{T} = \frac{\frac{1}{2}}{1+3-\frac{1}{2}} = \frac{1}{7}.$$

Thus with *a given staff* the output of the mine could be increased *one-seventh.*

If, instead of a *given staff*, we suppose the working places to be developed without limiting the staff, the output of the hewers employed at a given working place, and, consequently, that of the whole mine would be proportional to the quantity $\frac{1}{1-\alpha}$.

Supposing $\alpha = \frac{1}{2}$ the output *would be doubled.*

The quantities $\frac{\alpha}{1+\beta-\alpha}$ and $\frac{1}{1-\alpha}$ show what great advantages may be derived, as far as regards output, from the use of coal-cutting machines. It is essential, however, that the employment of these machines should not be attended with any serious inconveniences.

The first expense of purchasing the machines and necessary adjuncts will always be considerable, and the useful effect of a given machine will be considerably reduced if it is employed in narrow working places, or where the roof or the coal itself requires propping at the very face; for then much time and labour will be lost in moving the machine from one working place to another, and in shifting the props so as to let it pass along the face.

I think, therefore, that however important the employment of coal-cutting machines may appear from the above considerations, they may turn out to be very much less applicable in French than in English collieries.

(**158**) Perforators, or rock-drills, are machines for boring holes for blasting; they have much attracted the attention of engineers, ever since the first practical solution of the problem was given by M. Sommeiller, in his great work of piercing the Mont Cenis.

These perforators may act by rotation, but most often they act by percussion, imitating hand labour.

As a rotatory machine we may mention Leschot's perforator, driven at great speed by a small water-pressure engine invented by M. Perret.

The application of this engine to Leschot's perforator has been studied by Messrs. de la Roche-Tolay and Perret, and has been the means of simplifying the perforator very considerably, by doing away with the parts that effected the advance of the borer along the axis. All that is done, and this is far simpler and more satisfactory, is to keep the borer applied against the bottom of the hole by the constant pressure of water acting on its head; the amount of pressure is varied according to the hardness of the rock.

All the details of the machine have been carefully studied, and it appears that its use would extend in practice, if the high price of the black diamonds did not oppose a serious obstacle to its introduction.

Just as in the case of the hand machine, the harder the rock the more reason there is for its being employed. It is shown in figure 140 (*see* description of the plates).

(**159**) The first percussive perforator, which was ever worked practically was, as already stated, that of M. Sommeiller in tunneling through the Mont Cenis.

This tunnel, the longest yet made, had to be driven for a distance of 7 miles 1022 yards (12,200 metres); and the contour of the ground, save for a short distance near the two ends of the tunnel, forbade the use of air shafts, because they would have been so excessively deep, 500 fathoms and more (1000 metres) in the central part.

Thus a distance of more than 7 miles had to be driven with *only two* working places or *ends* (*fore-breasts*). From the nature of the rocks passed through, it is probable that even working with three shifts, it would have been difficult to drive more than 5 to 8 fathoms per month by ordinary hand labour; so that at the somewhat excessive rate of 109 fathoms (200 metres) yearly, it would have taken *at least thirty years* to complete the tunnel.

Such a length of time rendered the undertaking almost impossible for a commercial company on account of the expense, which would have become excessive, from the accumulation of the interest of the capital employed in the enterprise, and especially because of the loss that a gap of this kind must have caused to the two lines of railway that were to be joined. The greatest rapidity of driving was therefore an essential condition to be fulfilled. In order to execute this great work, M. Sommeiller, after numerous experiments, proposed and succeeded in carrying out two ideas. The first, suggested by M. Colladon, was to employ compressed air as a means of transmitting to the working places the power derived from falls of water near the extremities of the tunnel; compressed air had never before been used at such a distance from the power. The second idea was to apply the compressed air to work perforators. Mr. Bartlett, an English engineer, seems to have been the original inventor of these perforators, but Sommeiller greatly improved them.

The machines for compressing the air have been described in the *Cours de machines*, (Nos. **390** *et seq.*).

We have here only to speak of the boring machines, which were gradually improved by the inventor to such an extent that the rate of driving became greater and greater as the work proceeded, in spite of increased difficulties due to the lengthening of the tunnel.

It would probably have taken at least 30 years to drive the tunnel by hand labour, and in 1862, when Savoy was ceded to France, the French and Italian governments estimated that it would take 25 *years longer* to drive the remaining 10 kilometres. However, with Sommeiller's machines this distance of more than 6 miles was tunneled *in less than* 9 *years*, and the rate of progress often exceeded 36 fathoms a month.

(**160**) Figure 141 represents *one of the machines* of which several were carried on the same stand. They worked at the face of the tunnel, and received compressed air brought from outside by a line of cast iron pipes, $5\frac{1}{2}$ inches ($0^{\text{m}}\cdot14$) in diameter, which at the close of the workings exceeded $3\frac{3}{4}$ miles (6 kilometres) in length.

The machine figured shows the final result of the successive improvements introduced by the inventor, as their expediency became evident in the course of practical working.

This machine performs automatically all the movements required in a perforator, viz., back and forward stroke, rotation and advance of the drill as the hole is deepened. When the drilling part has been fed forward to the full extent of its course it can easily be brought back for a longer borer to be inserted.

The blow is effected by the excess of the pressure of the compressed air on the free end of a piston, above that which it exerts on the annular surface surrounding the piston rod. The return motion is produced by the pressure on the annular surface when the slide-valve puts the other side of the piston in communication with the atmosphere. The size of the rod may be arranged so as to reduce, as far as may be thought fit, the power employed in bringing back the piston and the quantity of air consumed for this purpose.

In order to render all the other motions free from the irregularities and the wear inherent to percussion, they are derived from a small special machine, which is simply a double-acting air engine, the speed of which can be regulated at pleasure. This small machine gives a continuous and regular rotatory motion to a longitudinal shaft which is made use of in order,

Firstly, to move the slide valve of the boring cylinder;

Secondly, to rotate the tool slightly during the return stroke;

Thirdly, to feed the whole boring part along the frame, in proportion as the hole is deepened;

Fourthly and lastly, to bring back the whole boring part, when it has reached the end of its course along the frame, and when a longer borer has to be put in.

(**161**) Figure 142 shows the stand on which the boring machines were mounted.

At first, there were eight machines, and the end or face was originally 13 feet (4 metres) wide by 9ft. 10in. (3 metres) high; the machines were made to bore a series of ordinary holes, $1\frac{3}{16}$in. to $1\frac{1}{2}$in. ($0^{m}\cdot03$ to $0^{m}\cdot04$) in diameter by 3 feet ($0^{m}\cdot90$) deep, and a series of large holes $3\frac{1}{2}$in. ($0^{m}\cdot09$) in diameter, called clearing holes. These were not charged with powder, but, as their name points out, served only to disengage the rock and so help the holes that were blasted.

Half-way up the end or face, 8 holes of $1\frac{3}{16}$in. ($0^{m}\cdot03$) and 4 clearing holes were bored along a horizontal line, so as to produce a central cavity 3 feet ($0^{m}\cdot90$) deep, 5 feet ($1^{m}\cdot50$) wide and about 1ft. 8in. ($0^{m}\cdot50$) high; around this central cavity, fifty or sixty other $1\frac{1}{2}$in. ($0^{m}\cdot04$) holes were bored, arranged in several horizontal lines and lines embracing the perimeter of the gallery; when these were blasted, the face was advanced a distance equal to the depth of the holes.

The eight machines employed originally, bored these 60 or 70 holes in 6 hours; the rest of the shift of 12 hours was taken up in charging the holes with cartridges 1 foot ($0^{m}\cdot30$) long, tamping, firing them in several regular volleys, quickly breaking down any remaining rocks with pick and crowbar, and, finally, removing the stuff so as to be able to put up the stand again ready for work in the next shift.

By this process, the rock was broken up into fragments not larger than $\frac{1}{7}$ or $\frac{1}{6}$ of a cubic foot (4 to 5 cubic decimetres), a convenient size for filling, and at the end of each shift the face was found to be pushed forward and all ready to receive a fresh set of holes.

The regular daily progress was thus *double the depth given to the blast holes;* and the depth of the holes depended on the nature of the rock.

This method of working may be considered as wasting a great deal of powder, compared with what would have been done if hand labour had been used; but, as has been seen, the essential point was to *drive quickly*, and breaking up rocks by manual labour had to be avoided as much as possible, otherwise the stuff could not have been cleared away as fast as the holes were bored. Besides, in order to gain time, the section of the end was gradually reduced, until at last it was only 8ft. 2in. by 9ft. 2in. ($2^{m}\cdot50$ by $2^{m}\cdot80$), the number of boring machines was increased to 14, and the holes were made from 3ft. 5in. to 4 feet (1 metre to $1^{m}\cdot20$) deep. In this way it was possible to obtain a progress of 40 fathoms ($74^{m}\cdot6$) a month, or *more than four times* as much as could have been done by hand.

This work would have been greatly accelerated by employing dynamite, which would have allowed the use of deeper holes.

(**162**) As a practical detail, the shape given to the borers should be noticed. Instead of having a simple straight or slightly curved cutting edge, the bit is made Z-shaped and is turned in the direction shown by the arrow (fig. 143).

This arrangement helps the boring of the hole and prevents it from becoming triangular, as happens sometimes with unskilful miners.

It is evident that a borer with a plain bit can turn in a hole, not only when the hole has a circular section with a diameter equal to the length of the cutting edge, but also when the section is a curvilinear triangle, constructed by means of an equilateral triangle, the side of which is equal to the cutting edge, and each apex of which, such as B, is the centre of an arc of 60° passing through the two other apices B′ and B″ (*see* fig. 143). Still more commonly, the section might be a polygon formed by an uneven number of curvilinear sides, each side being an arc of a circle described from the opposite apex as a centre, with a radius equal to the diameter of the bit.

Another interesting detail is the arrangement employed for cleaning out the holes. Too much time would have been lost if the perforators had been stopped in order to use a scraper. A sort of fire-engine was used which threw a stream of water with great force into the hole, and was moved about from one hole to another. The pressure was obtained by keeping the water in a fixed reservoir, connected by a pipe and cock with the compressed air contained in the feed pipe coming from the reservoirs of the compressors.

As rapidity of execution was, as we have said, an essential condition to be fulfilled, it was necessary to have a large number of reserve machines in order to avoid losses of time. Thus, for 14 machines in work at one time, there had to be a set of 60.

Each machine had a maximun length of 9ft. 2in. ($2^{m}\cdot80$), and weighed 5cwt. 13 lbs. (260 kilogrammes). It gave 250 to 300 blows per minute, requiring for each blow, with a maximun stroke of 10 inches ($0^{m}\cdot25$), rather more than 61 cubic inches (1 litre) of air at an effective pressure of $4\frac{1}{2}$ atmospheres. All the parts were made according to uniform models and were fitted beforehand; so that any spare part would fit any machine.

The weight of the machine may appear somewhat great, but it was very properly thought preferable to make each part sufficiently strong, although the handling and setting up were rendered somewhat more difficult.

(**163**) We have entered into details concerning Sommeiller's perforator and its use, which will allow us to shorten what we have to say about other more or less analogous machines which have been proposed and employed of late years.

We consider the tunnel through the Mont Cenis as a most remarkable work, in which the methods employed have constituted a great progress in engineering.

We think that compressed air was decidedly the best means to be employed in a work of this kind for carrying the motive power necessary for rapid work to the face; we believe also that, in the present state of the art, the only important improvement that might be made in the methods adopted, would be the substitution of dynamite for powder; and further, in a work of this kind, this substitution would probably effect an increase of progress, almost in the proportion of the increased depth that it would be possible to give to the bore holes.

It may perhaps be said that the inventor, in trying to have the perforator completely automatic, made a very ingenious machine no doubt, but at the same time a very complicated one, which could be simplified with advantage. This may be done for instance by giving up the automatic feed movement during the boring. It is impossible to do without men to look after the working of the machines, and these men may just as well feed the drilling part forwards along a screw, by means of a handle, sufficiently to let the piston always have its full stroke, without striking against the ends of the cylinder.

This simplification, analogous to that of which we are have spoken in connection with coal-cutting machines (No. **157**), would be particularly useful in an ordinary mine level, where the machines may easily be looked after, because they are necessarily few in number.

(**164**) Numerous perforators have been tried during the last twenty years. We may mention Schwarzkopff's machine, in which compressed air acting on a piston drove a sort of hammer against the borer. We have already seen that this system is inferior to the plan of making compressed air act directly on the tool itself. We may also cite Schumann's machine, which was not sufficiently automatic; then the machines of Dœring, Bergstrœm, Sachs, Haupt, Crease, Burleigh, etc., etc., in most of which ingenious mechanical movements may be observed. However, it seems to us that too much trouble has been taken, either to reduce the weight of the machine so as to facilitate the handling (some machines have been made weighing less than 1cwt.), or to make it too completely automatic, for this cannot be done without complicating the parts.

A very light and at the same time complicated machine is necessarily weak, and requires frequent repairs. We think it is better to make a perforator *simple* and *strong*, even if these requirements should cause it to be less easily set up and less automatic; for, as we have just said, this is a *theoretical* rather than a *practical inferiority*.

Among these machines we may point out the Burleigh drill, which has already been used in many places in America and in England, and is now being tried at the Saint Gothard tunnel.

We shall mention, lastly, a machine invented lately by Messrs. Dubois and François. The latter followed the construction of Sommeiller's machines at the Seraing works, and witnessed the birth of the various improvements that were gradually introduced; he knew and appreciated the reasons for these improvements, and his machine, without perhaps being the final one that will be sanctioned by practice, appears to us at least to satisfy the conditions of effective working, and to be comparatively simple in construction. It is shorter than Sommeiller's machine, though nearly as heavy; it has a much greater striking mass and gives fewer blows per minute; these circumstances are favourable to the mechanical effect, and lessen the wear and tear.

(**165**) The principal numerical data concerning Sommeiller's machine and that of Dubois and François, which have been mostly extracted, or calculated, from a paper by M. Pernolet in the *Bulletin de la Société minérale de Saint-Étienne* for 1873, may be summed up as follows :—

	SOMMEILLER'S PERFORATOR	DUBOIS AND FRANÇOIS' PERFORATOR
Total length of the machine.	9ft. 9$\frac{1}{4}$ins. (2^{m}·98)	7ft. 2$\frac{1}{2}$ins. (2^{m}·20)
Weight of the machine complete without the borer. .	5cwt. 0qr. 13lbs. (260 kilogr.)	4cwt. 1qr. 9lbs. (220 kilogr.)
Weight of the striking mass.	44·1lbs. (20 kilogr.)	70·5lbs. (32 kilogr.)
Diameter of the piston. . . .	3·15 inches (0^{m}·08)	2·75 inches (0^{m}·07)
Area of back end of piston. .	7·79sq : in. (50·26 sq : centim.)	5·96 sq : in. (38·48 sq : centim.)
Front end, deducting the rod.	2·65sq : in. (17·08 sq : centim.)	2·92sq : in. (18·84 sq : centim.)
Useful surface for percussion.	5·14 sq : in. (33·18 sq : centim.)	5·96 sq : in. (38·48 sq : centim.)
Moving pressure in effective atmospheres.	4$\frac{1}{2}$	4$\frac{1}{2}$
Maximum stroke of the piston.	9·8 in. (0^{m}·25)	11·5 in. (0^{m}·292)
Number of blows per minute.	250	150
Number of turns of the borer per minute.	10	20
Total pressure on the piston.	3cwt. 0qr. 11lbs. (157 kilogr.)	3cwt. 2qr. 10lbs. (182$\frac{1}{4}$kilogr.)
Half the *vis viva* of the striking mass at the moment of the blow.	274 foot-pounds (38·km.)	369 foot-pounds (51 km.)
Velocity of the mass at that time.	20 feet (6^{m}·1)	18ft. 4$\frac{1}{2}$in. (5^{m}·6)
Half the *vis viva* employed per minute in producing the blow.	68,500 foot-pounds (9,500 km.)	55,350 foot-pounds (7625 km.)
Corresponding horsepower. .	2·1	1·7
Volume of air expended by the machine for each blow of the borer.	75·9 cub. in. (1^{lit}·244)	95·75 cub. in. (1^{lit}·509)
Volume of air expended per minute.	11 cub. ft. (311^{lit}·)	8·3 cub. ft. (235^{lit}·)
Work that would be effected by this volume of air at 4$\frac{1}{2}$atmospheres.	106,920 foot-pounds (14760 km.)	80,662 foot-pounds (11153 km.)
Number indicating the useful effect of the machine. . .	$\frac{68,500}{106,920} = 0·64$	$\frac{55,350}{80,662} = 0·68$

(**166**) Figure 144 gives an idea of the Dubois and François machine, where the pressure of the air is employed directly, not only for producing the blow, but also for rotating the drill.

It was first employed in the Marihaie mines (province of Liége), and has been recently used in making a large crosscut, which had to be driven as quickly as possible at the Ronchamp mines (Haute-Saône). The results as regards rapidity of driving, were most important, for the rate was more than doubled; with more practised workmen, there might have been even a certain economy in cost (leaving out of account the expense of erecting the machines for compressing the air and the pipes for conveying it).

The tools for making the holes and the apparatus for keeping them clean are the same as those used with Sommeiller's machine.

We may point out here that it is a useful plan with hard ground to bore deep holes (5ft. 6in. to 6ft. 6in. [$1^{m}\cdot70$ to 2 metres]), and blast them with two successive charges of powder; the first charge is put in at the middle of the hole above a plug of clay rammed down very tightly and the second at the bottom of the hole after the clay has been picked out. Thus, with a minimum loss of time in putting the machine in place, you effect a greater progress than could have been obtained with a single charge which could not have been placed so deep.

(**167**) The different machines which have been spoken of (Nos **149** to **166**) appear to us to be such as can be recommended for practical use; or at all events they deserve a serious trial, when it becomes a question of *increasing the daily output* of the miner, so as, if possible, to reduce the net cost of the mineral, or when it is necessary to *hasten the execution of a given drivage.*

We shall just mention here, *but only as a reminder, as these things are not especially connected with the object we have in view :—*

1. A large number of excavating machines which have been invented especially in America, and descriptions of which may be found in various works, especially in G. Lambert's *Voyage dans l'Amérique du Nord;*

2. The use of the plough for effecting by animal power what is done by the pick, in ground which, though loose, has a certain consistency, which prevents its being at once removed with the shovel (this system has been successfully employed in Siberia in working certain auriferous and platiniferous alluvia);

3. The arrangements employed by Messrs. Borel and Lavalley in excavating the Suez canal, and carried out under the direction of M. Voisin;

4. Various machines which appear to us to be either too complicated, or unsuitable for the hard rocks that the miner usually

meets with, such as Captain Beaumont's machine, which cuts mechanically the circular groove and central hole proposed by M. Berreins; that of Mr. Penrice, which is intended to do away with the use of powder and make the work continuous, without other stoppages than those required for changing the tool, by means of cutters arranged all over the face so as to chip the whole rock into small pieces, which can be carried mechanically to the rear of the machine; that of Messrs. Valauri and Buquet, called an *excavator*, which is intended — by an arrangement similar to that of the new coal-cutting machine — to make a series of parallel cuts leaving blocks that can be easily detached.

We do not think it likely that owners of mines will generally require, or indeed would, as a rule, be able to employ such complicated and cumbersome machines, either for exploring or ordinary working; and as far as breaking ground is concerned, it seems that the use of mechanical appliances should not *in general* be extended beyond the limits which we have already assigned to them.

(**168**) We sum up finally by saying:—

1. If it is simply a question of *increasing the useful effect of the miner*, there is reason to hope for some advantage from experiments which may be made with a view to improve the mechanical conditions of his work, especially following the train of ideas pointed out in Nos **147**, and **149** to **152**.

2. If it is a question of *replacing the power of the working miner by some other force acting at the working place*, compressed air appears to be the motive power which ought, as a rule, to be preferred; and this medium may be applied with very great advantage, as far as concerns amount of output or speed of working, either in holing coal, in *the somewhat rare cases* (perhaps even exceptional in France) where the seams are suitable for the use of machines, or *much more readily* in driving levels in rock, with the aid of powder or dynamite.

5. Lastly, the importance of these advantages cannot be calculated in a general manner, because it will depend essentially

on local circumstances; all that can be said, is that this importance will increase very rapidly for coal-cutting machines in proportion as the seams worked are *regular in their mode of occurrence*, and, for perforators, in proportion as the rocks to be driven through become *harder*.

CHAPTER VII.

TIMBERING AND WALLING.

(**169**) In Chapter V we discussed the processes by means of which underground work is executed; and in the succeeding chapter we referred to the various attempts that have been, and are still being made to introduce mechanical appliances, whereby the labour of the workman may be lightened or even superseded.

In whatever way, however, the excavations have been made, they cannot usually be left open, even for a short time, without being supported in some degree. This is effected, according to circumstances, either by means of timber or masonry. We shall discuss these two methods in succession, and, in concluding, we shall give a few numerical data which are applicable to them.

§ 1. — Timbering.

(**170**) Sometimes special workmen called timbermen, repairers, etc., are employed for this particular work; sometimes the miners themselves undertake to set up all the props that are required in their working places. The former system can be followed where the roof is sufficiently solid to admit of the timbering being put in at leisure, after the face of the work has advanced somewhat; the latter, where the nature of the roof is such as to require timbering, as soon as the mineral has been removed. In the latter case, the price paid for mining includes the payment for setting up props: the timber is always furnished by the proprietors. In some cases, however, a small sum is allowed to the miner for each prop or frame set up by him; this is intended to counteract any tendency to neglect this work, which might be considered a hindrance to the advancement of the face. The miners are so prone to neglect propping, that when deputies visit their working places they have usually to recommend additional timbering. Plenty of prop-wood should be always at hand, and attention should be paid to the lengths really required, as the men are apt to exaggerate.

The ordinary kinds of timber found in the market may be arranged in four classes: hard wood, resinous wood, white wood, and fine-grained wood. Among the hard woods are included the different varieties of the oak, evergreen oak, chesnut, elm, beech, and ash; among resinous woods, pine, fir and larch; white woods, poplar, aspen, birch, hornbeam, alder, and acacia; lastly, among fine-grained woods are box, cherry, apple, pear, mountain ash, mulberry, etc. Each of these different kinds of timber has qualities which fit it for certain uses.

White oak is, *par excellence*, the wood for timber-work, not only on account of the dimensions of the balks that can be obtained, but also on account of their great strength. It resists the influence of the weather and of the bad air of mines, and when kept constantly moist lasts for a long time. Evergreen oak, which is found in the South of France, differs from the former by its smaller dimensions; it is also heavier, and, consequently, more difficult to handle. Chesnut tree often attains a large size, but is usually cut when young; the branches are pliable; it is destroyed by the bad air of mines, but lasts well when placed under water.

Elm, beech, and ash are not so plentiful in France as oak; they yield pieces which are easily bent and are thus suitable for being employed in positions where they have to be curved either temporarily or permanently.

Resinous woods are distinguished by thin long straight trunks and low density; they can thus furnish either long beams, or short, light, straight pieces which are well adapted for timbering.

Pine timber is strong and durable when not exposed to heated or impure air, and is best when kept constantly wet. Fir (*Abies*), which should not be confounded with pine (*Pinus*), is certainly the most plentiful timber in all the great forests of Europe (principally the variety *A. picea*). It is also remarkable for its large dimensions, but is inferior to pine in regard to solidity and capability to resist bad air or high temperature. Larch, which is only abundant in certain localities, is considered to be at least equal to pine and possesses the same good qualities to the same degree. White woods are in general neither strong nor durable; they can hardly be employed in mines and are usually sold in the form of planks; on account of their softness they resist shocks well. Poplar, aspen and birch have nearly the same qualities. Acacia has the peculiar property of resisting the bad air of mines even better than hard woods. Experiments were made by placing alternate *sets* of oak and acacia in galleries which were warm, dry, and imperfectly ventilated; the oak sets were altered in a few months, and it was found that those of acacia were quite sound after the oak ones had become perfectly useless. The alder is excellent under water or when buried under moist earth; it supplies very straight easily worked pieces. Hornbeam has a fine close grain and forms a link between white woods and fine grained woods. The latter are suitable for turning; they are employed for making bearings in machines and as fixed supports which require to be accurately made; but they have no importance from the present point of view, and in case of need a piece of heart of oak carefully selected can replace them in all their special uses.

(**171**) In pausing to consider the various applications which may be available to the mining engineer, we shall make the following recapitulation:

1. Oak is used in the form of square pieces for the frame-work of buildings, the foundations of machinery, tubbing, and in the form of props for ordinary timbering in mines.

2. Evergreen oak is hardly employed, except in the form of props; or, cut up in the direction of the grain, it is used for making the handles of tools.

3. Chesnut, grown as coppice wood, may be employed for making baskets (*corves*) and also for the handles of tools.

4. Elm may be occasionally employed like oak for making frames for timbering; its ordinary and special employment, however, is in the construction of carriages where it is used for the spokes, etc., of the wheels. It is also a good wood for turning.

5. Beech is especially applicable for pieces which require to be curved, on account of its flexibility.

6. Ash, which is essentially strong and pliable, and therefore suitable for resisting accidental strains, is useful for the shafts and poles of carriages, and for the same reason it is preferred to every other wood for the handles of tools.

7. Pine may be considered to be the most suitable timber for mines, as it yields pieces which are both strong and durable, more regular in form, lighter, and, therefore, more easily handled than pieces of oak. But, when used for frame-work which is exposed to the weather, it does not resist like oak. It may, however, be employed for the pulley-frames of winding pits. A great height is more easily obtained when this timber is used than when oak is employed; but the pulley-frames will be less durable whatever care may be taken for their preservation.

8. Fir is a very suitable wood for light structures, of great length. It is, besides, much employed in the form of planks for the details of the joinery work of buildings, for the boxes of wagons, for air-pipes, etc., etc. It is not very suitable for mining timber, although it is employed in those localities in which it is abundant.

9. White woods are best employed in the form of boards for making the bodies of waggons or tubs, packing cases, air-pipes etc. They are excellent for these special purposes. As they are easily compressed, they are capable, to some extent, of adapting themselves to the form of openings into which they are thrust, and this quality renders them peculiarly applicable for *sheeting* and the first wedges of tubbing of which we shall speak hereafter. Acacia has a special employment viz., for the large pins which join the timbers

of wooden ships. It is also an excellent prop-wood, but is not sufficiently abundant to be used for this purpose.

10. Alder is employed for piles; being easy to bore in the direction of its length it is suitable for pump tubes and for the permanent tubing of artesian wells.

11. Hornbeam is used for making pulley blocks, etc.

12. Lastly, the fine-grained woods are used in making bearings for trunions, the teeth of gearing, screws, and in fact pieces of any kind which are subjected to friction and therefore require to have a fine grain which takes a kind of polish.

In concluding this enumeration we will only add, that oak props are used in most of the mines of the north of France, evergreen oak in the South, and pine in various localities in the South and Centre.

(**172**) Timber for mines can be bought in the market and has seldom to be purchased standing. In the latter case, the purchaser must form an estimate both as regards quantity and price, of timber for carpenter's work, timber for the mine, poles, etc.; and of accessory products, fire wood, wood for making charcoal, faggots, bark, etc. A valuation of this kind requires a special knowledge which forms part of the art of forestry, and we shall not here enter into its details.

A mine-manager does not usually occupy himself with these matters, but confines himself to purchasing the timber by cubic measure, by weight, or most frequently by lineal measure. In the last case it is stipulated, that the pieces shall have a certain minimum diameter at the small end, and they are bought either of the full length, or of the length required for the different seams that are worked.

The terms of purchase and the prices vary greatly, and prices have, in general, a tendency to rise on account of increasing scarcity of the material.

The following are some examples :

Timber in the form of logs for carpenters' uses may cost $7\frac{1}{2}$ d., $8\frac{1}{2}$ d. or $11\frac{1}{2}$d. per cubic foot (25, 30 or 40 francs per cubic metre) and might reach even 1s. 5d., 1s. 10d., or 2s. 4d. (60, 80 or 100 francs per cubic metre) according to the dimensions and quality. Of late years as much as 5s. 6d. per cub. ft. (150 francs per cubic metre) has been paid for pieces of the best quality intended for tubbing.

Prop-wood costs 15s, 17s. or 21s. per ton (18, 20 or 25 francs per 1000 kilogrammes).

The price per running foot varies according to the dimensions from $\frac{1}{2}$d. (15 centimes per metre) for thin pieces, to 3d. (1 franc) for thick props of 8 to 10 inches ($0^{\text{m}}\cdot20$ to $0^{\text{m}}\cdot25$) at the small end. The mean price is about 2d. per running foot (60 centimes per metre).

In some localities round wood is bought in deducting one fifth; that is to say, the section is estimated by means of an empirical formula and one fifth is deducted, which gives almost exactly the section of the square piece that could be furnished by the tree. For this purpose the circumference is measured with a tape, $c = 2\pi r$, in the middle of the length, and the fourth of this quantity is squared. The calculated quantity is $\left(\frac{1}{4}2\pi r\right)^2 = \frac{\pi^2 r^2}{4}$, and $\frac{4}{5}$ of this is $\frac{1}{5}\pi^2 r^2 = 1.97r^2$, or practically $2r^2$, which is the area of the square inscribed in a circle of the radius r.

Timber is delivered either with or without its bark: the latter system is preferable, as bare wood is more easily preserved and is equally strong.

(**173**) In many cases timber is purchased only at certain seasons of the year, consequently much of it requires to be stored for a considerable time; and as it should be carefully preserved, the store should, if possible, be roofed in and well ventilated. If the store is not roofed, it should by preference have a northern exposure; its floor should be paved and gently inclined so as to facilitate the drainage of rain water. The large pieces should be piled up longways resting on supports, and the poles on end.

Timber which remains long in store should be turned over from time to time, and the decaying pieces should be removed. It is best to use the pieces in order, according to the length of time they have been in the store, and to finish one lot before beginning the next.

If the timber has not been delivered in the form of props, it should be cut with a saw rather than with the axe, beginning at the thick end so as to have the least waste. The cutting should be done outside the store, or if not, the splinters and sawdust should be carefully removed. This precaution is advisable in order to prevent the beginning of decay to which heaps of waste wood are subject after a time, as the decay is easily communicated to sound timber. Timber decays more rapidly in the mine than in fresh air, and it has been remarked that this alteration takes place most quickly in dry return air-courses in which the air is much vitiated.

The decay which is attributed to a fermentation of the sap shows itself on the surface by the appearance of an easily recognised cotton-like mould; at the same time the wood becomes softer by degrees until at length a sharp instrument can be easily driven to the core by the force of the hand. This rotting is *exceedingly contagious*. The downy clusters developed on one of the pieces of a frame, spread rapidly to the others and to the adjoining frames, either along the top poles or the rock.

Sound pieces of timber placed in galleries infested with this mould are seldom able to resist for longer than a few months.

The development of this malady, which is called the *dry rot*, is retarded by using only timber cut at a favourable time of the year — Autumn or Winter rather than Spring or Summer — and by preference deprived of its bark. The same object is attained by an active ventilation, which possesses other advantages, and becomes daily more important as the output of individual mines is increased.

Lastly, it has been observed that frames of oak or pine which have been placed in shafts passing through water-bearing strata usually endure for a long time. This fact has suggested the idea of reproducing the same conditions artificially in drier strata, by having in one of the corners of the shaft a small metal pipe pierced with minute holes, from which a fine rain is made to play upon the frames of timber.

(**174**) Other methods for preserving timber are also employed: —

The timber is coated with paint or tar, not only on the parts that will be exposed, but also, and more especially, on the ends, before the pieces are set up.

A solution of sulphate of copper or other antiseptic is injected into it, according to Dr. Boucherie's method.

The extremities of pieces which are to be buried in the ground are carbonized. Lapparent's method is to singe the whole surface by the flame of a gas jet which is moved along the piece of timber. If there is no gas at hand, Hugon's modification of Lapparent's process may be adopted: the timber itself is moved in front of a flame which issues from a hole in a kind of retort fed with coal.

These different processes for preserving timber, which are of great importance in some of its applications — such as railway sleepers and telegraph poles — have not yet been much applied to timber for mining purposes. It should be mentioned, however, that they are not very applicable in the last case — at least to the timber used in the ordinary working places, which constitutes the greater part of the consumption of a mine — since the timber so employed is generally crushed or broken, long before it is rendered useless by decay.

(**175**) The props usually employed have rarely a diameter of less than 3 to 4 inches (8 to 10 centimetres), or more than 10 inches (25 centimetres); the largest props are sawn in two longitudinally so as to form half-round pieces which serve as sole-pieces for frames.

Trees of smaller diameter and of several yards in length are partly cut up for prop-wood; still smaller ones are used as *lofting*, (*lagging*, or *lining*), being placed above the caps parallel to the face so as to support the roof. The separate poles which form the lofting are fastened together by means of laths obtained by cutting thin poles into two or four pieces longitudinally.

Lastly, in coal mines, where the roof is very friable, bundles of twigs, or mats specially manufactured for the purpose, are intercalated between the roof and the timber, so as to prevent small fragments of sterile matter from falling among the broken-down coal, and deteriorating its quality.

Branches of pine are employed for lining, either singly or tied together into small bundles; or, where the lining must be very close for the purpose of keeping back runing earth, planks may be employed; in other cases, the slabs obtained in cutting up timber into planks will be found useful.

We have seen that the timber is sent from the store to the mine already sawn into the required lengths. The timberman who sets up the props has usually no special tool except his axe which weighs from $4\frac{1}{2}$ to $5\frac{1}{2}$ pounds (2 to $2\frac{1}{2}$ kilos), figure 145; on one side of the head there is a cutting edge which is not quite parallel to the handle, and on the other side is a poll which is used for driving up props. The axe scarcely varies except in the length of its handle which is regulated by the height of the working places. The handle should be made of ash, split out so as to be made quite along the grain. The timberman should also be acquainted with the use of the pick, and should be able to bore and blast if necessary, in order to make room for a frame.

Joints made by means of the axe must of course be simple, and are confined to those in which plane surfaces are in contact; this tool is not suitable for making tenons or mortices, or generally, any joint in which one piece is inserted into another.

Nothwithstanding the simplicity of his work, the timberman must proceed conformably to certain principles, which are none other than the most elementary notions regarding the strength of materials. They may be summarized as follows: —

A piece of timber has, in general, to resist either a longitudinal pressure which tends to break it by crushing, or a transverse pressure which tends to break it by bending. In the first case, it should be set up so that the longitudinal pressure is borne uniformly by all points on the transverse section in a direction perpendicular to the section; if the pieces are long and liable to bend, their resistance may be materially increased by putting in struts from one frame to the next, or between the two legs of a frame. In the second case, the length of each piece should be diminished as much as possible, and where at all practicable the ends should be inserted in grooves or *hitches*. In either case, attention should be directed to giving stability to each piece by placing it in such a position that if a small movement of the rock were supposed to take place, in the direction of the resistance under consideration, the effect of the movement would be to tighten the timber and increase the load upon it.

In a stall, for instance, where the seam makes an angle α with the horizontal plane, a prop intended to support the roof should make the same angle with the vertical, or rather a *slightly smaller angle*, when fixed in its place.

(**177**) These principles are generally acknowledged to be correct by all miners. There is, however, one question about which there has been much controversy and it has elicited the expression of different and even contradictory opinions from competent persons.

It is the following : —

When a gallery requires to be timbered, should this be done in a substantial manner at the first, then afterwards be carefully inspected and kept in good order by repairing frames that have broken under pressure, putting in additional frames where they appear to be necessary, etc. ? Or, on the contrary, should the first timbering be considered to be only a provisional one, intended to last for a limited time during which it should hinder falls of the roof and sides that might obstruct the gallery, and prevent a sinking of the roof or rising of the floor, both of which might take place at the same time; and then, only after the temporary timber has been broken, should a substantial timbering be put in ?

Both systems have their supporters, and probably both sides are right from their own particular point of view : in other words, one or the other system should be preferred according to circumstances.

For example, the first timbering should be substantial and should be kept in good repair, if the rock is homogeneous, not liable to become disintegrated through contact with atmospheric air, and has no tendency to thrust inwards and gradually block up the galleries. A first movement, which would increase more and more if allowed to begin, is thus prevented.

This is, therefore, a case for the first system.

If, on the contrary, the first movement of the ground is irresistible, as, for instance, in the case of a gallery kept open through the *goaf*, or *gob*, for the purpose of communicating with the face, then the second system should be applied.

Indeed it is evident that the, gob (*stowing*, *filling up*), cannot be made sufficiently solid at first to resist a general subsidence of the roof, and is not thoroughly effective until the weight has squeezed it into a nearly solid mass. It would be useless to try to prevent this first movement by any system of timbering however strong : the only thing to be attempted at first, is to keep up those slabs of stone which tend to detach themselves from the roof, and afterwards, when the roof has settled permanently, the legs which have been crushed can be replaced by more substantial ones. Sometimes legs can be even altogether dispensed with, if the *pack-walls* have been solidly built, and a strong roof is left after the fall of the false roof.

By paying attention to the foregoing observations and to local experience, the manager of a mine will be able to decide in what manner a gallery should be timbered at first.

Such are the generalities which should be mentioned in connection with this subject, which deserves the close attention of every engineer, not only because it involves the security of the workmen, but also because timbering is often a very expensive item in the cost of mining which can be much modified by good management.

To these generalities we shall add some details about the cases which ordinarily present themselves in the course of practical working.

(**178**) **Timbering of long-work or of ordinary stalls.** — In most methods of working applied to beds, as we shall see further on, stalls, or walls of greater or less width, are driven forward : the roof is temporarily supported for a certain distance behind the face by timbering, while still further to the rear it is either allowed to fall or is supported by stowing through which the roads necessary for circulation are maintained.

The most simple form of timbering consists in setting up a prop under any part of the roof which is found to be insecure when sounded with a mallet; the nature of the sound indicates whether or not the first bed of the roof adheres firmly to that above it. The prop ought to be cut of such a length that it cannot be set up in its proper position, that is to say, *nearly perpendicular to the plane of the bed* (see No. **176**) without being struck heavily with a mallet or the poll of the hatchet; its foot ought to be placed in a slight hollow cut in the floor with a pick, this is done with a view to setting it on the solid rock or gaining a firm hold of the floor where its surface is smooth and slippery. In other cases, it is placed on a small heap of rubbish which is sometimes covered with a board to distribute the pressure, and sometimes surrounded with an iron ring to prevent it from spreading.

A wedge-shaped board (*lid*, or *tymp*), is placed between the top of the prop and the roof and driven into place by blows of the sledge: in this way the prop is firmly fixed when it is first set up (see fig. 146 and 147).

A prop such as we have described does not usually remain in place for longer than a few days; it is removed when the face has advanced a short distance, so as to allow the roof to fall or to make room for gob-stuff. The small heap of rubbish under its foot is of advantage at first, as it gives a certain degree of elasticity, allows the roof to begin to sink without necessarily breaking the prop, and afterwards facilitates its removal. When the rubbish is scraped out with a pick, or the ring struck upwards with a hammer, the prop usually becomes sufficiently loose to permit its being knocked out by a blow for the mallet, and it can then be employed again for the same purpose.

Instead of placing props irregularly and only in places where they are found to be necessary, it is more usual to set them up in rows in front of the face at distances of 1 to 5 yards from each other, the distance between any two rows being equal to the daily advancement of the face.

A new row of props is set up daily either close to the face or at a little distance from it, and the timber in the rear, which is no longer required for the support of the roof, is removed and replaced by stowing, or the roof is allowed to fall.

The same props may be used over again several times if they can be taken out; but many are lost when a great pressure of the roof or a threatening fall prevents their being removed in the usual manner. In this case, when the method of working requires the roof to fall at a short distance behind the face, the props are weakened by cutting them with an axe so as facilitate their crushing; for experience has shown, as might have been expected, that the pressure on the face diminishes if the roof is allowed to fall in a regular manner in the rear, and is not kept standing over too great an area.

(**179**) The possibility of employing the same prop again and again in regular seams, in those countries where timber is scarce and the price of cast iron low, has led to the introduction of small pillars of cast iron of a length suitable to the thickness of the bed. These pieces may either be solid and have a section similar to a connecting rod, or they may be made hollow like a pipe: both kinds are used in England. In order to facilitate their removal, they may be made in two halves connected by a short piece of chain; when joined together they are held by a tubular ring which passes over the joint formed by their oblique faces which are in contact. In order to disjoin them, it is only necessary to strike the ring upwards with a hammer, and as soon as it frees the joint, the oblique face of the upper piece slips on the oblique face of the lower one and the two fall on the floor together (see fig. 148).

It may be remarked that props of this material might be oftener employed than they are at present, especially in mines connected with iron works; for, in that case, when one of them is broken the fragments are not necessarily lost but can be re-cast in the same form.

(**180**) Instead of solid props, hollow ones may be used, furnished with ferrules and provided with a strong screw by means of which they can be jammed against the roof. They are used in some mines of the department of the Nord for supporting the roof behind the face. They are removed daily and carried forward a short distance in the direction in which the face is advancing. Their length is 10 or 12 inches (25 or 30 centimeters) less than the thickness of the bed. They are surmounted by a cap of iron with a hole in the centre through which a steel screw with a square thread passes. The screw is 2 or 3 inches (5 or 6 centimeters) in diameter; it has a square head, and is raised or lowered by turning a nut which rests on the cap, by means of a long spanner. By turning the nut the top of the screw can be pressed forcibly against the roof, or rather against a long beam which is used for this purpose. The foot of the prop rests on a circular sole-piece of the same diameter as its own, or somewhat larger.

This arrangement gives a certain elasticity to the system which is favourable to its preservation when the roof presses heavily. Fig. 149 represents this apparatus and its details. It was invented by M. Dermoncourt one of the officials of the Anzin Company, and although it seems to present certain advantages, it has not yet been employed in other mines. In order that it may be employed to full advantage, it appears to require a nearly level bed with a good roof.

(**181**) When isolated props are insufficient to support a roof which is apt to break into small pieces, they are not applied to it directly. They are then hollowed at the top, placed in rows parallel to the face, and made to support poles which run from one to the other. Short rods (*lagging*) are placed crossways between the poles and the roof, with their ends resting in little hitches cut in the top of the coal, until they can be supported by a new line of poles; and, lastly, if these short pieces are still insufficient owing to the jointy nature of the roof, twigs or branches are placed above them before they are driven up tight.

Props used for this purpose have a diameter of 4 to 8 inches ($0^{m}\cdot1$ to $0^{m}\cdot2$), and a length equal to the thickness of the bed; the poles are ten feet (3 metres) long, and 3 to 4 inches ($0^{m}\cdot08$ to $0^{m}\cdot1$)

in diameter; the rods are 4 feet (1·20 metres) long and $1\frac{1}{2}$ to 2 inches (4 to 5 centimetres) in diameter, and serve for a daily advancement of $2\frac{1}{2}$ to 3 feet ($0^{m}\cdot80$ to $0^{m}\cdot90$).

This system of timbering is represented in figure 150 for a flat bed, and in figure 151 for a steep one : the last figure shows also the upper and lower galleries, the former serving as an air-course and the latter as a road-way. It is employed in many collieries in the North of France and in Belgium, where it is necessary on account of the brittleness of the roof, in order to obtain the coal sufficiently clean. It is practised with much intelligence and skill by the miners of these districts, who are thus enabled to work to advantage some beds which would be considered unworkable in many other districts. The space behind the faces is filled up with stowing, and the timber, being left behind, is completely lost.

It is evident, of course, that as the nature of the roof varies, every degree of support can be employed, from single isolated props, to the complete timbering just described.

(**182**) **Timbering of an ordinary gallery.** — A gallery requires what are called *frames* (*sets* or *durnzes*) for its proper support. A complete frame consists of a *sole-piece* (*foot-piece*, *sill*, or *sleeper*), two *side props* (*legs*, or *arms*), and a *crown* (*cap*, or *collar*). The sole-piece, which is ordinarily half round, is obtained by cutting the larger props into two pieces longitudinally. The flat face is placed on the floor.

The side props rest in seats suitably cut on the back of the sole. Their larger end is uppermost. They are slightly inclined so as to give the form of a trapezoid to the frame, which is thereby increased in stability, while at the same time the breadth carried by the cap is diminished and the useful size of the gallery is not impaired. The horns of the cap and legs, are cut so that the pressure of the former is supported by the full section of the latter.

The frame is tightened up after it has been placed, by putting in short pieces of wood between it and the rock, especially above the collar.

Figures 152 represent the ordinary arrangement as already indicated in N° **176**. The frames are placed according to necessity at distances which vary from 20 inches to 6 or 7 feet ($0^{m}\cdot5$ to 2 metres) apart.

(**183**) The frame described in the foregoing number may be called the *normal frame*, or *set;* it is susceptible of a great many modifications, according to the size of the gallery, and the direction of the pressures which it has to resist.

We shall here give some examples :—

A very high gallery — say for instance $8\frac{1}{2}$ feet ($2^{m}\cdot50$) — may be divided into two compartments by horizontal *spreaders;* these may be of use either for stiffening the uprights or for forming an air-course above, or a water-course under the compartment destined for a travelling road.

The spreaders are made with a groove at each end, and should be of such a length that they become jammed between the side props when they are raised to the proper height. If necessary, they are tightened with wedges, and are maintained in their position by a *bracket*, or *cleat*, nailed to each of the side props. A flooring is laid on the spreaders when the upper compartment is intended for a return air-course, but when the lower compartment is to be a water-course, a simple plank for walking on is laid along them (see fig. 153).

A wide gallery in which two tramways are required, may be divided into two parts by a median line of props, which rest on the soles and support the middle of the caps. They should be cut and set up in the same way as the cross-pieces (see fig. 154).

In a steep gallery in which the frames are placed nearly at right angles to its axis, they are sometimes tied together, and so held in their respective positions, by nailing boards to the consecutive pieces, and by this arrangement the effects of an unforeseen movement of the rock are prevented.

The sole-piece may often be omitted when the nature of the rock renders this admissible, and then the frame consists only of two side props and a collar (two *legs* and a *cap-piece*).

When one side of the gallery is liable to give way, while the other is firm, one side prop and a cap are sufficient. In this case, one end of the cap is placed in a hole (*hitch*) cut in the solid side while the other end is supported by the prop. The joint of the side prop with the cap will then have one of the forms N° 1 or N° 2 shown in figure 155, according as the pressure is supposed to come mostly from the roof or from the side.

When both sides of the gallery are solid, a simple cap or stempel may be employed for supporting the roof; its ends then rest in hitches cut in each side next the roof.

The last case often presents itself in working a lode; when the sides (*walls*) are solid and the level occupies the whole thickness of the lode they may be left without timber while the roof (*back*) is supported. The support for the roof may be required, either immediately, if the lode itself is not firm, or after it has been worked away, and the space above the level is filled with deads. The weight of the filling up is then carried by the caps or *stull-pieces*, which are covered with boards (*stull-covering*), or poles (*lagging*), to prevent the stuff from running through. These stull-pieces are placed nearly at right angles to the plane of the lode and rest in hitches whose depth depends on the solidity of the walls; one of the hitches has to be cut of such a form as to allow the piece to be easily put in its place; a wedge may then be driven in tightly to stiffen the stull-piece and make it less liable to be bent under pressure. (See fig. 156.)

(**184**) The system of timbering that has been already described, is applicable when a drift can be cut in advance of the timbering, although the rock need not necessarily be very solid.

It often happens, however, that ground of different degrees of consistency has to be traversed, varying from fallen roof-stone on the one hand, to running sand full of water, forming a nearly liquid mass.

The principle of the method to be pursued (called *spilling*), is the same in all such cases, but the details are varied according to the consistency of the stuff. The ground has to be held back by a suitable timbering, not only on the outside of the frames already placed, but also between the last frame and the face; in some cases even the face itself has to be supported. The face is advanced by uncovering a small area at a time, removing the stuff to about the same depth as the side laths have been already driven, then replacing the *breast-boards;* after this the side laths are driven forward, then the face is advanced, and so on alternately until there is room for another frame.

According to the nature of the ground, the outside lining of the frames consists either of strips of wood with spaces between, or of closely fitting *laths* which are sometimes even jointed together; they are driven forward diverging slightly towards the front, in order that they may be able to bend under the pressure from the outside without contracting the face too much. The corner laths should be broader in front than behind, so that they may fill up the pyramidical space formed by the whole set.

The frames are often made alternately large and small : the larger frame supports the middle of the laths while the smaller frame which succeeds receives a new series of laths which surround it on the outside and pass obliquely to the interior of the larger.

Figures 158 and 159 are sketches of the arrangements for work of this kind : the former supposes the ground to be loose but not running, such as fallen roof; the latter, on the contrary, supposes the ground to be of such a running nature that it cannot be kept back unless the laths are jointed. The second case is much more difficult than the first, for it is necessary to support, not only the roof and sides, but sometimes also the floor by well jointed laths. Even the face has to be sustained by breast-boards held against it by struts or stays applied to the last frame put in. If the ground is very running, these breast-boards are made only slightly more than half the width of the level, and are stayed by struts placed parallel to the axis of the drift. These methods are usually employed by the Silesian miners.

In all cases, the work should be conducted in such a way, that no more stuff is removed than what corresponds to the dimensions of the gallery, increased by the volume of the timber. Every additional removal of stuff is not only useless but injurious, since it sets the ground in motion and increases the pressure. Any further running of the stuff must be prevented by using laths jointed together as closely as possible, while the interstices are filled up with straw, etc.

When the ground is wholly composed of more or less fine running sand, a set of laths is easily driven forward by the blows of a sledge. When, on the other hand, there are blocks which stop the cutting ends of the boards, they are allowed to fall out if not too large; but if they are likely to leave too great spaces, they are cut away sufficiently to let the laths pass, and the rest is allowed to remain.

Lastly, when the ground is so loose and fluid that it runs almost like water, so that the exposure of only a very small portion of the face would lead to an almost indefinite influx of stuff, it has been recommended to drive wedges into the face by means of a ram, and so to force back rather than to remove the ground. When the pressure resulting from this operation has become so great that the blows of the ram are no longer effectual, some auger holes are bored in the wedges, and the stuff allowed to run out until the pressure has been reduced. The holes are then plugged up and the work of driving the wedges is continued as before. The ram may be made of a beam suitably hooped and hung by a chain from the cap of one of the frames last set up.

In this process, wedges have been employed, not only in the face but also in the floor of the drift, in such a way that the vertical wedges were driven downwards, as soon as the horizontal ones were far enough advanced to permit of this being done. This system, which is represented in figures 159, has been successfully used in very difficult ground in Belgium; the progress was greater, and the quantity of stuff removed per lineal yard less, than by the common system with laths like that practised in Silesia:

(**185**) **Timbering of a shaft.** — A shaft is a work of importance which is usually intended to last for a considerable time, and, for numerous reasons which shall be given further on, it should be *walled* and not lined with timber; it should have a circular or elliptical section — in every case *curvilinear* — so as to be suitable for the employment of masonry. It may be necessary, however, to put in timber temporarily, until it can be replaced a by substantial lining of masonry.

The excavation is made of the form of a polygon circumscribed about a circle, whose diameter must be equal to that of the finished shaft, increased by twice the thickness of the walling. The timbering is composed of pieces overlapping at their ends, where they are cut obliquely so as to adapt them to the form of the polygon. These *frames* have laths or poles placed behind them for the support of the sides, according to the nature of the ground; they are put in place in descending order, and are suspended by means of a series of *straps*, or bearers, to a carrying frame whose sides are prolonged, so that they rest either on the surface or in recesses in the solid rock.

This timbering, which is represented in figure 160, is removed frame by frame as the nature of the ground will permit, to make room for the definite lining of masonry as it is built upwards.

(**186**) When timbering is intended to form the definite lining, the section of the shaft is necessarily rectangular; the timbering then consists of a series of frames or sets similar to those used in galleries, but with the differences which result from the usually larger section, the necessity of maintaining them at an invariable distance from each other, and, lastly, the importance of making everything so substantial at first, that repairs, which might hinder the ordinary work in the pit, may be required as seldom as possible. The length of the lesser side of the rectangle, is determined by the sizes of the *kibbles*, *skips*, or *cages*, that are to be used; that of the greater side, by the number of distinct compartments required. Two compartments are usually set apart for drawing minerals (of course one might be sufficient); one may be required for pumping, and another for ladders, or to serve as a downcast or upcast.

The dimensions of the rectangle having been determined, the shaft is laid out so that the lesser side is parallel to the strike of the beds which we suppose to be stratified (*).

A set consists of four pieces of timber — two long (*wall plates*), and two short (*end pieces*) — ; these are either round or square according to the importance of the shaft.

The sets are placed vertically above each other, and maintained at a distance of 5 to 6 feet apart by means of supports, (*studdles*), placed in the angles and fastened to each set (see fig. 161).

Where the nature of the ground is favourable, the sets are built upon each other in series; each series begins with a set of bearers which differs from the other sets in so far, that the wall-plates are made longer, and their ends rest in deep hitches cut in the solid rock. A lining of poles or more or less jointed laths is placed behind the sets and jammed tightly by means of wedges.

When the timbering has to be done from above downwards, as the pit is deepened, the successive sets are hung from an upper frame by means of pieces nailed from one set to the other.

If timber is plentiful and cheap, a shaft in loose ground may be lined with frames close together (fig. 162).

The *buntons* (*dividings*, *byats*, or *dividers*), which divide the compartments, help at the same time to stay the wall-plates; for this reason these pieces are not cut through to half their thickness, but are cut as shown in fig. 165, so as to utilize them as stays as much as possible, and not to weaken the wall-plates to any great extent.

The interior faces of the sets and buntons, carry the guides which conduct the cages, or the air-tight casing of boards required for an air compartment.

The figures referred to, represent the principal details already given, corresponding, in the case of shafts, to those given above for galleries (Nos. **181** and **183**).

(**187**) When the ground is so loose that the sides must be sup-

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(*) In a shaft sunk on a lode, the longer side is parallel to the strike of the lode. *Translators.*

ported by timber at once, we have the case similar to that described in No. **185**, and similar methods are followed.

The principle of the work consists in placing the sets as the shaft is deepened; each set is hung from the preceding one, and laths which are sometimes jointed, are driven in behind it in a diverging manner. The laths are driven even in advance of the sinking, and the bottom of the shaft is covered with planks so as to allow small portions to be excavated at a time.

This work is generally preceded by an excavation at the centre of the pit, lined with boards nailed to a square frame 2 ft. 8 in. ($0^{m}\cdot80$) square, which has the double object of dividing the sinking and forming a well (*sink*), from which the water can be raised without taking up the sand at the same time.

Figures 164 represent in plan, and section parallel to the wall-plates; the above is the system of *spilling* as practised in Silesia. Figure 165 is another section of the same shaft, parallel to the end-pieces; it shows a system of vertical pieces which are placed in the corners, and stayed against each other in such a manner as to prevent as much as possible every deviation from the perpendicular.

Lastly, if the ground is so liquid that even small portions of it cannot be uncovered for an instant, the bottom of the shaft might be filled up with pointed wedges, which could be driven in by means of a ram so as to force back the ground. This process corresponds to that already mentioned for galleries, No. **185**.

§ 2. — Walling.

(**188**) This means of support is frequently employed in mines; it is therefore important that we should point out those cases in which it ought to be preferred to the more commonly used methods of timbering.

Firstly, in regard to first cost, the two methods are not comparable. Good walling built with mortar, costs at least three or four times as much as a perfectly complete timbering for an ordinary gallery, and at least twice as much for a large shaft. On the other hand, a timber lining may cost much more for repairs; it may happen, for instance, that at the end of several months, or a year, it will be necessary to place new sets between those first put in; after a time, both the newer and the older sets will have been successively replaced, as their pieces give way on account of the pressure of the ground, or are destroyed by dry-rot, especially in return air-shafts or galleries. The cost of maintenance, which increases with time, may, therefore, more than counterbalance the smaller first cost, so that at the end of five or ten years, a gallery lined with masonry will be found to have cost less in the aggregate than a timbered one. It should be mentioned also, that this calculation takes no account of the loss of work which would be caused by stoppages for repairing a timber lining, especially in the case of a shaft through which a large amount of stuff has to be drawn.

It should be represented, however, that the choice between the two methods should be modified in a subordinate manner by the relative prices of the materials, the cost of workmanship in the district, and, principally, by the length of time during which the work is to be kept open.

If the question be closely examined, it will be found that walling has not been employed as often as it might have been with advantage. In order, however, that this remark may be correct, it must be understood to apply only to the case in which the walling can be made so substantial at first, that it will last for the whole length of time during which the gallery is to be kept open, without requiring notable repairs; that is to say — referring to the considerations of No. **177** — to the cases in which a definite timbering may be put in at first, and excluding those in which there is a first irresistible movement of the ground, which would break up and destroy any masonry however strongly or carefully built.

On the whole, it may be said, that the practice of walling ought to become more general as timber gets scarcer and dearer, as mines become deeper and more extensive, and the works below ground have to be kept open for longer periods. It should be considered, moreover, that walling is indispensable in certain cases, as, for instance, in large excavations such as tunnels for railways and canals, or in the chambers destined to receive ventilating furnaces or steam boilers. Nevertheless, it does not seem probable, that walling could altogether supplant timbering in the ordinary workings of a mine.

(**189**) We may distinguish two different kinds of walling : walling with dry stones which is more like ordinary stowing (*gobbing*), and true walling with mortar; each of these may be further subdivided into, walling with parallel joints, like pillars intended to resist vertical pressure, and walling with converging joints, forming arches to resist lateral pressure.

The materials employed are rubble-stone, brick, and, very exceptionally, hewn stone. The rubble-stone is rough and more or less dressed : limestone and coal-grit are readily employed, also gneiss, mica-schist, slates and other rocks with a more or less distinct cleavage, which split into flat easily handled blocks. Bricks have a great superiority on account of their rectangular shape, and the simple proportion which exists between their three dimensions, which is usually that of the numbers 1, 2, and 4. For instance, the length may be 9·4 in., the breadth 4·7 in., and the thickness 2·4 in., (24, 12, and 6 centimetres) forming a solid of $9{\cdot}4 \times 4{\cdot}7 \times 2{\cdot}4 = 106{\cdot}05$ cubic inches ($24 \times 12 \times 6 = 1728$ cubic centimetres). Supposing the mortar joint to be $\frac{3}{8}$ inch (1 centimeter), thick, a brick will occupy a volume of $9{\cdot}8 \times 5{\cdot}1 \times 2{\cdot}8 = 139{\cdot}94$ cubic inches ($25 \times 13 \times 7 = 2275$ cubic centimetres), or there will be 333 in a cubic yard (440 in a cubic metre) if the joints be well made, or, roundly stated, 400 (500), taking waste into account.

These bricks ought to be properly burnt; if they are burnt too little they have not a sufficient degree of hardness, and if too much they are vitrified on the surface, so that the mortar cannot bind them ; overburnt bricks however are better than underburnt ones. The earth used for making them should be distinctly clayey and free from calcareous nodules, for these would be changed into quicklime during the process of burning, and would slake, and destroy the bricks when they were exposed to moisture as in mines. The requisite degree of burning is ascertained either by observing the colour for a given clay, or by the ring emitted by the bricks when they are tapped lightly.

Bricks are particularly well adapted for the rapid construction of arches. The side walls, or piers, are often built of rubble-stone and the arches of brick.

(**190**) It is not our intention to enter into the minute details which belong to the art of building, we shall simply point out certain rules which ought to be observed in regard to buildings underground.

In the first place, hydraulic mortar is generally employed; it should be made thick, should be used as sparingly as possible, forming simply a continuous thin bed between the successive courses, and should completely fill the spaces left between the stones of the same course when they are pressed closely together. When the stones or bricks are porous, they should be moistened before being put in their places.

No space should be left, either in the body of the masonry, or between the masonry and the ground that is to be supported, and pieces of timber, even poles and laths, should be removed as far as possible. All spaces behind the walls, left vacant by the removal of timber, should be carefully packed with rubbish (*attle*), or better still, with concrete.

When it has been decided to wall a level, the work should be done forthwith in a sufficiently strong manner. (*See* No. **188**).

In masonry with parallel joints, which has to act like a pillar, the joints should be perpendicular to the pressure to be supported.

In arches, the chord of the arc should be nearly at right angles to the pressure; the imposts, or springers, should be as solid as possible, and the thickness should increase as the arch becomes flatter, for a chord of given length. It would be quite useless to try to give formulae for calculating the thickness, since the *amount* of the pressure which the arch will have to sustain, is unknown, and hardly even its *direction*.

Masonry is constructed in successive courses, in each of which care must be taken to break joint with the preceding; the joints of one course are also made across those of a preceding one in order that the mass may be tied in every sense. The tieing is increased by the employment of binders : old timber, cut so that its length is equal to the thickness of the masonry, may be conveniently employed for this purpose.

Having given these generalities, we shall now proceed to consider the various cases that present themselves in practical working.

(**191**) **Walling of a gallery through stowing for maintaining communication with the working face.** — This work is less walling properly so called than a kind of filling up which is generally combined with the employment of timber. The space in the rear of the working face is usually filled up with rubbish furnished by the bed itself, or taken from another part of the mine, or brought from the surface. The rubbish is thrown in with the shovel, no special care being taken to pack it against the roof; a continuous wall, however, is built along the side of the gallery which is to be reserved, or lines of pillars made with the best stones picked from the rubbish, and faced with a certain amount of care on the side next the road. In this masonry, old props may be very advantageously employed as binders through the whole thickness of the wall, which may be 5 to 7 feet ($1^{m}\cdot50$ to 2 metres) and upwards. If it is necessary to support the roof of a gallery formed in this way, caps may be used whose ends repose on the side walls, and often on pieces of old timber placed longitudinally, so as to distribute their pressure over a sufficient base.

Fig. 166 represents this system which gives, at a small cost, a sufficient support for the several weeks or months during which the gallery should remain open; it is preferable to a true walling with mortar which would be too expensive, and would not resist the inevitable sinking of the roof more effectually.

Instead of being made through the stowing the road might be made along the side of the solid coal, so as to limit the quantity of timber required on one side; it is well to remark, however, that this position instead of being advantageous is often the reverse, for the roof breaks at the side of the solid when it sinks upon the stowing, and all miners know well that, in this case, a road is more easily kept in the middle of the stowing than in the line which separates the stowing from the solid.

(**192**) **Walling of an ordinary gallery.** — In this kind of walling there are a certain number of cases to be considered.

In a gallery, it is often composed of two side walls of quarry stone $3\frac{1}{4}$ feet (1 metre) high, surmounted by an arch of $3\frac{1}{4}$ feet (1 metre) radius : thus, when the walling is finished, the gallery is 6 ft. 6 in. (2 metres) wide, and 6 ft. 6 in. (2 metres) high in the middle (fig. 167).

The side walls are sunk 4 to 8 inches (10 to 20 centimetres) into the floor, and are 2 to $3\frac{1}{4}$ feet ($0^{m}\cdot6$ to 1 metre) in thickness. The arch is seldom more than two bricks or 18 inches ($0^{m}\cdot50$) thick, and sometimes it is only one, or one and a half.

If the gallery was timbered in the first place, it often happens that the timber must be removed and the gallery enlarged to make room for the masonry. But when the masonry itself can be built in the interior of the frames, the latter ought to be removed as well as the lagging (*laths*), and all the resulting empty spaces should be carefully filled up.

The construction of the side-walls does not present any peculiarity. Centres for the arch are formed by means of strong bars of iron, bent to the required curve, and provided with the necessary boards; each bar has two toes which rest on the side-walls.

This arrangement has the advantage, that the work of building the arch may be carried on without interrupting the traffic in the gallery.

(**193**) If it is seen that the pressure comes, not only from the *roof* but also from the *sides* and *floor*, in consequence of the tendency of the last to rise up, a walling in the form of an *ellipse* (or rather a *curve with several centres*) is employed, in order to resist the pressure in every direction.

The complete walling comprehends, firstly, an inverted arch, or *invert*, at the bottom, the chord of which is equal to the breadth of the gallery.

Adding to this first element the size of the gallery at a given height, and its total height, we have all the elements necessary to determine the section.

We proceed in the following way:

Let AB be the width at the base (fig. 168), CE the greatest width at a given height, DD′ the height from the key-stone of the arch to the chord of the invert at the bottom. Introducing the chord BC, and drawing from its middle point a perpendicular until it cuts the horizontal line CE, we find in O the centre of the arc BC. From m as a centre the quarter circle DF is described, and DG is taken equal to $\mathrm{D}m = m\mathrm{G}$. The angle D$m$G of the equilateral triangle is 60°, and the angle GmF which is its complement is 30°. Draw CH parallel to GF and HO′ parallel to mG, and the centres of the arcs CH and DH, which complete the half profile of the gallery, are found in O′ and O″. The three arcs BC, CH and HD coincide in the points C and H.

The corresponding angles at the centre, are: for the first, the angle COB which depends on the relative position of C and B; for the second, the angle CO′H which is 30°; and for the third, the angle HO″D which is 60°.

As to the invert of which AB is the chord, it may be described by means of an arc of a circle of which O‴ is the centre and O‴B the radius, and then it will coincide with the arc BC at the point B. But a depressed arch is more often employed, the centre being somewhere in the vertical DmD′, in supposing it to have a given curve D′D″, that is to say, in making a circle pass through the three points AD″B. The centre O^{IV} will be found by drawing a perpendicular from the middle of the line BD″ until it cuts the vertical DmD′.

The section of the gallery will present an acute angle at B of which $\mathrm{OBO}^{\mathrm{IV}}$ is the supplement. It is convenient in this case to place a corner stone at B, cut in such a way as to form a springer for each of the arches BA and BC.

The thickness of a wall of this kind is not the same at all points. It ought to depend at each point, partly on the radius of the curve, and partly on the unknown pressure that will be developed. We should have a kind of limit if we supposed the ground to be so movable and running as almost to approach the state of a liquid, in which case the pressure would be uniformly distributed and would everywhere act in a direction perpendicular to the external surface. In order to obtain an equal strength at each point, in this case, we should require to make the corresponding thickness proportional to the radius of the curve. Usually, the thickness of the upper arch is one brick, or one and a half, and of the sides, two bricks, or two and a half, when very strong lateral pressure has to be resisted.

The plan given above, which consists in tracing the half outline of the cross section of the gallery with three centres, or, taking a bottom arch into account, with four centres, is sufficient for galleries of small section such as those ordinarily constructed in mines. The number of centres is usually increased for galleries of large section, or an elliptical profile is adopted.

(**194**) When a gallery has been driven in running ground with the aid of the special methods of timbering described at the end of No. 181, it is often found convenient to replace the sets and laths by walling, after the ground has become drier and less shifting. This work is done backwards, from the inner end of the gallery towards the entrance, as in this way laths can be more easily supported after a set has been removed to make room for the walling, and then the laths can be drawn out after the walling is built up. Timbering is replaced by walling, set by set, and for a given set, piece by piece. The uprights are cut at the foot, in the first place, and the sole-piece together with its bottom laths are lifted, in order to make way for the bottom arch; then the uprights themselves are cut away progressively as the side walls rise up, the cap, etc., being supported by provisional props. After this, the centre is set up, the top parts of the legs and the cap are removed quickly, and are forthwith replaced by a course of the arch.

This work is easily described but difficult to carry out, and can only be done by skilful workmen. The art of the workman consists in dividing, as much as possible, the removal of a set, and sustaining provisionally the parts which remain, in such a way that no part of the ground is unsupported by the laths, until the masonry itself is brought to bear against it.

A building of this kind is more solid, and more easily executed, when good hydraulic mortar is used.

(**195**) For ground of the kind just described, a method has been proposed and carried out successfully, which consists in walling the gallery directly as it is driven.

The face of the work is maintained and advanced by small parts at a time, in the manner described in No. 181. The circumference of the gallery is kept up by plates of iron which are held in place by iron frames. They are always supported by the ground in advance of the cutting, and in the rear they rest on the masonry which is advanced in stages of about $3\frac{1}{4}$ feet (one metre) in proportion as the cutting allows the hinder frames to be removed and placed in front.

The iron frames are made of two pieces for the purpose of being easily taken down. They are carried by an iron sole-plate into which they are fitted by a mortise. The iron sole-plate rests on a wooden one which is pushed aside when the frame has to be taken down.

The three frames are kept parallel, or bound together by means of two iron rods which pass through their interior ribs and are cottered on right and left to each rib. The iron laths which are supported by the frames, are furnished with a series of holes, by means of which they can be forced forward with the point of a lever, as the work advances.

This arrangement is represented in fig. 169 as a whole, and in its principal details relative to the frames themselves and to tieing them together; the iron laths and the manner of supporting them are also shown (see plates).

This method is very advantageous, because the expense incurred for laths in the ordinary system described in the preceding number, is saved; but it does not, perhaps, adapt itself with the same ease to all the circumstances of piercing very difficult ground.

(**196**) We have seen, in the case of timbering, that under certain conditions it is not necessary to use complete sets of four pieces for frames; and in like manner it is easy to see, that walling may sometimes be confined to two side walls when the roof is sufficiently solid, and sometimes to a more or less flat or elliptical arch, if the sides of the gallery are very firm while the roof is more or less liable to give way. It is also evident that, when seats of sufficient solidity cannot be obtained, imposts for the arch may be made by means of suitably arranged wall-arches.

There may thus be a large number of different combinations which are easy to imagine; several examples of these are given in figures 170 to 179; they are taken from Gätzschmann's work on walling in mines.

These different figures, for an explanation of which we refer to the description of the plates, represent different cases of drifts made in lodes. They suppose the walls to be sometimes solid, sometimes more or less loose; sometimes also, they suppose that the lode is intact below the gallery, at other times, that the ground immediately above, is either already worked, or will be worked without delay.

These arrangements are met with in the lodes of Saxony, where walling has been more generally employed than in most other metalliferous districts.

(**197**) **Walling of a shaft.** — We have already said, that a shaft differs from a gallery in having generally a larger sectional area; it differs also in the position of its axis which is usually perpendicular.

The first of these circumstances demands an increase of the means of security which may be required by weak ground ; the second permits them to be diminished.

However, the first may be considered as by far the more important, and a shaft is usually made as secure as possible, both on account of the length of time it has to last, and because of the great inconvenience which would result if frequent repairs were required which might hinder or stop the winding or pumping.

It may, therefore, be said that, as a rule, a *pit likely to be long in use, should be walled.*

This principle having been admitted, the circular form is that which affords the greatest facility for the execution of the masonry and at the same time gives the best conditions of resistance to a pressure coming from any direction.

However, the whole section of a round pit cannot be so easily utilized to advantage as that of a rectangular one; but this is a secondary inconvenience as regards expense, and may, on the contrary, be an appreciable advantage when the ventilation is considered.

Besides, the inconvenience indicated may be partially avoided by giving to the pit an elliptical section, or still better, a section of the general form of a rectangle but having the sides in the form of arcs of circles of large radius.

The last system is much employed in Germany; but in England, Belgium and France the circular form is generally preferred, and seldom with a smaller diameter than 10 feet (3 metres) or more than 13 to 16 feet (4 to 5 metres).

Within the last twenty years, many pits have been sunk having a diameter of 13 ft. (4 metres). If the walling is to be two bricks thick, then the excavation should be at least $16\frac{1}{2}$ feet (5 metres) in diameter, reducible to 13 feet (4 metres) at those points where the ground is sufficiently firm and the beds nearly horizontal, when they can be left without any means of support.

Even in this case, however, it is usually considered safer to build a lining of the thickness of at least one half brick, so as to prevent any possibility of an accidental slip. This precaution is always observed, even where the ground is solid, either for the first few yards below the surface, which are always more or less disintegrated by atmospheric agencies, or for the purpose of keeping back the rubbish extracted from the shaft, which is often employed for forming a bank round about the *mouth* (*collar*), of two or three yards in height above the natural surface level.

These few yards of walling are sometimes placed on a foundation formed in the ground itself when it is solid. Bricks or quarry-stones dressed on five sides, and cut in the form of voussoirs are employed : they are about 1 ft. 4 in. to 2 ft. 4 in. wide ($0^{m}\cdot40$ to $0^{m}\cdot70$). The side turned away from the pit, is left rough. The space betwixt the wall and the earth is filled with clay tightly rammed, in order to prevent the infiltration of surface water. Sometimes the wall is built of a conical form, widening somewhat towards the top, in such a way that the mouth of the pit is rather greater than the ordinary section.

(**198**) When a pit requires to be walled, it is not usually the case that a bed of sufficient resistance is met with, whereon the walling can be rested immediately.

Under these circumstances, it is placed upon a carrying frame called a *curb*, or *crib*.

The ordinary work, in ground of tolerable firmness, is carried on in a series of successive sections.

Supposing the pit to have been sunk and walled to a certain depth : the sinking is recommenced with a diameter equal to that of the masonry; after this, the excavation is gradually enlarged as it descends, leaving a sort of cornice which sustains the curb of the last section of the masonry. The sinking is then carried on for a certain number of yards, varying according to the firmness of the ground. When a bed suitable for the seat of a new curb has been reached, or when it is expedient to continue the walling, the seat for the curb is cut, and the sinking is continued for a short distance, to form a sump or well; the curb is then put into place, and the walling built upon it. When the curb immediately above has been nearly reached, the cornice is removed in small portions at a time, and replaced by props which bear on the newly constructed masonry; these props are removed one by one, as the masonry is raised to support the under surface of the curb.

When the walling has been finished in this manner, the shaft presents a series of sections which have been built in descending order, each section, however, having been built from below upwards.

These different sections are separated from each other by curbs which remain fixed in the wall.

The foregoing is a general description of the work.

It should be understood that, in order to carry out the construction of a lining of this kind properly, the rules pointed out in No. **190** should be attended to. There are, however, special circumstances in a work of this kind, requiring additional details which are not necessary in walling a gallery.

In the first place, it is necessary to provide a solid bearing for each section of the masonry to rest on. The object of the carrying frame, or curb, is to provide this bearing, and at the same time as it presents a regular surface for the first layer of stones, to distribute the pressure over the whole surface of the cornice. Sometimes, the curb simply rests on the cornice; or it is wedged firmly against the side; or it is supported by bearers, that is to say, several of the pieces which compose the frame are made longer, and have their ends inserted into deep hitches.

The object of the last arrangment, is to relieve the cornice when the sinking is continued. However, the cornice has not to bear the whole weight of the masonry, since the packing behind, and the slight movements of the ground when it comes to bear against it, would often prevent the masonry from descending when once the mortar has set, and then even the cornice itself might be removed.

The curb is sometimes formed of square timber, in pieces which form a polygon inscribed within the circle of the pit, sometimes of two or three courses of thick planks, placed upon each other so as to break joint, and held together by bolts. In the latter case, a circular ring is formed whose interior diameter is the same as that of the masonry, while its breadth is at least equal to the thickness of the wall.

In the second place, the men do not work standing on the ground as in walling a gallery, so that some arrangement for supporting them at their work is required.

Two methods are employed for this purpose : either they descend and work in a large elliptical tub, or repairing Kibble (*gig* Cornwall), not more than 2 ft. 8 in. (80 centimetres) deep; or they support themselves on a stage as the building rises by means of beams fixed in holes left provisionally in the masonry (*). These beams support a temporary floor of planks on which a larger number of men can work than in the tub, so that the time taken up in raising the stage is amply repaid.

Lastly, some means should be taken for getting rid of the water which sometimes trickles abundantly from the walls of the shaft and would hinder the work if it were allowed to fall on the last course of masonry as it is being built up; endeavours are therefore made to conduct it to the bottom of the section, where it can flow out. For this purpose a cast iron tube is built in at the bottom of the section, or a large horizontal auger hole is made in the curb itself, communicating with a vertical one.

The outlet thus provided, is placed in communication with a vertical tin tube pierced with holes which is lengthened as the building rises, or with a triangular space formed against the side behind the masonry by means of two boards. While the packing with concrete behind the wall is going on, care must be taken to keep the surface of the packing a little below the top of the last course and inclined towards the point where the tube or the boards have been fixed.

In this way all the water which exudes from the surface of the section which is being walled, both that from the part already built, and that from the still exposed part of the rock, flows out by the orifice at the bottom.

When one section has been completed and it is again necessary to resume the sinking, the water can be kept back either by shutting a cock provided for that purpose, or by driving a plug into the hole; or, if it is considered better to allow the water to flow out so as not to saturate the masonry prematurely, a canvass hose is fitted to the orifice and by this means it is conducted to the well (*sink*), and

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(*) In England, the stage is sometimes suspended in the shaft by two ropes which pass over pullies and are manipulated by means of crabs at the surface. *Translators.*

prevented from falling like rain on the heads of the workmen

A similar expedient is made use of for getting rid of the water which exudes from the walls of the other sections. It is arrested by one of the curbs on which the masonry has been kept a short distance back from the edge, for the first two or three courses. A gutter is formed in the upper surface of the exposed part of the curb, and the water falls into it drop by drop; an oblique hole to which a mouth-piece or small tube is fitted, communicates with the gutter, and thus the water is conducted to the *fork* or to a special reservoir. This arrangement is called a *gargoyle.*

The preceding is the description of ordinary walling, and may be called the normal process. It supposes that the ground is firm enough to allow of the sinking being carried on without timber for several yards, until solid ground is reached on which a curb can be placed.

Fig. 181 gives a general idea of the work as it has been described above; the pit is supposed to be completely walled from the surface downwards to the second last section AB. Sinking is then proceeded with, timber being put in where necessary, to a depth CD where a new section is begun; a cornice has been left under the curb AB; a sump has been cut out below the level of CD; the new curb is in place, and the walling has been commenced on it which will be raised to the lower surface of the curb AB, after the cornice has been removed.

(**199**) As the ground becomes less firm, the number of curbs has to be increased or their distance from each other diminished, and the time arrives when the solidity which can be no longer found in a cornice, has to be sought for in a support higher up the shaft.

The curbs may thus be placed at distances of two yards or less, each being hung from an upper curb by iron rods, or by beams firmly nailed from one to the other and reaching to the carrying curb which is held fast in the rock, or rests on the surface.

The support at the surface may be obtained in various ways. For instance, a large frame may be employed with its ends resting on the surface, if it is firm; or the ends may rest on thick planks, if the surface is yielding.

Otherwise, a number of wooden beams placed radially round about the shaft, may be employed; they project over the edge to a distance of about 4 or 5 inches (10 or 12 centimetres). The number of supports of this kind may be increased as required. Each of these is pierced at its inner end by a vertical hole through which a long iron rod, screwed at its upper extremity, is passed; the rod has a kind of claw at its lower end, on which the curb rests; the screws serve for adjusting the bearings of the curb.

(**200**) If the ground is very running, and the pit, which has been timbered in the first place in the manner described in No. **187**, requires to by walled immediately afterwards, then the conditions are the same as those already described for galleries in No. **194.**

It is therefore expedient to proceed in the same way.

The walling is done at once from the bottom upwards. An invert of hemispherical form or more or less flattened, is built to form a solid foundation on which the first course of masonry is placed. The ordinary work ought always to be conducted in such a manner, that every part of the ground may be supported until it comes into contact with the masonry; thus the frames should be removed piece by piece, and the laths, if not left in, are drawn out progressively from below upwards, the drawing out of one series not being completed until the end of the next has become engaged behind the masonry.

Proceeding in this manner, the exterior of the masonry is inscribed in the interior of the rectangle formed by a series of laths. It may, however, happen that the section that could be obtained in this way is not large enough; for it is often the case that the pit has been sunk of small area in the first place, in order to facilitate the work.

The final walling should then be made at the same time as the pit is enlarged, that is to say, in the same measure as the masonry is raised. The laths which sustain the sides are treated as if they were breast-boards; that is to say, each is removed successively, a little earth is scraped out, and the lath replaced immediately at the bottom of the excavation thus produced. The provisional support of the ground above is provided for, by driving in planks horizontally at the top of the enlargement. When a certain space has been enlarged in this way, it is immediately built up with a corresponding course of masonry. In this manner the finished pit may have a greater interior section than the original timbering.

(**201**) Lastly, in the very running watery ground, which is often encountered in Silesia and the Ruhr basin, a system is followed which consists in walling the pits directly; in this respect, it ressembles the system of No. **195**, but differs from it essentially in the fact that, no support being obtainable whereon to raise the masonry, the whole column is allowed to descend and the building is done at the top.

The arrangement includes a curb armed with a cutting shoe, which serves as base to the whole walling; on this, a kind of moveable tower is built, whereon new layers of masonry are placed as it descends.

The lower *cutting* curb is placed at the bottom of a preliminary excavation of large diameter, which has been timbered as the nature of the ground has required. The masonry is raised on this curb.

At distances of about two yards from each other, curbs are intercalated in the masonry; they are tied to each other and to the cutting curb, by means of bolts which pass through the masonry itself.

Otherwise, the tying together of the different curbs is effected by means of beams which serve also to divide the pit into compartments.

Besides, the masonry is, as it were, boxed in by a close lining of planks nailed to the curbs over the whole outer surface. Lastly, if it is necessary to divide the pit into compartments, the principal buntons are made to rest on the curbs in holes left in the masonry for this purpose.

All these arrangements are made with the object of preventing, as much as possible, the dislocation of the masonry and the resulting friction of the ground during the descent of the tower.

The tower descends in virtue of its own weight, or, if necessary, it is loaded. The descent is assisted and regulated by excavating in the bottom of the pit. The bottom is covered with boards, and the work of deepening is advanced by uncovering small areas at a time and excavating according as the nature of the ground requires, or as the tower has a tendency to sink more or less unequally.

In very running watery ground, the difficulty is to keep down the bottom, rather than to excavate; for it may happen that the current of water caused by the suction of the pumps tends to bring the sand, etc., into the interior of the tower, in which it rises above the level of the bottom curb, in proportion as it is more fluid and as the pumps work more energetically.

In these circumstances, as we have already said, it is necessary to endeavour not to raise more stuff than that which corresponds to the space which should be excavated.

All that is raised in excess of this, tends to set the ground in motion, and to produce irregular pressures which increase the friction, and have the effect of causing the tower to deviate from the vertical.

In fine, a work of this kind is a very delicate matter, and should be classed among the most difficult tasks which present themselves in mining.

Fig. 183 represents this system of sinking as it is applied to round pits of small diameter in Silesia.

Fig. 184 gives the details of a cutting curb on a larger scale.

This system is also employed in the Ruhr district for large rectangular pits. The tower has then the general form of a rectangle; but the sides, instead of being rectilinear, are slightly convex towards the outside, in order that the masonry, acting like an arch, may be able to resist the pressure.

This is the system by which towers are forced into the ground in some localities, for the purpose of sinking shallow wells of small section for *obtaining* water.

At the other end of the scale, are the shafts 46 feet (14 metres) in diameter, which were sunk in the same way, to form approaches to the Thames tunnel.

In this work, the question was, how to retard the descent of the tower which tended to sink in consequence of its own weight. It was carried on a system of piles the heads of which were successively uncovered and then driven down by rams.

The tower then descended a short distance of its own accord, forcing down the piles that had not been driven, until it rested on the top of the deeper ones.

Of late, civil engineers have employed a similar system to that described, for the purpose of sinking foundations of buildings in bad ground.

Instead of first cutting a hole and then building the foundation in it, the masonry is built on the surface and descends by its own weight, while the earth is dug out from beneath.

The earth from the bottom is taken up through a hole reserved in the middle of the block of masonry itself; the system is the same as for sinking a pit, except that the tower is replaced by a rectangular piece of the same dimensions as that which is intended to be sunk. In this case, the ground may be as bad as possible, but with only a limited quantity of water.

§ 5. — Numerical data relating to timbering and walling.

(**202**) In the first place, we shall limit ourselves to the consideration of common and simple cases which allow of exact calculation such as cannot be made in the case of works executed in loose ground, especially if it is very wet. For it may happen, under the latter circumstances, that the bulk of the expense is incurred for pumping, and not for the execution of the work itself.

1. *Timbering of a gallery with frames.* — We shall suppose a gallery timbered with frames (*sets*) without sole-pieces, the legs being 6 $\frac{1}{2}$ ft. (2 metres) long, the cap 5ft. (1.50 metres), besides a lining of laths.

Suppose that there is a frame and a half in every lineal yard (metre) of the gallery, and that the timber costs 5 $\frac{1}{2}$ d. per lineal yard (0 fr. 60 per lineal metre).

	PER YARD.	PER METRE.
Each frame will require 9 yards ($8^{m}\cdot25$) of props, at 5 ½d. (0 fr. 60)	4s. 1 ½d.	(4 fr. 95)
We shall suppose 11 yards (10 metres) of laths at 1 ¼d.	1s. 1 ¾d.	(1 fr. 50)
Total for materials	5s. 3 ¼d.	(6 fr. 45)
Total cost of labour for bringing the timber to the timber-yard, shaping it, preparing the place, and setting it up, 1s. 8d. (2 francs) per frame, or per current yard (metre).	2s. 6d.	(3 fr. 00)
Total	7s. 9 ¼d.	(9 fr. 45)

Thus the cost of timbering a gallery of considerable section in a substantial manner, may vary from about 7s. 6d. to 8s. 4d. per current yard (9 to 10 francs per metre).

2. *Timbering of a pit.* — Suppose a pit of 13 feet (4 metres) in length, and 4·4 ft. ($1^{m}\cdot30$) in width inside the timber, divided into three compartments — two for winding and one for pumps.

Suppose one frame per yard (metre) formed of beams 8 inches ($0^{m}\cdot20$) square, in cross section.

We have then : two pieces 14 ft. 4 in. long	= 28 ft. 8 in.	($4^{m}\cdot4$ = $8^{m}\cdot80$)
Two pieces 5 ft. 8 in.	= 11 ft. 4 in.	($1^{m}\cdot7$ = $3^{m}\cdot40$)
Two pieces 4 ft. 4 in.	= 8 ft. 8 in.	($1^{m}\cdot30$ = $2^{m}\cdot60$)
Total	48 ft. 8 in.	($14^{m}\cdot80$)

Say $48\cdot7 \times 66^2 = 21\cdot16$ cub. ft. at 1s. 10 ½d.	= 59s. 7 ½d.	($14^{m}\cdot80 \times 0\cdot20^2 = 0\cdot592$	at 80 francs = 47 fr. 56)
Corner pieces (*studdles*) 13ft. at 10d.	= 3s.4d.	(4^{m}· at 1 fr.	= 4 fr. 00)
82 feet of laths at 0·457d.	= 3s.1 ½d.	(25^{m}· at 0 f. 15	= 3 fr. 75)
Guides. 5 yards at 2s,6d.	= 12s.6d.	(5^{m}· at 3 fr.	= 15 fr. 00)
Total for materials	58s.7d.		(70 fr. 11)
Cost of putting in the timber and sundries	8s.4d.		(10 fr. 00)
Total	66s.11d.		(80 fr. 11)

That is, in round numbers £3.7s. per yard (80 francs per metre) for very ordinary timbering, in a shaft rather under than over the usual dimensions; and this does not include the surface expenses.

3. *Ordinary walling of a gallery.* — It is here necessary to assume certain prices, as they vary much in different localities.

We shall suppose building stone, brought to the spot, to cost 3s 2d. per cubic yard (5 francs per cubic metre).

Some years ago, bricks burnt in the open air in heaps could be obtained in Belgium at 5s. 10d. to 6s. 8d. per thousand (7 to 8 francs); they were made with brick-earth found on the spot. They can still be had at about 8s. 4d. (10 francs) which is a lower price than elsewhere. If we take the price at 16s. 8d. (20 francs) per thousand we are perhaps rather under than over the average prices at which they may be obtained in France.

A cubic yard (metre) of a building made with quarry-stone, requires 5 to 8 cubic feet (2 to 3 hectolitres) of mortar according to the more or less regular form of the stones: a mason and his assistant will build this amount in ·46 (·6) of a day.

A cubic yard (metre) of masonry in brick, requires less than 5 cubic feet of mortar, and only ·38 (·5) of a day, of the work of a brick-layer and his assistant.

We shall take the cost of mortar at 3d. per cub. foot (1 franc per hectolitre) and the wage of a mason and his assistant at 5s. (6 francs) per day.

Thus for a cubic yard (metre) of masonry we have:

	QUARRY-STONE.	BRICK.
Materials. . . .	3s. 2d. (5 fr.)	6s. 4d. (10 fr.)
Mortar.	1s. 11d. (3 fr.)	1s. 3d. (2 fr.)
Workmanship. .	2s. 3d. (3 fr. 6)	1s. 11d. (3 fr.)
Total. . .	7s. 4d. (11 fr. 6)	9s. 6d. (15 fr.)

If we consider the gallery mentioned at the beginning of No. **192**, we have:

Two side walls 3 ft. 11 in. ($1^m{\cdot}20$) high and 2 ft. 7 in. ($0^m{\cdot}8$) thick or 2·3 cubic yards (1·92 cubic metre) per running yard (metre) at 7s. 4 ½d. (11 fr. 60).	16s. 11 ½ (22 fr. 27)
An arch of 3 ft. 3 in. (1 metre) radius and of the thickness of a brick and a half will give 1.63 cubic yards (1.57 cubic metres) per running yard (metre); we shall estimate the cost at 11s. 5 ½d. (18 francs) instead of 9s. 6d. (15 francs) having doubled the expense of workmanship on account of the difficulties to be contended with in building the arch, say 1.63 C. Y. ($1^m{\cdot}57$) at 11s. 5 ½d. (18 fr.).	18s. 8d. (24 fr. 66)
Total.	35s. 7 ½ (46 fr. 93)

Say 36s. (47 francs) per current yard (metre) for the walling of an ordinary gallery.

This cost will be much reduced if building stone is found in the mine itself. Under this head, the reduction in the cost of side walls may be estimated at 7s. 3d. (9 fr. 60) and then the total price is reduced to 28s. 4d. (37 francs). It would be reduced to 18s. or 19s. (25 francs or 24 francs) if the building stone, being found in the mine, were supposed to cost nothing, while bricks were taken at 8s. 4d. (10 francs) per thousand.

It will be seen that the cost of this walling is at least double that of timbering, and it may even be more than quadruple.

4. *Ordinary walling of a shaft.* — We shall suppose the shaft to have a diameter of 13 feet (4 metres), and the masonry to be 4 half-bricks thick.

We shall have per running yard (metre) :

8·46 C. Y. at 11s. 5d. (7^{m}·07 at 18 fr.)	= 96s. 11d. (127 fr. 26)
Filling with concrete a space of the average width of about 7 in. (0^{m}·20)	25s. 0d. (30 fr. 00)
Total	121s. 11d. (157 fr. 26)

Say in round numbers 120s. per yard (160 francs per metre) not including the cost of labour at the surface.

These figures, which may be taken as a kind of mean from which more or less should be deducted in each particular case, according to the variations of the elementary prices, are : 7s. 6d. to 8s. (9 to 10 francs) for timbering, and 18s. to 28s. (37 to 47 francs), for walling a gallery; 67s. (80 francs) for timbering, and 120 s. (160 francs), for walling a shaft.

(**203**) The above figures refer to certain simple cases of timbering and walling.

The question may be asked, however, what relation does the total annual expenditure, on all the works of a mine, bear to the production. As may be easily imagined, this figure varies greatly according to local circumstances, and also in consequence of the fact that the timbering of ordinary working places is usually the principal item of expense; moreover, the solidity of the roof is the essential element which causes the cost of timbering to vary.

We shall cite as an example the case of the Grand-Combe mines. An exact calculation showed a consumption of 1·85 feet of propwood per ton (·5665 metres per tonne) of coal raised, costing on the average 2d. per foot (0 fr. 65 per metre); say an expense of 3 ½ d. per ton (0 fr. 37), the timbermen's wages not being included.

This figure is perhaps rather under than above the average for continental mines.

Certainly there are mines in England, in which the cost for timber is less than one half of that given above, notwithstanding the high price of timber; in Belgium, on the other hand, and in the north of France, it is very much greater.

On the whole, the conditions may be considered *very favourable* in France, if the cost of timber per ton of coal, is less than 2 ½ d. to 3 d. (0 fr. 25 to 0 fr. 30); and they are *average*, if the cost be double this amount : some examples could be given of instances in which it has reached 1s. 3d. to 1s. 8d. (1 fr. 50 to 2 fr.) and more.

These wide variations must naturally be expected.

CHAPTER VIII.

ON MAKING AND SUPPORTING EXCAVATIONS OF SPECIAL FORMS OR DIMENSIONS.

(**204**) In the three preceding chapters we have studied, firstly, the various manual and mechanical processes for *making* ordinary excavations underground, and secondly, the means of *strengthening* them.

These works are : shafts and galleries intended to intersect the deposit at given points, and galleries, stalls or long-walls which are driven in the bed itself for the purpose of working it.

In order to complete this information, it is desirable to enter into some details regarding certain special works, which constitute, as it were, peculiar points in the network of underground workings.

We shall consider in succession :

The points where galleries branch ;

The points where galleries open into the winding shaft and from which the products of the mine are sent to the surface : these are called *pit-bottoms*, *landings*, *hanging-on places*, *hooking-on places*, *plats*, etc. ;

Excavations made for the purpose of collecting and storing water : *reservoirs*, *sumps*, *forks*, or *lodgements* ;

Special excavations in which machines are set up in the interior of the mine, such as engines worked by steam or compressed air, horse gins, and water wheels ;

Lastly, galleries of large section, such as tunnels for canals or railways.

Although the last mentioned works are not very closely connected with mining, they ought, nevertheless, to be well understood by mining engineers who are often deputed to carry them out.

(**205**) **Branching or bifurcation of galleries.** — These points are met with, for example, when a crosscut intersects a deposit, and two levels have to be driven from its extremity in the deposit itself; or when one of these levels reaches a point at which the deposit bifurcates, a circumstance which often happens in a lode; or, again, when a level is crossed by a gallery following the dip.

If both galleries are timbered, a strong frame is set up at the entrance of each of the four or three branches which set out from the common point of intersection.

The roof then remains unsupported in the kind of cross-way formed at the point of intersection; but it may be easily supported by placing strong poles under it resting on the caps or collars of two opposite frames.

If the galleries are walled, the point of intersection will form an ordinary groin, on the top of which the rubbish which was removed at first, to allow the arch to be constructed, must be carefully packed up to the roof; it is, however, often simpler and more practical to make the arch of the principal gallery several yards higher at this point than at other places, so that the arch of the branch is altogether contained in its side-wall.

This arrangement is represented in fig. 185, of which one section is made along the axis of the principal gallery, and the other along the axis of the branch.

(**206**) **Pit-bottoms, landings, or plats.** — The gallery which opens into the winding shaft, should be enlarged as it approaches the pit, so as to make room for the sidings (*partings*, Wales) in which the trains of full tubs (*trams*) are received, and the trains of empties made up; it should be of sufficient width for two lines of railway, and should open into the shaft with a width equal to that of the one or two winding compartments.

At the same time, it is often made higher at this point, to facilitate the sending away or receiving of the corves, or kibbles, in which the mineral is carried when cages are not employed, or to give room for loading and unloading the different decks, when very high cages with three or four decks are employed.

If the shaft is timbered and of rectangular section, the end pieces of the frames opposite the landing, or plat, are suppressed, and then these frames, have only three or two sides according as there is a landing on one side, or on both sides of the shaft; that is to say, according as one level, or two levels in opposite directions, set out from the shaft.

The usual method of fixing the remaining sides of frames in this position, is to replace the support of the suppressed sides, by vertical posts (*studdles*), placed in the corners of the shaft, and held in their places by special cross-beams, one at the roof and the other at the floor of the landing. Figure 186 gives an ideal plan and cross-section of a timbered landing.

The timbering shown in the figure referred to, will not always be sufficient; it is often necessary to employ very strong frames placed nearly close together, or to replace the legs by walls of masonry, which support thick planks on which the caps or collars rest; the latter may be either large round, or square timber.

(**207**) Instead of timber caps, iron ones have been employed, cut to the required length and slightly curved; they may either be specially made of the double T form, or old railway rails of heavy construction may be used. These caps, placed, for example, at distances of 18 inches ($0^{m}\cdot5$) apart, may be covered over with ordinary light tram-rails lying flat above them and serving the purpose of laths.

A lining of this kind costs more than an ordinary timbering but is more substantial and does not require so much ripping of the roof for the same height of landing.

Another means of supporting the landing, which is also very strong, is to employ timber in such a way that its resistance to crushing comes into play rather than its resistance to bending as in ordinary frames; that is to say, it is placed under the same conditions as the stones or bricks which form an arch.

Every variety of arch can be built of this material: either complete arches with several centres and an invert, or arches placed on ordinary foot-pieces, suitably cut at their extremities to form springers, and hooped at the same points to prevent them from splitting. The arch-blocks, or voussoirs, may be 12 inches ($0^{m}\cdot30$) square, for example, and 20 inches ($0^{m}\cdot50$) long in the direction of the axis of the arch, and have the grain parallel to that axis.

Sometimes they are continuous with broken joint as in ordinary masonry; sometimes they form a series of discontinuous arches which can be tied together with iron rods, while the rock between them is either left bare, or supported by laths resting on two contiguous arches, etc., etc.

A lining of this kind may be less expensive than walling, or even than ordinary timbering with frames, and give the same degree of solidity; since short pieces of timber, such as the cuttings of frames which would be otherwise of little value, may be employed in constructing it.

These systems have, besides, the important advantage, that they require less repairing, and have a certain flexibility which permits them to resist better than masonry slight movements resulting from the natural thrust of the ground, or from the effect of workings carried on in the neighbourhood.

The employment of timber as an arching material deserves some attention. We would here remark that, in certain localities where timber is plentiful and cheap, this process is employed even in galleries of ordinary dimensions. It is applicable in ground which thrusts strongly inwards, in anhydrite, for example, which is met with in salt mines. This rock swells gradually while it is becoming hydrated, and exercises an increasing pressure, which no ordinary timbering could resist.

Figures 187 and 188 represent examples of the iron caps and wooden arches which have been described. In the wooden arch it will be seen that there is a belt of iron passing round the outside and fixed to the lower arch-blocks by wood-screws. The object of this arrangement is to equalize the pressure on the various arch-blocks, but it is by no means indispensable.

(**208**) If the shaft is walled and cylindrical, while the gallery leading into it is rectangular, then the outline of their intersection is formed by two vertical straight lines and two horizontal arcs of a circle.

Two strong square beams are set up at the sides, against the masonry.

The space between these side posts is kept open by joining them with two portions of a curb, the lower forming a threshold to the landing and the upper, which has its extremities built into the masonry, a lintel. If it is considered expedient, the weight can be sustained, besides, by an arch which carries the pressure to the right and left into the mass of masonry below.

Otherwise, especially if the landing requires to be high, the two side beams or standards are omitted, and the masonry above the entrance is sustained by a curb engaged in the walling. The top of the hanging-on place, or plat, is then joined to the roof, or back, of the level, by a sloping arch which acts like a buttress to the masonry of the shaft. The plan and elevation of this arrangement are shown in figure 189.

This method is not always sufficient, if the weight of superincumbent rock be great, or if the ground be set in motion from any cause.

Movements of this kind distort the column of the shaft which was originally quite vertical, to such an extent, that it is sometimes impossible to draw a vertical line from top to bottom *every part of which is in the interior of the pit.*

For the purpose of resisting, as much as possible, the effects of these movements, which make themselves felt at the hanging-on place, such places should be established in the best conditions for ensuring solidity, and, instead of employing the usual materials and methods, recourse should sometimes be had, as we have already mentioned, to more resisting materials, such as iron, and special arrangements, such as arches in wood.

(**209**) **Reservoirs for water.** — It sometimes happens, when the water is not very abundant, that no other reservoir is provided besides the sump, which is formed by continuing the pit to a depth of a few yards below the level of the landing or plat, and in which the water can accumulate during the daily or accidental interruptions of pumping.

The sump, fork, or well, is made at least 16 or 20 feet (10 or 15 metres) deep, and often 33, 50, 80 feet (10, 15, 25 metres) and more, according as the quantity of water is more or less considerable.

In a pit of 13·123 feet (4 metres) diameter, the sump can contain 848 gallons per foot in depth (125 hectolitres per metre); in a depth of 32·81 feet (10 metres) it will contain 27,822 gallons (125 cubic metres), and this is a greater quantity than that which has to be pumped daily from many mines.

If, however, provision has to be made for prolonged stoppages of the pumps, if the quantity of water is great, or if it is desirable to have only clean water coming to the pump, it will be necessary to have reservoirs that can contain the quantity accumulated in several days, and from these it can flow into the well after the impurities have settled.

These reservoirs can be conveniently made like levels to the dip of the main level, and connected with it by two inclined openings, through which the water finds its way instead of going directly to the well.

The bottom of the reservoir is placed in communication with the top of the well by means of a pipe furnished with a cock which can be opened or shut at pleasure from the landing, by using a long rod furnished with a handle.

A reservoir of this kind need not differ from a level of ordinary dimensions; it should generally be arched, even in solid ground, to prevent the effects of weathering produced by long contact with the water.

If necessary, these reservoirs can be supported at their intersection with the shaft, in the manner indicated for hanging-on places, (No. **207**), with this exception, that collars and laths of iron are not to be recommended here, on account of the continual presence of water.

(240) Rooms for machines, stables, etc. — We have already said that there is a tendency to increase the number of machines employed in mines for various purposes, especially for haulage along the levels or from dip workings; and it may be presumed that this tendency will increase in proportion as mines become deeper, and for that reason more extensive, and as greater familiarity is acquired with the use of compressed air.

At the present time, machines have to be set up very often, and it is probable that, in future, they will be required more and more.

If a steam or compressed air engine is to be employed, the type ordinarly chosen is the horizontal engine with two cylinders, as it does not occupy much height and can be placed in a chamber which may be merely an enlarged level.

A gallery set apart for this purpose, should be walled like an ordinary level with two side walls and a semi-cylindrical arch.

A gin, or *whim*, requires a circular chamber whose radius cannot well be less than 8 to 10 feet ($2^{m}\cdot5$ to 3 metres), and whose height may be 5 ft. 3 in ($1^{m}\cdot60$) at the circumference, and 9 ft. 10 in. (3 metres) at the centre.

An excavation of this kind cannot always be easily maintained in loose ground.

It may be lined with a circular wall round the circumference, supporting a flat spherical arch, above which no empty spaces or timber should be left.

To avoid difficulty in its construction, the chamber may be made square, and roofed with a cylindrical arch; the circle of the gin is then inscribed in the square.

(**211**) Chambers intended for hydraulic machinery, do not require to be of any particular shape, except those for large water wheels. Many examples of the latter are found in metal mines, where the contour of the surface often permits the creation of considerable falls of water, which are connected at the bottom with an adit level.

The general form of such a chamber is the same as that indicated for a gin, but with this difference, that the greatest dimension is in the vertical instead of in the horizontal plane.

A gin chamber is *a sort of disc placed horizontally;* a chamber for a water wheel is a space *of similar form placed vertically.*

The latter is, therefore, much more easily supported than the former. Its natural position is in the plane perpendicular to the strike of the deposit that is being worked, and, consequently, also to the strike of the rocks, if the deposit is a bed or a bed-vein.

It often happens that the flat faces on each side of the water wheel do not require to be walled; they are then made slightly concave, for if they were quite flat the tendency of the rock to thrust towards the open space, might lead to falls of stone at the insufficiently supported centre. Sometimes these faces require to be lined with masonry, and they are then made of the form of very flat cylindrical arches with vertical axes.

The canals, or *leats*, which convey the water to and from the wheel, may, according to circumstances, either be in the plane of the chamber or at right angles to it, according as they are cross-cuts or levels along the strike.

Figures 190 and 191, which are taken from M. Gätzschmann's work already cited, represent two chambers for water wheels established in planes perpendicular to the lodes; the first is in strong ground, the second, in ground which requires a complete walling.

(**242**) **Tunnels of large section.** — Tunnels of large section for railways or canals, differ essentially in some points of view from the galleries of a mine. A gallery $6\frac{1}{2}$ feet (2 metres) wide and $6\frac{1}{2}$ feet (2 metres) high under the keystone, has a section of 38 square feet (3.5 sq. metres); whereas the section of a large tunnel is often ten times as great.

The largeness of the section, and the permanent character of the work, do not permit of timber being employed as a means of supporting it. If the ground is very solid, the tunnel is left without any support, but otherwise, it is walled.

The time required for making the excavation, is generally a very important consideration in a work of this kind, since it is of no advantage until it is quite finished. Meanwhile, during the progress of the work, the capital which has been expended already is quite unproductive, and so also, to some extent, is that which has been absorbed in the construction of the two lines of railway which it is intended to connect.

A work such as this is not usually carried on only from the two extremities, but intermediate shafts are sunk along the line of the tunnel, and in this way the points of attack are multiplied. Two headings are driven out from each shaft, until they meet the corresponding headings coming from the contiguous shafts.

These shafts will be multiplied in number according as the work has to be pushed on more rapidly; and the distance between any two will be made less, according as they are deeper, so that if all the shafts are commenced at the same time, as we suppose, the headings from any two adjoining ones may also meet after the lapse of a certain time from the commencement.

The expenses incurred in starting, and also, up to a certain point, the cost of execution, notably that incurred for superintending the drivages and extracting the stuff and water, will increase with the number of the pits; but it is only natural to suppose, that the advantage of rapid execution cannot be obtained gratuitously. In every case, a balance must be made between the extra cost of increasing the number of shafts, and the advantages to be derived from having the tunnel soon finished and in operation.

These calculations will often show that, in the case of an important line of railway, it is of great importance to multiply the points of attack in such a way, that the completion of the work may retard, as little as possible, the opening of the entire line. The operations on the Mediterranean railway, for cutting the Nerthe tunnel, were carried out in this spirit. This tunnel was the longest in the world before the Hoosac tunnel was made in the United States, and the Mont Cenis tunnel in Europe : these are respectively 4·7 miles (7600 metres) and 7·6 miles (12200 metres) long.

In cutting the Nerthe tunnel, twenty-four intermediate shafts were sunk, the deepest being 164 yards (150 metres); the shafts, together with the two extremities, gave fifty points of attack. The *mean* length of each heading was only 109 yards (100 metres) and the headings were shorter towards the central part where the shafts were deepest.

It is not always possible, however, to carry on the work in this way. At the Mont Cenis, for example, most of the shafts would require to have been 1000 yards deep, and more towards the central parts, and they would require to have been sunk at points where the same facilities in regard to hydraulic power, etc, could not have been obtained as at the two extremities. It was, therefore, thought advisable not to attempt these difficult sinkings, and to try to resolve the question of rapid execution by employing mechanical means while operating only at the two ends. The success of this arrangement has been complete, and we are led to believe that this tunnel has been cut *as quickly* as if the points of attack had been multiplied while employing the ordinary methods, and undoubtedly *at less cost.*

The same system is carried out in cutting the St. Gothard tunnel which has been already begun and will be about $9\frac{1}{4}$ miles (14,920 metres) in length when completed.

The course followed in making the Nerthe tunnel, under quite different circumstances, can also be fully justified : and it may be concluded that, in any given case, very careful study will be required in order to decide which of the two methods should be preferred.

(**213**) This study may be submitted to calculation, at least under one of its aspects.

Let q be the known and *nearly constant* cost of sinking a shaft, including all the expense of acquiring ground and setting up machinery;

x the unkown number of shafts of nearly equal depth to be opened over a length l;

S the section to be excavated;

S′ the section of the lining;

P and P′ the cost of haulage per lineal yard, for each cubic yard of rubbish and walling materials.

The total cost of underground haulage for the rubbish, calculated for the mean distance $\frac{l}{4x}$, will be:

$$\text{PS} \times l \times \frac{l}{4x} = \text{PS}\frac{l^2}{4x}$$

and similarly for walling materials we have:

$$\text{P'S'}\frac{l^2}{4x}.$$

The total expense Q will then be:

$$\text{Q} = xq + (\text{PS} + \text{P'S'})\frac{l^2}{4x} \tag{1}$$

The minimum will correspond to $\frac{d\text{Q}}{dx} = 0$.

Let

$$q - \frac{l^2}{4x^2}(\text{PS} + \text{P'S'}) = 0.$$

$$x = \frac{1}{2}\sqrt{\frac{\text{PS} + \text{P'S'}}{q}} \tag{2}$$

The corresponding value of q will be given by the formula,

$$\begin{aligned} \text{Q} &= \frac{l}{2}\sqrt{q(\text{PS} + \text{P'S'})} + (\text{PS} + \text{P'S'})\frac{l^2}{4} \times \frac{2}{l}\sqrt{\frac{q}{\text{PS} + \text{P'S'}}} \\ &= l\sqrt{q(\text{PS} + \text{P'S'})} \end{aligned} \tag{3}$$

and the distance between the pits $\frac{l}{x}$ by the formula,

$$\text{D} = \frac{l}{x} = 2\sqrt{\frac{q}{\text{PS} + \text{P'S'}}} \tag{4}$$

Equation (1) gives the cost of a given number of shafts spread over a distance l;

Equation, (2) the number x which corresponds to the minimum cost;

Equations (3) and (4), the value of this minimum, and the distance between two adjoining shafts.

It will be observed that, in the case of the minimum, the total cost for pits is equal to the sum of the costs of the underground haulage of rubbish and buildings materials.

With the aid of these formulæ *an idea* can be obtained of the expenses that will be incurred with pits *at different distances apart*, and the results may then be compared, from a financial point of view, with the consequences which would arise from hastening or retarding the work.

We say *an idea* only; for, in the foregoing empirical calculation, the question has not been considered in all its aspects : it would be necessary to include in the total cost of shaft, not only its first cost, but also the working expenses which depend on the length of time during which it is to be in operation, and, consequently, on the distance between the pits.

(**214**) If it has been decided to employ intermediate shafts, a detailed study of the subject will have to be made : the depths of the various pits will be determined by the profile of the surface along the line of the intended tunnel. A detailed geological investigation will have to be made, in order to ascertain the nature of the ground that has to be traversed, the probability of finding more or less water, etc. It will be seen that, with the aid of these elements, an estimate may be made as to the probable time required for sinking each pit and the rapidity with which the headings can be driven.

Proceeding in this way, we can determine how the pits should be placed along the line, in order that the condition already specified, may be fulfilled, viz., that the headings advancing towards each other from opposite directions, may all meet about the same time.

Having decided by very careful surveying operations, the position in which any shaft should be sunk in order that it may intersect the axis of the tunnel, there is nothing to hinder us from placing it at a certain distance on one side of the axis, if the surface operations can be thereby facilitated. After the pit has been sunk to the calculated depth, it is only necessary to cut a short gallery of given length to reach the axis of the tunnel, and then to drive the two headings from this point in the exact direction which they should follow, until they meet the headings from the two nearest shafts.

(**245**) Without occupying ourselves in this place with a discussion of the geometrical operations which are requisite to ensure the exact meeting of the various headings, nor with the means employed in sinking the pits, pumping, getting rid of the rubbish, establishing ventilation, etc., we shall confine ourselves to saying that everything should be done *substantially*, at the same time having regard to the short duration of the work; thus, for example, the winding engine should be amply powerful, but it may be covered with a mere deal shed; the pit should be secure, but it will be more often timbered than walled, etc., etc.

(**246**) We shall consider shortly the operations of the workmen employed in driving the headings and putting in the walling. This work, like the corresponding work in the small galleries of mines, differs essentially according to the nature of the ground. The methods employed are similar, but, as may be imagined, their application is rendered more difficult by the larger section, the augmentation of the difficulty being, besides, more marked, for a given section, according as the nature of the ground is worse.

It may also be said, notwithstanding the example of the Thames tunnel, that miners *can drive their small galleries* through ground in which it would not be practicable to establish large tunnels.

Whatever be the nature of the ground, a small gallery is begun and pushed on as rapidly as possible, so as to hasten the moment when communication will be established with an adjoining shaft. This gallery is usually driven in the position that will be occupied by the arch of the finished tunnel, but sometimes, on the contrary, it is on the level of the floor.

This manner of proceeding has many advantages. The communication may be advantageous in regard to ventilation; and it secures an escape for the workmen in the event of a fall, or if any circumstance should occur to interrupt the working of the pit; for example, if the timber took fire. A terrible instance of this kind was seen at the Hohenstein tunnel in Switzerland, when all the men underground were suffocated. It enables us to ascertain whether any small error in direction has crept in, and affords an opportunity of making the necessary corrections in height and direction, so that the large sections may meet with precision. Lastly, it allows the points of attack for enlarging the tunnel to be greatly increased, so that the large section can be finished almost as soon as the small one.

(**217**) Let us suppose the small tunnel to be in course of excavation, and consider how the works of enlargement, and walling if required, are carried on.

For the sake of fixing the ideas, we shall further suppose that the section of the tunnel is elliptical like that of the Nerthe, that its dimensions are 23 ft. 9 in. ($7^{m}\cdot25$) at the level of the chord of the *invert*, and its height and greatest breadth 26 ft. 3 in. (8 metres). This section is larger than what is absolutely necessary for a railway with two lines of rail; it is, however, a maximum that will not often require to be surpassed.

If the ground is firm and does not require to be walled, or if it requires to be supported only here and there between the face and the point where the walling is being constructed, the first part of the work is very simple.

The small tunnel is pushed on with a reduced section of 53·8 to 64·6 square feet (5 to 6 sq. metres) at most, and a height equal to about one third that of the finished tunnel. The rock is blasted by means of gunpowder or dynamite, and the work is carried on day and night without interruption, in shifts of at most eight hours. As soon as this gallery has advanced 13 to $16\frac{1}{2}$ feet (4 to 5 metres), the sides may be attacked at a short distance from the face, and opened to the full width.

The bottom, occupying about two thirds of the height of the tunnel, then remains to be removed, and this is done by forming it into two or three stopes each of which is a distinct working place.

It is obvious then that a large number of men may be engaged at the same kind of work, since they are spread over a considerable length of the tunnel.

This length will comprehend, for example, 13 feet (4 metres) for driving the heading, about the same space for cutting the sides to the full width, and about 33 feet (10 metres) for each stope, making altogether about 130 feet (40 metres) when the work is in full operation.

This method of excavating is represented in figure 128 which has been already described in Chapter V under the head of breaking gronnd.

(**218**) When the ground, although still solid, requires to be supported provisionally before being walled, the work is carried on in the following way :

The heading, having been pushed forward for a certain distance, is timbered according to its requirements, and at a distance of $6\frac{1}{2}$, 10, or at most 13 feet (2, 3 or 4 metres) behind the face, the work of enlarging to the full width is carried on, until room has been made for the masonry of the arch.

This excavation is timbered with diverging props placed in the direction of the radii, and standing on strong sole-pieces or cross-beams, made of two pieces united by a scarf-joint so that they can be set up or taken down easily, while at the same time they give a support to the roof across the whole width of the excavation.

Two rows of these props are set up, one at each end of the excavation, and if necessary a third may be placed in the middle between the others. Each prop either supports the rock directly, or has a longer or shorter piece of flat timber (a *lid*) intervening.

After this timbering has been completed, the construction of the arch is begun immediately.

Thick oak planks are placed on the ground to serve as springers for the arch; centres are then set up and the arch is built piece meal; the props are removed; the spaces above the arch are stowed up, and successive rings of masonry are constructed.

When the two arcs of masonry approach each other and there remain only a few bricks to be built in to form a key, the outer bricks, *extrados*, are first laid in their places, bedded with good hydraulic mortar, and then the inner ones, *intrados*.

After this work has been repeated in several stages, we have an excavation of some length, lined with an arch whose springers are formed by a series of planks which rest on the ground, as well as on the cross-beams of the original timbering.

Two trenches are then cut close to the springers, one on each side; they are made 5 ft. ($1^{m}\cdot50$) wide at the most, and are carried down to the level of the invert; there is thus a mass of rock left between them, which serves to support the cross-beams and so to keep up the planks which form the springers of the arch.

When this work has been completed, the ground immediately under the springers is removed in small portions at a time, and props are applied to the under surface of the planks in proportion as it is laid bare. In the space excavated in this manner, a pillar of masonry is built up until it under-props the springer; each pillar has *toothing stones* at its sides, which serve to connect it to the adjoining pillars, and when this has been done there is a continuous side-wall supporting the arch.

The central block of rock is now removed and an invert built if necessary: the latter can be easily joined to the foot of the side walls.

The work may be shortly described, thus:

1. A small drift is cut at the top of the intended excavation, then widened out and the arch built.

2. Two narrow trenches are cut and widened, one at the right hand side, the other at the left, under the springer of the arch; the side walls are then built.

3. The central block of rock is removed and the invert built, if necessary, thus completing the masonry.

This system supposes that the ground has a certain degree of solidity, sufficient, at any rate, to ensure that the central block gives considerable support to the arch, through the medium of the cross-beams which rest on it. That mass would be useless if it did not fulfil this object, and it would be worse than useless if it had to be stayed up in order to keep the trenches open on each side.

(**219**) When the ground is so bad that it requires to be completely walled up at once with an elliptical lining including an invert, it appears best to imitate the process described in No. **195**, for ordinary mine galleries which have been driven in ground of this description and *are preferably* walled immediately.

The only difference is, that the immediate walling is *optional* in the case of small galleries, and *absolutely necessary* in that of large tunnels.

The work is conducted in the following manner, proceeding in stages of three to four yards at most.

The upper gallery is widened to the right and left until there is sufficient space to contain the masonry of the arch; the roof is supported by a timbering of strong poles parallel to the axis of the tunnel, one end of each pole resting on the top of the last zone of masonry the other in a recess in the face; the poles are also temporarily supported by props.

A garniture, or lining, of laths is placed above and behind the poles according to requirement.

This process of widening having been completed, two large beams, each of which consists of two pieces, are placed across the excavation with their extremities resting in recesses, *hitches*, in the sides; each of these serves as a sole-piece for a row of diverging props, which are set up to support the poles and replace the provisional props already mentioned.

The upper part of the excavation, including the space to be occupied by the arch, has now been completed and is supported provisionally; but the arching is not yet proceeded with as in the previous case, since there would be no sufficient foundation on which it could rest.

A trench is now sunk in the axis of the tunnel, its sides being a downward prolongation of the sides of the original heading which existed before the widening was begun; this trench is widened to the right and left, and the cross-beams are supported by means of obliquely placed posts in proportion as their under surface is exposed; when this operation has been completed, two more cross-beams are placed on the floor, vertically below the two first, and vertical props, footed on the lower beams, are made to sustain the weight of the upper ones; at the same time, obliquely placed stays give support to the poles which keep up the sides of the newly made excavation.

A second trench is now cut vertically below the position of the last, and the same operations are gone through as those we have just described, with this exception, that the props which sustain the lower pair of cross-beams, are footed on the floor of the excavation.

In this way the excavation is completed in three stages, 4 yards long in the direction of the axis, and of the necessary height and breadth to contain the final lining of masonry.

The following is then the state of matters:

Notwithstanding its great dimensions, the excavation is entirely timbered with pieces of wood of ordinary sizes, thanks to the employment of the cross-beams.

The props, and the beams which they rest upon or support, act as trusses, of which there are either two or three, one towards each end of the space, and sometimes one half-way between them. The beams of these trusses are suitably tied together.

If the face has a tendency to fall, it is supported by breast boards stayed with struts.

The upper gallery has progressed in advance of the excavation under consideration, while in its rear is the walling of the last section which supports the ends of the poles.

The question is now how to wall this excavation.

The invert is first built, either with bricks or stone, but at the sides it terminates with hewn stones which form the springers of the elliptical walling with which the sides and roof of the tunnel have to be lined.

The building is done correctly, according to plan, with the aid of templets placed at suitable points; and as the masonry rises the poles and lining of laths are removed, and the spaces behind it are carefully stowed up.

After this part of the masonry has been finished, there remains only the arch proper to be constructed; the centres are set up, and as the walling gradually grows in height the poles are removed as well as possible. If certain poles have to be left, in order to prevent immediate falls, care is taken to provide a certain space for them in the masonry, so that they have a little play and can be drawn forward to serve as timbers for the next section of the excavation. The spaces left for this purpose should be filled up as well as possible afterwards.

Such is the system that may be followed in ground which is loose, yet not altogether without a certain consistency.

It will be remarked that, according to this system, easily handled props of ordinary dimensions are used, even for an excavation of any section however large; and also, that walling built in one piece from the bottom upwards, is substituted for the provisional timbering, and is, therefore, in a better condition as regards solidity than it would have been if it had been built in sections in descending order.

Figure 192 is a transverse section of a tunnel in course of construction, according to the methods just set forth: the work of excavating, and the timbering, have just been completed; and the templets have been set up by the aid of which the invert and the lower part of the side-walls are to be constructed.

(**220**) We have said above, that the system just described is applicable to ground which, although loose, is not altogether without consistency; but it may be asked what can be done when the last condition does not hold good, and running ground has to be dealt with?

When a case of this kind presents itself, perhaps the best thing to do is to *alter the route* of the railway or canal, so as to avoid the difficulty. If, however, the circumstances of the case did not permit such a deviation, then the work would be one of *great difficulty*, but perhaps not of *absolute impossibility*.

The process to be followed would resemble that which was adopted by the celebrated Brunel when he made the Thames tunnel.

This system ultimately depends on the same principles as those which have been enunciated in the description of the foregoing system; but it is characterized by the employment of what Brunel called a *shield*.

The masonry is executed in a series of short bands over the whole perimeter of the tunnel. The shield, which is placed in advance of the band last executed, is a large metal frame divided by partitions into a certain number of compartments. Each compartment has cutting edges in front and is closed by a moveable door which can be moved backwards or forwards in the compartment. The forward progress of the face is effected by opening these doors one after the other, scraping out part of the ground in front, or allowing it to run out, and then closing the door immediately.

The whole shield is then advanced at once, either by means of screws or hydraulic presses which push horizontally, having the last band of masonry as a fulcrum. Meanwhile the doors are allowed to move backwards little by little, as the pressure of the ground in front requires.

The space betwixt the masonry and the shield is entirely closed in, by a series of long iron plates which rest on the masonry behind, and on the shield in front, and can be drawn forward one by one.

Such is the description of Brunel's system which is more easily described than carried out.

This work cost much time and money, and is unique of its kind at the present day.

More difficult ground than the alluvium of the Thames might be found; but it is seldom that an engineer as intelligent and full of resources as Brunel is to be met with.

It is reasonable to suppose, that this system might fail occasionally, and, consequently, the establishment of a tunnel in very running ground should not be attempted, unless the exigencies of the case are very great.

(**221**) **Enlargement of a tunnel.** — In constructing a railway, it is usual to prepare the principal engineering works for two lines of rails, even when only one is to be laid down at first. Sometimes, however, some of these works are prepared only for one line of rails, and they have to be enlarged when it has been decided to lay down a second line, as in the case of a tunnel.

This work may, therefore, sometimes present itself to the engineer; for example, we may quote the case that happened several years ago, when the tunnel of Terre-Noire on the St. Etienne and Lyons railway had to be enlarged.

The small original tunnel may, in principle, be considered to represent the little upper advanced gallery which has been mentioned in the preceding numbers, and the work of enlargement as a sort of widening process. The work of enlargement, however, must usually be carried on without interrupting the traffic on the existing railway : indeed, this will usually be a necessary condition.

A commencement is made by setting up a flooring of strong planks at such a height that the locomotives, with their funnels shortened if necessary, can pass under it. The workmen stand on this flooring, and the rubbish resulting from the ripping and cutting of the sides as well as the new building materials are laid upon it. Openings are made through it at convenient distances, to allow the workmen to have access to the waggons which are brought under the flooring during the intervals between the passage of the regular trains. The work is done by taking down the old arch to the level of the springers, and then enlarging the space until there is room for the new arch which is to be substituted. The excavation is timbered provisionally with posts which rest on the ground or on the flooring. The centres are then set up, and the new arch is built. One side of this arch rests on the rock, or on beams laid on the rock, if it is sufficiently solid, and the other side on the impost of the old walling.

When this first part of the work has been finished, the process of widening the tunnel at the level of its floor is begun; at the same time the side wall is built up, until it underpins the springer of the arch. This is done in sections of two to two and a half yards at a time.

The line of rails can then be removed to the other side, and the old impost taken out or repaired.

Figure 195 represents the successive stages of this work.

(**222**) These examples of special kinds of work might be multiplied, but those we have given are sufficient to show the principles to be applied to the different cases which present themselves in practice.

The various figures that have been given, indicate approximately the cost of works of this kind as far as *excavating and supporting* are concerned, the conditions being average ones.

It must be mentioned, however, that accessory expenses have to be added to these figures, such as, the cost of underground haulage and raising the stuff to the surface, that of pumping which may vary even more, and, lastly, the cost of accidents that may occur in very difficult ground.

For example, short tunnels have been made in easy ground at a cost of £ 8.10 s. per running foot (700 francs per metre), comprising all the expenses; £ 12 per foot (1000 francs per metre) may be considered very reasonable; in hard ground £ 24 (2000 francs) may be allowed; but it would be possible to give examples of tunnels which cost £ 45 or £ 50 (3500 to 4000 francs) and more, in cases where water or running ground hindered the work.

When a work of this kind has to be undertaken, it is necessary to make a special examination, in order to be able to estimate the cost within certain limits which are necessarily wide apart; and whatever the care with which the examination is made, we cannot hope to arrive at an exact estimate on account of the contingencies.

It is not generally advisable for a large company to undertake the execution of this kind of work, on account of a waste of time and money which it is difficult to avoid; on the other hand, a contractor who has a fixed price for the work, must necessarily take accidents and unexpected charges into account; and if these do not actually occur, the company has spent a certain amount of money without return.

It appears, therefore, preferable, either to employ contractors who undertake the different kinds of work required, at fixed prices, or to establish a system of interested management, in which the manager who carries out the work, obtains a certain proportion of the difference between the actual cost and a certain price fixed in advance to serve as a basis.

CHAPTER IX.

ON MAKING AND SUPPORTING EXCAVATIONS IN VERY WATERY GROUND.

(**223**) In the preceding chapters, we have discussed the means which miners employ for making and supporting ordinary mining excavations, and also the special cases which the engineer has to encounter in practice.

We have also given the principal elementary data by the aid of which more or less precise estimates can be made, as to how much a certain work will cost in time and money, if the conditions are not exceptional.

The exceptional conditions are: either the extremely loose nature of the ground, or the great quantity of water to be contended with.

In the former case, the principal miscalculation is likely to be an error as regards the amount of time that will be occupied in finishing the work.

In the latter case, the expense of pumping may be very considerable, or so great as to render the undertaking *financially impossible.* It may even become *practically impossible*, for instance, when the whole pumping compartment of a sinking shaft becomes filled with pumps which cannot cope with the quantity of water flowing in.

This case has presented itself on more than one occasion, in sinking through the strata which overlay the Coal Measures in the North of France.

(**224**) The two circumstances may exist quite independently of each other : for instance, there may be a very fine-grained sand containing little or no water, or rocks full of fissures which produce water abundantly. It is easy to conceive also, that the two circumstances are often found united, for the very reason that loose, disintegrated, ground is easily permeated by water.

In the last case, the difficulties are greatly increased; for, in order that the workmen may have access to the working face, the water must either be pumped, or be able to flow away freely. In either case, it has a tendency the carry the loose stuff with it, and it then becomes more easy to excavate than to prevent the formation of irregular empty spaces. These would give rise to intense, unequally distributed pressures, which are difficult, and sometimes impossible to resist.

Mining engineers are much interested in the question of traversing very water-bearing ground. It often happens, indeed, that valuable seams or lodes are overlain by ground of this kind, which has to be sunk through before they can be reached. We have already drawn attention to some examples in the departments of the Nord and the Pas-de-Calais, and we might also mention those of the former department of the Moselle near St. Avold. In the northwest of the Mons basin, in the Ruhr basin, etc., etc., similar difficulties are encountered, and it is obvious that, as the reqnirements of mining industry make it more and more necessary to open out deposits which do not crop out at the surface, the question has a growing importance.

For a long time the question was solved only by the employment of *tubbing;* but it has been recognised of late, that this method is either insufficient or too expensive, under certain circumstances, in the form in which it has been generally applied.

At the present day, there is a tendency to substitute certain new processes which seem to be applicable to all cases, and which thus constitute a must interesting emprovement in the art of mining.

In the following pages we shall describe the ordinary method of tubbing in the first place, and point out the respects in which it is weak or insufficient; and afterwards, we shall refer to what has been done, or proposed, to remedy these deficiencies.

§ 1. — Ordinary tubbing.

(**225**) The art of tubbing, which had long been practised in the Mons basin, was introduced into the department of the Nord when the Anzin and Aniche mines were begun; it then extended towards the West as new mines were opened, first in the Nord, and then in the Pas-de-Calais.

The Coal Measures are covered partially in the neighbourhood of Mons, and entirely in the Nord and Pas-de-Calais, by newer rocks of Cretaceous age called *dead measures.*

The Chalk beds near the surface contain many fissures, and are very permeable to water; so that, when a shaft in course of sinking reaches the level of the wells or shallow valleys which intersect the country, it drains the ground over a wide area, extending sometimes to nearly a mile in radius.

As long as the shaft is passing through the Chalk proper, the affluence of water is great.

In consequence of the numerous fissures which intersect the ground, the reservoir which furnishes the water is, in a manner, indefinite, and the quantity which flows into the pit is only limited by the capacity of the little underground channels which open into it.

Fortunately, some impermeable beds of marl, underlie these strata, and are sufficiently thick and plastic to follow the sinking of the ground caused by the underground workings, without cracking.

The process of tubbing which is applicable in traversing ground of this kind, consists in providing the pit with a water-tight lining, placed in position piece by piece as the sinking proceeds, so as to reduce the extent of surface by which the water is given off, and by this means to lessen the quantity.

The tubbing is carried down into the impermeable beds, and then the water is completely and definitely shut off; it, serves therefore, to diminish the quantity of water during the sinking, and afterwards, it prevents the water from flowing into the lower workings through the shaft.

Without this process, pits could not, in general, be sunk through very watery beds; and without the beds of marl, the fissures caused by the workings would carry down so much water as to render any kind of mining impossible.

(**226**) The process usually followed, is applied in the following manner :—

Suppose that one section of the tubbing has been completed and joined to the one above. Then the water pressing towards the sides of the shaft, is kept back and cannot enter, except at the bottom, which is a simple circular well, sunk within the circumference of the tubbing.

The work of sinking is now recommenced, the shaft below the bottom of the tubbing being gradually enlarged in descending, so as to leave a kind of ledge for the support of the base of the tubbing.

As the pit is deepened, the quantity of water increases, and has to be raised by pumps of suitable power; engines of as much as 200 horse power are often required to work them.

As soon as a firm bed is reached, supposed to be impermeable enough to retain part of the water coming from the strata above it, the sinking is stopped, and a well 3 to 6 feet deep is made in the centre of the pit. After this has been done, a horizontal seat for the tubbing is carefully prepared with the pick.

A *collar-crib*, or *curb*, is first placed on this seat; it is a polygonal frame composed of square pieces of oak placed in simple juxtaposition; these are jammed against the sides of the shaft with wedges, so as to hold them vertically below the corresponding pieces of the tubbing above. In this way a good horizontal base is formed, whereon the *wedged* (*wedging*) *curb*, or *crib*, the essential piece of the tubbing, is placed.

The wedged curb is formed of pieces of oak of the very best quality : they should be shaped with great care, verified on a templet, joined together, and numbered at the surface, so that they may be placed again in the same order at the bottom of the pit. When placed on the collar-curb they have a space of a few inches between their exterior surface and the rock; and in this space it is necessary to form the impermeable joint.

For this purpose, a board of soft wood is applied to the exterior surface of each piece; these boards are of the same height as the corresponding pieces of the curb and $\frac{3}{4}$ inch to 1 inch (20 to 25 millimetres) thick. Moss is now rammed in tightly between these boards and the rock, and afterwards two series of flat wedges of soft wood are driven in betwixt the curb and the boards; in one series of these wedges the heads are uppermost, and in the other they are lowest, so that the boards are forced back parallelly to themselves, and thus the moss is compressed against the rock. Wedges with square heads are then driven in, wherever the slightest opening is perceptible, and when there is no more room, an iron spike is driven in with a heavy hammer, and withdrawn again, to make room for still more. When wedges of soft wood will no longer enter, oak ones are employed, and this process is continued until the whole mass between the boards and the curb is so compact, that the iron spike itself rebounds from the surface without penetrating.

The moss is so compressed by this process, that it becomes moulded over the surface of the rock and introduced into the smallest fissures, so that it is no longer seen.

The heads of all the wedges which protrude above the top of the curb are cut off; and if the wedging has warped some of the pieces of the curb, their upper surface is planed until a perfectly horizontal surface has been restored.

If there is occasion for it, a second similar curb is placed on the first, sometimes a third, and even a fourth, according as the ground requires it, in order to obtain sufficient impermeability.

Ordinary tubbing is placed above these wedged curbs; it consists of a series of jointed curbs placed together with as much precision as the wedged curbs. The ordinary curbs do not, however, require to be so thick as the wedged curbs as they have not to sustain the pressure of the wedges. As the tubbing rises up, the space behind the curbs is filled with small stones, or better still with hydraulic concrete.

When the bottom of the next higher portion of tubbing has been nearly reached, the projecting rock which forms the ledge is carefully removed, and new curbs are successively built in, until only one is required to complete the junction. The joints of the portion in course of construction, are now pressed together by means of short screw-jacks, which are applied below the collar-curb of the portion above; the space remaining to be filled is then carefully measured, and the pieces of the last curb are made of such a height that they enter without sensible play. These pieces are placed together in the ordinary way, care being taken to stay them, in order to hold them against the pressure of the water; and the last piece required to complete the polygon, is introduced obliquely, and drawn forward into its position by means of two handles.

The vertical and horizontal joints have still to be calked; this is effected by opening them to a depth of 1 to 1 ¼ inch with a chisel, and carefully ramming in hemp steeped in tar. This is done over the whole of the joints, first from top to bottom, and then from the bottom to the top, so that each joint may be gone over twice.

This work being completed, the sinking is resumed; the well is enlarged in proportion as it is deepened, and the same series of operations is repeated, until a bed has been reached which is suitable for establishing a new system of wedged curbs.

Figure 194 represents, in plan and section, the general arrangements described above.

At A, the enlarged details of a wedged curb are shown.

(227) The foregoing are the ordinary arrangements, but they are occasionally varied.

1° It is often possible to dispense with the collar-curb and to rest the wedged curb, or system of wedged curbs, directly on the rock.

2° We have supposed that all the pieces of the same curb have the same height. Sometimes, however, they are made of different heights, firstly, because there may be less waste in cutting the timber, and secondly, because if one of the pieces happens to burst out, the remaining ones are held in place by the corresponding pieces of the upper or lower curbs, and thus prevented from being pushed out also.

In our opinion, these reasons are insufficient to recommend the adoption of this practice which we find to be essentially bad. It does not permit the various pieces of a curb to come close together at the junction of their oblique faces; and the same face being in contact with those of the two pieces above it, leads to inequalities in the distribution of the pressure, and, consequently, to overstraining at the points of greatest pressure.

3° Certain engineers establish what they call a *returning of the water level*, by means of various contrivances whose object is to have a communication through the wedged curb, between the spaces behind the different sections of the tubbing.

They endeavour to explain the usefulness of this arrangement by a system of reasoning which, in our estimation, does not rest on a sound knowledge of hydrostatics.

We consider this returning of the water level to be perfectly useless.

4° In order to keep the calking in place, and to assure the impermeability of the joints, strips of wood are sometimes nailed over the whole of them, both vertical and horizontal, to prevent the hemp being expelled by the pressure of the water.

It is possible that this practice may have some advantages.

5° It has been proposed to nail a joint-cover of waterproof cloth or india rubber to the back of each piece near the bottom, to prevent the pressure of the water from acting on the calking, or even to render the calking itself superfluous.

This arrangement appears to be a good one.

6° Lastly, the curbs have sometimes been joined to each other by pins which fit into holes corresponding to each other in the faces of two pieces placed one above the other; the object of this arrangement is to assure the exact position of the pieces, vertically above each other, without difficulty.

This arrangement is mischievous in principle: the superposed curbs should be independent of each other, in order that the pieces of which each is composed may comport themselves like the arch-stones of an independent arch.

It is necessary, in fact, that the same pressure should be established at the vertical joints of any two superposed frames, and this may possibly require a slight relative displacement of the corresponding pieces, according as they are more or less flexible, or, as the joints have been more or less pressed together when the curb was put in.

It cannot, therefore, be otherwise than incorrect to bind these pieces together.

(**228**) Tubbing requires oak timber of the very best quality and without flaw, but this is not always to be procured easily.

The first linings of this kind were employed for square pits of small section. Tubbing is generally made polygonal with 8, 10, 12, or more sides. The number of sides is increased with the diameter and depth of the shaft, in order to avoid difficulty in finding suitable pieces of a proper length.

The length of one yard should not be surpassed.

The pieces should be prepared beforehand on an accurate templet, and should be numbered by the row, and by the piece, in order to insure accuracy in placing them.

They should be preserved in a cool damp place under cover, until they are required, in order to prevent them from drying and getting warped.

The thickness of the pieces forming the tubbing can be calculated theoretically (see *Cours de mécanique*), and the formulæ show that this thickness increases with the diameter of the pit, and with the pressure of water which they have to resist.

Near the surface they may have a constant thickness of about 4 inches ($0^{m}\cdot10$), and after that, as the hydrostatic pressure has to be taken into the calculation, the thickness is increased by half an inch at a time up to 8 or 10 inches (20 to 25 centimetres), but this limit is not easily exceeded in practice.

Thus, for instance, in the case of large pits of 13 feet (4 mètres) in diameter and upwards, which are now sunk through as much as

180 yards (160 metres) of watery strata, it has been found very difficult, or almost impossible, to obtain sound timber, of the requisite thickness for the lower parts of the tubbing.

This difficulty, together with the high price of timber in England, where, on the contrary, cast-iron was cheap, induced the English, first of all, to substitute cast-iron for timber, and the practice has since extended to the continent.

(229) Metallic tubbing may be placed upon the same system of collar and wedged curbs as wooden tubbing. On the other hand, the wedged curbs themselves may be of cast-iron. They are then composed of a number of pieces which, when placed in position, form a polygonal contour on their exterior surface, and a circle of the diameter of the shaft on their interior. The pieces are hollow, and open towards the outside. The cavity in each piece is completely filled with a block of wood which projects a little beyond the cast-iron. It is against these blocks that the boards of soft wood bear, that is to say, the boards which are used for the purpose of driving back the moss by means of wedges, as already described.

The ordinary tubbing is placed upon the wedged curbs. Each ring is composed of a certain number of panels, or segments, of which the height is 2 ft. ($0^{m}\cdot60$) and the thickness $\frac{1}{2}$ inch to 1 $\frac{1}{2}$ inches according to the pressure of the water. Each panel has a flange all round the edge, and besides this, it has two diagonal ribs which serve the purpose of strengthening the casting. At the point of intersection of the ribs, there is a round hole 1 $\frac{1}{4}$ inch in diameter, and a bolt passed through this hole gives the means of lowering the panels into their places.

When the panel has been fixed in its position the bolt is removed and the hole plugged with wood.

The flanges are about 4 inches (10 centimeters) in breadth, and those of two contiguous panels do not come into direct contact, Both vertical and horizontal joints are formed by interposing strips of deal (*sheeting*) about 1 $\frac{1}{2}$ inches (4 centimetres) thick between the flanges, and these are pressed tightly by the weight of the tubbing above, and by the pressure of the water acting on the exterior of the cylinder. They are made water-tight by driving in flat wedges about 4 inches (10 centimetres) broad by $\frac{3}{8}$ to $\frac{1}{2}$ inch (10 to 12 millimetres) thick at the head, and then square pegs of the same thickness which serve to tighten up the wedges laterally.

In order to prevent the strip of wood (*lining*) from being driven out during the process of wedging, sometimes two of the corresponding flanges of each segment are provided with a narrow overlapping rim which closes the back of the joint.

In this way a section of the tubbing is raised up, until it comes near the wedged curb of the preceding section, and then a few rings of less than the usual height, or some wooden curbs, are used for the purpose of completing the junction.

The flanges are usually on the exterior, and then the inside of the pit has a smooth cylindrical surface.

The partitions, by which the shaft is divided into compartments, may be supported on a projecting rim with which each segment is provided, or on the suitably cut ends of stout planks nailed securely to the joints.

The flanges may, however, be turned towards the interior of the pit, and with this arrangement the filling up with concrete behind the tubbing is more easily managed. Besides, this arrangement gives greater facilities for supporting the pieces of timber which forms the partitions, the guides for the pump rods, etc.

Fig. 195 represents part of a cast-iron tubbing with the flanges on the exterior, according to the most common system.

(**230**) Tubbing of masonry has also been employed in England, at Liege, and more frequently in the Ruhr basin.

There is not usually a wedged curb at the base of tubbing of this kind, as the stone and the timber would not bind well together.

A wide base is often provided for the masonry, by cutting into the surrounding rock to a suitable depth, and the solidity of the base is assured by giving a slightly conical form to the seat, so that the pressure acts towards the solid rock. It is necessary to timber or wall the ground below this seat with great care, in order to prevent any movement, however slight.

This system is employed in the Ruhr basin for pits of large section; these pits are walled in the overlying dead measures, and timbered in the Coal measures.

Regular wedged curbs are also made for tubbing of masonry, in which the timber of the wooden curbs is replaced by properly cut stones.

Lastly, the ordinary masonry of the tubbing has sometimes been constructed with large stones, shaped with great precision, and having the joints between them filled with sheet lead $\frac{1}{8}$ to $\frac{1}{10}$ inch thick instead of mortar.

Well burnt bricks are, however, most usually employed in conjunction with good hydraulic mortar. The wall is three bricks thick, and sometimes, instead of breaking joint, it has been considered preferable to build it in three distinct concentric cylinders, each being built with as little cement as possible between the joints, and the three cylinders being separated from each other by a continuous layer of hydraulic mortar $\frac{1}{2}$ to $\frac{3}{4}$ inch thick.

The masonry should he built continuously, so that the courses may be well bound together, and the water should be allowed to run off freely until the mortar has set completely. One or more little pipes are built in at the base of the masonry to provide an escape for the water; they are afterwards closed by means of plugs or taps.

It is difficult to build tubbing of this kind in successive sections, and an endeavour should be made to build the whole height at once, by descending immediately to the depth at which the foundation is to be placed.

(**231**) The three methods of tubbing described above — with timber, cast-iron, and masonry — should not be employed indiscriminately; and it is, therefore, of great consequence to be able to appreciate their respective advantages thoroughly.

As regards first cost, masonry is the cheapest, and cast-iron the most expensive.

This, however, is the least important part of the question.

All three kinds may be equally efficacious at first, although masonry is not perhaps so absolutely water-tight as either of the other two. It is necessary, however, to bear in mind, that the tubbing will not remain quite impervious under an unequally distributed pressure, or when slight and not easily prevented movements of the column of the shaft, are induced by the development of the underground workings.

An elastic substance like timber can accommodate itself to these movements by bending slightly, and can be repaired by simply recalking the joints, or by means of small wedges.

A rigid substance like cast-iron will be ruptured in some places, under the same circumstances, notwithstanding the slight elasticity it acquires from the wooden joints, and such ruptures are difficult, but not impossible, to repair, by means of plates fixed with screws.

In a completely rigid substance like masonry, however, extensive cracks are produced; these are difficult to repair, even imperfectly, and sometimes they cannot be repaired at all when the pressure of the water is very heavy.

With regard to keeping in repair, it is thus seen, that wooden tubbing is superior to either of the other two kinds, and especially to masonry.

Lastly, if facility of execution is considered, the quantity of water flowing in, and the pressure which the tubbing has to sustain, must be taken into account.

When the water is very abundant, the work of walling is *laborious and often imperfect*, as the cement is apt to be washed away as soon as it is spread upon the joints.

Very great pressures may render the employment of timber *impossible*, on account of the impossibility of getting balks of sufficient size; whereas, cast-iron or masonry can be made as thick as necessary.

It appears to us, that the conclusions to be drawn from this comparison are : that wooden tubbing should be preferred when pieces of suitable size and quality can be obtained; and that, in the opposite case, when the diameter of the shaft and the pressure of the water render this system inapplicable, recourse should be had to cast-iron tubbing. This reasonable conclusion is confirmed by the practice which seems to prevail at the present moment.

(**232**) In the foregoing pages, we have supposed a complete tubbing, that is to say, one reaching from a lower impermeable bed up to the point in the shaft to which the water would rise and then remain at a constant level. This is the most usual case. Above the tubbing, a lining of any kind may be built, since it does not require to be water-tight.

It may happen, however, that the watery strata are only reached at a considerable depth below the surface: for instance, when a permeable bed is met with, lying between two impermeable ones, and drawing water from the outcrop; or a water-bearing fault.

In this case, only a partial tubbing is required, which need not extend far above or below the point at which the water is encountered; it rests on a wedged curb below, and has wedged curbs also above it. The latter are placed in the same way as the lower ones, the uppermost curb being an ordinary frame. Above these, a lining which need not be water-tight, is carried up, with the double object of supporting the walls and loading the curbs, to prevent them from rising under the pressure of the water.

If the sides of the shaft are solid and do not require a lining, the curbs can be held down by means of props, stayed against the top of the enlargement which was made to allow the curbs to be put in place and wedged.

Complete or partial tubbing is most usually employed in vertical shafts, but it is easy to understand that it may be equally well applied in cross-measure drifts in which watery ground is encountered.

There is nothing in the process described, which absolutely demands that the successive frames be placed horizontally; they might equally well be placed in a vertical or oblique plane. These positions would make no difference as regards the effectiveness of the tubbing; only, there would be a little more difficulty in placing the frames regularly.

It is not obligatory either, that the contour be a regular polygon; a trapezoidal contour, somewhat like the form of an ordinary gallery may be quite as well employed. If the pressure of the water were likely to be very great and the length of the pieces too much, each piece could be replaced by two, making an angle with each other, in such a manner as to form an octagonal section, which, although not regular, would be symmetrical in regard to a vertical plane passing through the axis of the gallery.

(**233**) Such is the system usually employed, when shafts or galleries intended to win a mineral deposit, have to traverse very watery strata.

The success of the undertaking depends upon the possibility of obtaining a good impermeable foundation for the tubbing. It is also taken for granted, that the workings will be isolated from the watery beds by strata of sufficient consistence to prevent the formation of clean fractures formed by the sinking of the ground through the removal of the mineral.

It is further assumed, that it will not be necessary during the progress of the work, to pump an indefinite quantity of water, as might be the case if the pervious bed cropped out in the bed of a river, or in the bottom of a lake which one could never dream of pumping out.

Lastly, it is assumed, that the watery ground itself is of such a consistence, that the water may be drawn away without causing it to move sensibly, and that a provisional resting place at least may be found in it, whereon to rest the tubbing.

If these various conditions are not all fulfilled, the tubbing may be inefficient from the very first; or it may become so, after the workings have been in operation for a time; or its very establishment may be difficult or even impossible.

To meet these difficult or impossible cases, the new systems which we shall now describe, have been proposed.

§ 2. — New processes.

(**234**) We shall suppose, after what has just been said, the ground to be so watery that we are neither able nor willing to attempt to pump the water; or that it is of such a running nature, that, even if it were possible to pump the water, as regards quantity, it would not be possible to do so without undertaking as it were a kind of pumping of the ground itself; or, lastly, we shall suppose the two circumstances united together.

The different processes, proposed or employed to cope with these difficulties together or separately, may be epitomized as follows :

1. If the ground is very watery and more or less running within a short distance of the surface, then, supposing the pit to be already sunk below the natural level of the water and provided with a sufficiently tight lining, a certain pressure of air — as great as the pressure of the water on the bottom—is maintained in the shaft. By this means the water is kept down; it does not require to be pumped; the ground is not drawn in as it would be otherwise; and the sides are in exactly the same conditions, in regard to stability, as they would be if the water could not rise higher in the shaft than the point at which it is kept by the pressure of the air. The workmen go into the column of compressed air and continue the sinking and lining at the bottom. The only limit to the employment of this system, is the maximum pressure of air to which it is safe to expose men, without prejudice to their health.

This system resembles the diving-bell as far as the labour of the men at the bottom of the shaft is concerned. It was invented by M. Triger who first applied it in sinking a shaft through the alluvium of the Loire, in an island formed by that river. The shaft was sunk through 65 feet (20 metres) of alluvium, without the necessity of pumping any water.

Since that time, the system has been often employed in other European countries, and in the United States, either for mining shafts begun in watery ground, or for civil engineering works in which not only watery strata but even water itself had to be traversed : as in making foundations for the piers of bridges, for lighthouses, etc.

It may be considered to be capable of very extensive application, and to afford facilities for the execution of works which might be almost impossible without its aid.

For example, we have already referred to the Thames tunnel which has not been imitated hitherto; its success was due to the great ability and perseverance of Brunel, and was attained by an expenditure of much time and money. It is certain that the employment of compressed air would have facilitated the work very greatly; and probably the better way to execute a similar work at the present day would be to divide it into separate portions, and join these afterwards : the work being done under water in somewhat the same way as in sinking foundations for piers of great length.

This is apart from our subject, however, and we shall only remark further that the resemblance already referred to, between the Triger system and the diving-bell, becomes still closer when the details of the two systems are considered. We should mention, in this place, the apparatus invented by MM. Rouquayrol and Denayrouze, and will return to its description further on. This apparatus was origniallly designed for penetrating into parts of a mine filled with impure air ; but the inventor soon employed it for entering any irrespirable medium whatever, and, consequently, for going into water as well as impure air. It admits the possibility of continuing work under water, and might be employed in joining the separate sections of the tunnel of which we made mention above.

2. It has been proposed to employ the Brunel shield, or a similar apparatus though different in detail, in sinking vertical shafts.

The system consists in tubbing the pit, not in successive sections from below upwards, but by lengthening the tubbing downwards by a series of segments successively fixed one below the other.

The lower face of the last segment serves, like the ring of masonry referred to in No. **220**, as a fulcrum for forcing a shield with cutting edges into the ground by means of hydraulic presses. This shield forms the bottom of a kind of sheath which reaches upwards, above the lowest segments, on their exterior. A tight joint closes the space between the sheath and the tubbing.

The bottom of the shaft is thus kept dry, or, at least, does not receive more water than the small quantity which penetrates through the joints of the tubbing and shield.

The shield is forced down by working the presses, and when it has sunk sufficiently far to make room for a new segment, the new ring of tubbing is put into place and joined to the one above with long wood screws. After this has been done the presses are again worked, and so on.

The shield carries a large tube whose axis coincides with that of the shaft; it descends from above the natural level of the water to the space below the shield, and affords a passage through which instruments for enlarging and clearing can be introduced, so as to facilitate the descent of the shield. The same tube also facilitates the sinking in another way:

When the presses are being worked, the water is allowed to flow through it into the shaft, and thus the resistance due to the pressure is reduced by the weight of a column of water having the section of the central tube for base. When it is again necessary to descend to the bottom, the water is taken out.

This system was invented by M. Guibal, professor at the Mons School of Mines.

3. Lastly, the system invented by M. Kind, the ingenious borer, and afterwards perfected and rendered quite practicable by the inventor and M. Chaudron, consists in sinking a shaft in the same way as a bore-hole of large diameter. After a good bed has been reached, the tubbing is introduced and lengthened at the top as it descends. There is a peculiar arrangement at the bottom whereby a tight joint is formed when it comes to rest on its base.

The lowering of the tubbing having been completed, it is only necessary to take out the water which fills the shaft, and thus the whole thickness of water-bearing beds has been traversed, and the tubbing put in place, while the water has remained at its natural level; no trouble has been required in pumping, such as would have been necessary if the pit had been sunk in the ordinary way.

Such are the general features of the new processes, and we shall now proceed to give more details regarding them.

(235) Triger's method. — In the first application of this process, which was made in 1839 for a mining shaft at Chalonnes (Maine-et-Loire), the alluvium of the Loire was traversed to a depth of 65 feet (20 metres) by means of a sheet iron tube 4 ft. 4 in. ($1^{m}\cdot 35$) in diameter, forced down by the blows of a ram. In the upper part there was a special air-chamber, provided with two man-holes by means of which it could be put into communication alternately with the external atmosphere and the interior of the pit. An air-compressing machine at the surface maintained the required pressure in the pit.

There were cocks for regulating the flow of air from the interior of the pit into the air-chamber, and from the air-chamber into the outer air, so as not to expose the workmen to too sudden changes of pressure when they entered or left the pit.

A windlass, or jack-roll, was set up in the air-chamber and another at the surface to lift the stuff in two stages. It was lifted first from the bottom of the pit into the air-chamber, then, after a certain quantity had accumulated, the lower man-hole was shut and the upper one opened, and the stuff was raised to the surface by means of the windlass at the top.

Figure 196 shows the whole of the arrangements employed by M. Triger at the pit at Chalonnes.

Besides the details given above, we may mention the contrivance by means of which the pit can be kept dry, in certain cases, without requiring to increase the pressure of the air in the interior, to the whole extent due to the pressure of the water. The tube A allows the water to flow out, as it accumulates and is acted on by the greater pressure of air in the shaft. The ascending column of water acts like a water-blowing machine, drawing in air by the cock B, which is opened to a suitable extent. The effect of this aspiration is to change the mass of the liquid into a kind of froth having a less density than water, thus allowing it to be raised to the surface where it flows out.

In this manner the pit at Chalonnes was easily sunk to a depth of 65 feet (20 metres); and, elsewhere, a depth of 92 ft. (28 metres) has been reached, without requiring to compress the air above a total pressure of 5 atmospheres — a limit that may be reached, but not surpassed, without danger to the health of the workmen.

Another artifice, somewhat similar to the above, consists in employing the tube, not for the exit of the water which cannot readily escape through the surrounding ground, but for getting rid of the solid matter itself. It is possible, with very running sands, to establish a current of air in the tube which carries up the sand and water together to the surface.

The process has also been varied in other respects. For example, the air-chamber having been erected above the level of the surface, a windlass was set up in it for raising the stuff from the bottom of the pit; and when it arrived in the air-chamber it was ejected to the outside through a large inclined tube furnished with doors at its two extremities. The exterior door was shut until the tube was filled; then the interior door was shut and the exterior one opened, so that the stuff ran out in virtue of its own weight.

Again, the employment of lamps or candles, which are inconvenient with compressed air, was dispensed with, the light being obtained through thick glass windows, such as are used in ships. These windows afforded a passage to the sunlight during the day, and to the light of reflecting lamps, etc., at night.

In one word, the Triger system has been employed by a large number of engineers, French and others, and has always shown itself to be very convenient and appropriate, in a multitude of cases.

The employment of compressed air deserves great attention from engineers, either in the complete form which the inventor gave to it, permitting the employment of many hands in a large undertaking; or in the simplified form which it has lately received from MM. Rouquayrol and Denayrouze, which seems well adapted for the work of a single individual.

To return to the application with which we are at present interested, that is to say, for sinking mining shafts, we would remark that it has been employed under different forms, and with different appliances from those used by M. Triger, and for pits of much larger diameter than that at Chalonnes.

From the first, the air-chamber was made a fixture at the level of the surface, or slightly below it, without being solidly connected with the tubbing. When the joints of wooden tubbing tended to open, under the pressure of the air in the interior, they were kept together by means of iron corner-pieces fastened with wood-screws; and the escape of air was further hindered by covering them with strips of cloth coated with clay.

It was possible, in this way, to pass through the most watery beds next the surface, and, after having reached the limits to which the process can be carried, to continue the sinking by the ordinary methods of tubbing.

At other times, when the watery strata were running, the wooden tubbing was replaced by a cast-iron one, composed of segments joined together by inside flanges; and this was let down into the pit and lengthened at its upper end.

In this case the lower circle of segments is furnished with a cutting-shoe to penetrate the ground under the action of forcing screws, or hydraulic presses, which act on the collar at the top of the uppermost ring.

The column is lengthened by placing new segments on the top, in proportion as the cutting-ring penetrates the ground; it slides in a packing-ring bolted to the base of the air-chamber; and the interval between the exterior of the column and the interior of the packing-ring is stuffed with moss to prevent the escape of air.

This system was employed at Seraing (near Liége) for traversing 53 ft. of the very watery alluvium of the Meuse. When a sufficient depth had been reached in the Coal Measures, the cutting-shoe was removed and replaced by a wedged crib, or curb, which was joined to the bottom of the tubbing by means of some ordinary wooden curbs.

Figure 197, borrowed from the atlas to the supplement of M. Ponson's work, gives the principal details described above.

(236) Guibal's method. — Guibal's process is not limited like that of M. Triger to watery ground near the surface. The object for which it was proposed and designed was to sink through 80 ft. of running sand, the top of which was about 85 yards from the surface. This was a case of very great difficulty, not only on account of the quantity of water and the very shifting nature of the ground, but also the great depth at which these beds were encountered. It would not have been possible to pump out the water without having the loose stuff drawn in violently by the current which would have flowed in under the enormous head of 85 yards.

It was, therefore, absolutely necessary to carry on the work under the same conditions as if the water were at its natural level.

M. Guibal attained this result without any pumping, and, consequently, he prevented any movements of the water which would have drawn in the sand.

The shield, or cutting prism, employed by him could cut out a regular octagon circumscribed about a circle of 10 ft. 8$\frac{3}{4}$ in. ($5^{m}\cdot27$) in diameter. The sheath surrounding it was also octagonal circumscribed about a circle 11 ft. 9$\frac{3}{4}$ in. ($5^{m}\cdot60$) in diameter. It was requisite to make it very thin, in order to reduce the dimensions of the tubbing as little as possible, and, at the same time, to have sufficient strength to withstand the pressure of the water. It was made of wooden boards 4 in. ($0^{m}\cdot10$) in thickness, lined, inside and outside, with bands of iron $\frac{3}{4}$ in. (2 centimetres) thick.

At the upper end of the sheath a tight joint was formed between it and the exterior surface of the tubbing, by means of india-rubber rings which the pressure of the water held firmly in position.

Although the tightness of this joint might seem to be doubtful at first sight, it turned out, on the contrary, to be perfectly sufficient during the whole operation, since the bands of india-rubber are not worn except by friction, and this only over a length equal to the whole height that the shield has to travel, say 70 to 80 ft.

Sixteen hydraulic presses, placed two and two under the eight pieces of the last section of the tubbing, served to force down the shield.

An instrument for scraping the sand in the open space below, was introduced through the central column; its arms opened out after it had passed through the tube, to such an extent that the natural slope of the sand was preserved.

This system, which is described with many details in a report published at Mons in 1856, is represented in figures 198 to 200; these figures are reduced from those which accompanied the report.

Figure 198 represents the shaft in plan and section, the shield with its water-tight joint, and the general arrangement of the hydraulic presses; figure 199 gives the details of the joint on a larger scale; and figure 200 those of the expanding scraper.

(237) Guibal's system must be acknowledged to be very ingenious, although it was not quite successful in the only instance in which it has been applied as yet.

Many difficulties were encountered in passing through the running sand; and, unfortunately, the surface of contact of the sand with the Coal Measures, upon which it rested immediately, was much inclined; so that, while one edge of the shield came to rest on solid ground, the other left an opening through which sand and water could pass.

Notwithstanding this difficulty which was due to a special circumstance, M. Guibal's system deserves all the attention of engineers.

(238) **Kind and Chaudron's method.** — This process, unlike the preceding, can show many successful examples at the present day; and there is a tendency to have recourse to it, not only in those exceptional cases in which it is indispensable, but even in cases in which the ordinary system of tubbing might be employed without an excessive expenditure of time and money. The application of this process provides against the contingent difficulties of the ordinary system; besides, it is reasonable to expect a considerable saving of money, if the whole cost of the necessary apparatus is not charged as part of the sinking expenses.

The process comprehends two essentially distinct operations; the sinking of the pit, and the tubbing.

(**239**) The sinking is nothing more than putting down a bore-hole of very large diameter. For information on this subject reference may be made to Chapter IV.

The apparatus, however, includes some peculiar arrangements. Thus, each cutting-tool is necessarily made with a number of cutters joined together.

It is even better, perhaps, to have two cutting-tools: one for sinking a central hole, the other for enlarging. This arrangement is of advantage in very hard ground, for obtaining a given rate of deepening, without giving an excessive weight to the instrument.

The large cutting-tool may have its separate cutters placed slightly behind each other, as regards depth, so as to make a conical excavation, which helps to bring the débris towards the centre of the shaft. The débris thus fall of their own accord into a bucket placed in the central hole, which is drawn up full after a boring has been made over the large diameter.

To complete the clearing of the shaft, an apparatus called a dredge is used; it had been already employed by M. Kind for ordinary bore-holes.

Figure 201 represents the cutting-tool for the large diameter. and figure 202 the dredge, shown open at the bottom of the shaft.

(**240**) Supposing the operation of boring to have been completed, recourse having been had, according to need, to all the artifices practised in the art of boring, the pit still requires to be tubbed; and it is this part of the work which specially characterzes the system.

The tubbing is composed of a series of cast-iron rings about 4 ft. 11 in. ($1^{m}\cdot50$) in height, cast in one piece, 1 to 1 $\frac{1}{2}$ inch (25 to 40 millimetres) thick.

While being let down, it is lengthened from the top, as has been said in No. **214**, but it descends without cutting the ground, and has, on the contrary, a little play.

Each ring is furnished at the top and bottom with an inside flange 4 in. (10 centimetres) broad. The rings are joined to each other by means of forty $\frac{3}{4}$ to 1 $\frac{1}{4}$ inch (2 to 3 centimetres) screwed bolts.

It is necessary to use many precautions and much care in making and joining the pieces; for any little defect that is discovered only after the tubbing is in place is very difficult to repair.

All the pieces are tested under hydraulic pressure acting on the exterior, or, in the same sense as the pressure to which they will be exposed. The usual test pressure is 15 atmospheres.

Every defective piece should be rejected. The faces of the two flanges ought to be turned simultaneously on a lathe so as to ensure a complete parallelism; for, otherwise, there would be a risk of the column not being perfectly straight.

The joint is formed by cutting a groove in each face, so that, when two faces are joined, there is a little channel enclosed by them. This channel is filled with a strip of lead, which is squeezed until the bolts cannot be screwed further.

The lead may be replaced by india-rubber which would accommodate itself even more completely to the slightest inequalities of the surface; but it is necessary to have a joint that will not alter with time, and it has not yet been ascertained how long india-rubber will last under the conditions which obtain in this case.

The assemblage of the different pieces forms a long tube, which is lowered into the shaft to act as a water-tight lining.

It still remains to be described, how the foot of the column is made water-tight, and how it is let down into the shaft.

The arrangement employed for assuring impermeability at the base, corresponding to the wedged curb, has received the name of the moss-box. It is made in the following way :—

The ordinary tubbing terminates at the bottom with a flange turned outwards. A movable ring, whose exterior diameter is rather less than the interior diameter of the tubbing, is fitted on the lowest segment, and has a flange at its base, also turned outwards, so as to correspond to the former. The space between the two flanges is filled with moss, well freed from earth, tightly rammed in, and held together by a net.

When the tubbing reaches the bottom of the pit, the movable ring is arrested first; the tubbing continues to descend by its own weight; the two flanges approach each other, compress the moss and force it against the rock. This pressing of the moss against the rock is partly due to the conical form given to the flanges. The idea is borrowed from the construction of ordinary stuffing-boxes; only, in this case, the surfaces of the flanges are convex in order to push the moss outwards against the rock, whereas in the ordinary stuffing-box they are concave, in order to press the packing inwards against the rod which passes through them.

The moss-box forms an excellent joint, on account of the great weight of the tubbing which rests upon it; and the pressure on the joint increases with the height of the column, as does also the head of water to which it is opposed.

(**241**) If we suppose the tubbing of a shaft to have a mean thickness of only 1·1811 inch (30 millimetres), the diameter to be 11·483 feet ($3^{m}\cdot50$), and the height 164 yards (150 metres), it is seen that the tubbing alone (not taking the flanges into account) will weigh about 330 tons (334,000 kilogrammes).

Although this enormous weight ensures sufficient tightness to the moss-box, it requires special contrivances for putting it in place. When a hermetically closed bottom is fitted to the column, it will displace a rapidly increasing weight of water, and soon become a floating body which would have to be pressed down, instead of being held back. If a tube concentric with the tubbing, open at both ends and provided with cocks at short distances apart, be now fitted to the bottom, it becomes possible, by means of the cocks, to load the floating mass with water reaching to a certain height in the annular space between the tubbing and the central tube. Care must be taken to shut each cock in succession before it becomes covered with water.

By means of this arrangement, the whole of which is represented in figure 203, it is easy to give the system a nearly constant weight in the water: for instance, 25 to 30 tons. This is necessary, in order to impart stability to the system, and to be able to maintain it more easily in the axis of the shaft.

The great weight of the column, and the weight of the pieces of tubbing which have to be handled in lengthening it, make it necessary to have the arrangements essentially different from those employed for putting tubes into ordinary artesian wells. The weight is borne by six rods which pass through holes in one of the flanges and are lengthened at the top; they are screwed at the upper end, and each has a nut made in the form of a pinion which is turned by means of an endless screw with a handle.

When it is necessary to put in a new ring, the iron rods are supported on keys at a certain distance below the top; the uppermost bars are then removed, the ring of tubbing is slipped into its position and the bars are replaced.

Figure 203, already referred to, shows the general arrangements of this system.

(**242**) The space behind the tubbing must be filled with concrete made with good hydraulic mortar. This cannot be done by hand in the ordinary manner, neither can it be done by simply pouring in the concrete at the top, for however hard-tempered it might be in the first instance, it would be diluted in its descent, and only pebbles would reach the bottom. It is necessary, therefore, to let it down in close boxes which are opened only when they reach the bottom by an easily conceived arrangement. The concreting should be finished quickly without interruption, so as to obtain a homogeneous and well-bound mass.

The concrete cannot, however, be considered to ensure the thorough impermeability of the joints of the tubbing, and, therefore, they should be water-tight of themselves; it hinders the water at different levels from communicating so easily, and would, therefore, diminish the amount of influx if the moss-box were not quite tight, or if a plate of the tubbing happened to give way.

The arrangement just described may be said to be exactly the reverse of the endeavour to connect the various water-bearing strata, of which we showed the entire inutility in No. **227**.

After the tubbing has been put in and the concreting finished, several days are allowed to elapse to give the concrete time to set hard. The water contained between the tubbing and the equilibrium tube is then pumped out. As the water sinks the cocks are opened successively; the tube is taken out in lengths, and at last the bottom itself is removed. Everything is now ready for resuming the sinking and continuing it by hand labour.

(**243**) Such is the very ingenious and practical system which is now employed by M. Chaudron in sinking many shafts in the Departments of the Nord, the Pas-de-Calais, in Belgium, and the Ruhr basin.

The process appears to be quite successful in all kinds of ground in which boring can be easily done, that is to say, in ground of suitable consistence; it is, besides, altogether independent of the quantity of water which would have to pumped if the bottom had to be kept dry.

It will evidently be more difficult to apply it in running ground which could not be passed through by a bore-hole without being tubed; and it would be necessary in these cases to have a provisional tube. As we have already remarked, however, a loose running ground which causes so many difficulties when the water is kept down, is much less to be feared when it is allowed to remain at its natural level; for in that case there are no currents, and the ground itself is not set in motion in the same way.

On the other hand, we may assume that running sands, which are met with at considerable depths, may be passed through with comparative ease by the Kind and Chaudron process, being held back at first by a sheet-iron tube; part of the original diameter, however, would have to be sacrificed to make room for the definite tubbing and the concrete.

(**244**) **Comparison of the three preceding methods:**

The three methods which we have just described, (Nos. **234** to **243**), have a common characteristic, namely, *that the work is carried on with the water at its natural level*, *or*, *at least*, *under the same conditions as if this were the case;* they are, consequently, independent of the quantity of water that would have to be pumped by the ordinary method, and at the same time that they save the expense of pumping, they avoid the difficulties which pumping creates with running sands.

They have, on the other hand, essential differences.

Triger's process is confined to watery ground near the surface, or not deeper than 100 feet (30 metres). It is a valuable resource in this respect, that it admits of the workmen being at the very bottom of the shaft, where they can remove with their own hands any obstacle that might prevent the sinking: for example, a boulder which would hinder the descent of the tubbing.

In the event of this process being only employed casually, it might be more advantageous to substitute the more portable apparatus of MM. Rouquayrol and Denayrouze, for the complex apparatus consisting of the air-compressing machinery and the air-chamber. Rouquayrol's apparatus may be employed to a depth of 65 feet (20 metres). It may even be assumed that, in cases of urgency, a greater depth, or even any depth could be reached, provided that during the operation the water could be lowered temporarily to within 65 feet of the point at which the workmen were engaged.

Guibal's process has the advantage over Triger's, in so far, that it is independent of the depth at which the work has to be done; but it requires an apparatus which is quite as complex; and experience has shown that its application is difficult. It offers fewer resources than the others, especially Triger's, in case of an accident resulting from the nature of the ground; for it is not possible to attack the ground except by means of instruments which require to be passed through the central tube. With Chaudron's process, on the other hand, the whole diameter of the shaft and all the artifices known to borers are available; and with Triger's process the workmen can apply themselves at the very point where the difficulty occurs, instead of having to manœuvre from afar, at the end of a long rod.

Kind and Chaudron's process has the same advantage as Guibal's in being applicable at any depth; besides, it is a more certain method, and can be applied in a greater number of cases.

Of the three processes, this appears to us to be the most preferable, in all cases where the watery ground is deeper than 98 feet (30 metres): and in the collieries of the Nord and the Pas-de-

Calais the depth is sometimes two or three times as much as this.

The possibility of its being frequently applied is, of itself, one great advantage of this system, in this respect, that foremen and labourers accustomed to the work can be more easily found; and the various operations, which are always of a delicate kind, will gain in security and rapidity of execution, when confided to a staff of men who have already had experience in conducting them.

We are of opinion that this system is destined to come into general use for all sinkings which are presumed to be very difficult on account of the depth of the water-bearing beds. We believe it will usually be found to save both time and money; there will be nothing to fear in new undertakings more than in those which have been already completed; and, when a new centre of production has to be created, there will be no hesitation in preferring two distinct shafts (one to serve as a downcast the other as an upcast), to a single shaft of larger section intended to serve for all purposes, including ventilation.

The first cost of two shafts will not, after all, be much greater; and there will be an essential advantage in regard to the security of the workmen as well as the greater extension that can be given to the workings.

It appears to us that mining companies who are opening out new centres of production should proceed in this way, in localities where they have difficult strata to pass through, and where it is intended to extend the underground operations over a large area.

(**245**) For instance, in situations similar to that in which the collieries of the Nord and the Pas-de-Calais are placed, a centre of production may very properly consist of two distinct shafts, at a short distance apart.

These shafts may be of equal size and have a diameter of 10 to 11 feet (3 metres to $3^{m}\cdot50$) at the most. One of them can be used as a winding shaft and downcast, the other as an upcast and for the purpose of letting down men, timber, etc. Both shafts should have winding engines, which may be of the same size, and if so, the one on the upcast may be worked expansively when its whole power is not required.

Such an arrangement appears to us to have evident advantages, one of the most important being that the one shaft serves as a means of egress for the men, in case of an accident to the other.

The upper part of each shaft might be sunk, by the Chaudron process, the same apparatus being used in both cases; and this part of the work would be done more rapidly and more economically than the corresponding portion of a single shaft of large section.

Moreover, the extraction of mineral can be carried on as rapidly as the capacity of the deposit will admit, and will not always be open to complete interruption when an accident happens to the winding engine, since that of the other shaft can be used immediately; and, in case of need, if a very large output were required, both engines could be employed at the same time.

CHAPTER X.

GENERAL OBSERVATIONS ON LAYING OUT, OPENING UP AND WORKING A MINE.

(**246**) If we reconsider the subjects treated in the preceding chapters we see that we now possess :—

Firstly, certain theoretical ideas concerning the origin and mode of formation of the various deposits of mineral substances, as far as science will allow at present; they are general ideas which, without explaining, from a chemical or mineralogical point of view, all the details of structure and composition that may be presented by a given deposit, are still sufficient for enabling us to understand in a general way how it was formed, for explaining its principal features, and, consequently, for guiding the miner practically in prospecting, or while actually engaged in working it.

Secondly, a knowledge of the course to be pursued by the miner in prospecting ground where the presence of a deposit is suspected, and in carrying out explorations, after its material existence has been proved, in order to ascertain whether it is workable at a profit or not.

Thirdly and lastly, a knowledge of the different technical processes which are at the disposal of the miner for carrying out and securing his work, from the employment of the simplest tools for digging, to the most complicated processes by which it is proposed either to economize labour or accelerate the work by the use of machinery, or to contend by the means that we have just made known, against the special difficulties which may result from large quantities of water and the loose nature of the ground.

We must suppose, in the present case, that the question whether the deposit can be *worked at a profit* has been decided in the affirmative. We may allow that, with the present means at our disposal, there are few, if any, material difficulties that the miner cannot in time overcome ; we shall suppose at all events that it is so ; that is to say, that the deposit can be reached without insurmountable difficulties from the financial and material points of view, and that we now have to organize and prosecute the working.

(**247**) This undertaking requires works of different kinds : firstly, the *winning* and *erection of plant;* these are works which are intended to be permanent, or, at all events, to last for a considerable time, and their object is to reach the deposit at once, to organize the means of extraction, pumping, ventilation, etc., in a word, to set up *a centre of production ;* secondly, *preparatory works*, characterised by this fact, that they have to be continued indefinitely, or at any rate repeated periodically as long as the working area created by the winning is made use of; such works are sinking shafts, driving crosscuts, driving new levels, etc., the expenses of which should be included in the general cost of working, or in any case added to it every year ; thirdly and lastly, *exploitation* or *removal of the deposit* itself, the object, or immediate result, of which is to produce a certain quantity of the useful substance that the deposit is expected to furnish.

These different kinds of work admit of some general observations, which it is advisable to recapitulate.

(**248**) Workings for intersecting a deposit in depth (*winnings*) consist of shafts or levels, or various combinations of shafts and levels.

Shafts may be either vertical, or inclined along the line of greatest slope of the deposit.

Levels may be *across the rocks*, or *along the strike* of the deposit. In the first case, they are generally called *crosscuts*, in the second case, simply *levels*.

Levels terminating at the surface (*adit levels*) have this advantage over shafts, that they save the expense of winding and pumping, at least if the workings are above them. They sometimes also have another often very important advantage: that of furnishing the motive power for subsequent workings below them, by creating falls of water of greater heights than the contour of the surface would admit.

Levels along the strike are useful, even while being driven, for the purpose of exploring the deposit and preparing to work it; crosscuts serve to explore not only the deposit, but also the enclosing rocks, and to discover any deposits that may exist parallel to a given deposit (see No. 28).

Vertical shafts correspond to crosscuts, and inclined shafts to levels.

Shafts may be necessary when the contour of the ground presents little difference of level, or, as may often happen in reworking old mines, when the *old men* have worked away everything above the level of the neighbouring valleys.

They have a somewhat important advantage over levels, from the fact that we are not tied down to begin sinking them at any fixed point, and that their position may be altered to a certain extent as may appear expedient, either with regard to the site at the surface or to the underground workings. The position of the mouth of an adit level, on the contrary, is generally a settled thing, or, at all events, cannot be fixed arbitrarily, when we lay down the condition that it should be placed at the lowest point consistent with its being of reasonable length.

In order to settle upon the site, it is necessary to have a graphic representation of the contour of the ground, and this site ought to be looked for along the bottom of the deepest valleys.

Vertical shafts are preferable to inclined shafts, when heavy pumping machinery has to be put up, for pumps and rods are more easily fixed, and require fewer repairs, when they are arranged vertically. However, many metallic mines may be quoted, especially in England, where large engines work pumps in inclined shafts, or in shafts which have been sunk vertically, till they intersected the deposit and have then been carried on along its dip. This arrangement of inclined shafts is justifiable in working a lode, when the enclosing rocks are very hard.

In this case, in fact, an inclined shaft allows the lode to be studied in detail during the sinking itself. If, however, a large output is required, the preference should certainly be given to vertical shafts; for, in order to obtain such a result, great loads must be raised, at velocities which are only admissible in vertical shafts, furnished with the best system of guides.

(**249**) For an important mine a single outlet, either shaft or level, is not generally considered sufficient. This system is only admissible in two cases: when the underground workings are of no great extent and there is no fear of fire-damp being given off, as in the case of many mines of iron ore, building stone, gypsum, etc.; or, if it is difficult and very costly to sink shafts, as in some places in the Newcastle coalfield, in the departments of the Nord, the Pas-de-Calais, in the district that formerly constituted the department of the Moselle, etc., etc.

Apart from cases of this kind, a new centre of production, which is not at once, or likely to be very soon, connected with other workings, ought to communicate with the surface by two entirely distinct outlets. A single outlet divided into two compartments by an air-tight partition, so as to induce ventilation, *must not be considered as fulfilling this condition.*

It is well known that in England, manufacturers, and the public generally, are little disposed to accept a regulating and protecting legislation such as the French government (yielding, it is true, as a rule, to public opinion) is always to ready to introduce. Nevertheless, even in England, an exception has been made to what may be called the English system of government, on the point in question. An Act of Parliament, passed in 1862 and amended by another Act in 1872, compels all owners of coal-mines worked by shafts, to have two entirely distinct shafts or outlets.

The new Act of 1872, states precisely the conditions under which the two shafts must be sunk.

They must be separated by natural strata of not less than 10 feet in breadth, and connected by a communication of not less than 4 feet wide and 5 feet high.

Each shaft or outlet must be provided with proper apparatus for raising or lowering persons, either in actual use or available for use within a reasonable time.

Any of Her Majesty's superior courts of law or equity may, upon the application of the Attorney General, prohibit by injunction the working of a mine where these provisions are not rigorously carried out, and where no exemption from them can be claimed under any of the exceptions stated in the Act.

These provisions have been made in consequence of the disasters that have happened in mines provided with only one shaft, when some great accident has destroyed the ventilation and means of egress.

There have been instances of great explosions of fire-damp, felt even at the surface, which destroyed the brattice or partition from the bottom of the shaft to the top, filled the bottom of the shaft above the hanging-on places, with a mass of entangled timber, and so closed up every outlet for the workmen shut up in the mine, rendering it impossible to reach them in time.

The partition may also be destroyed otherwise than by an explosion, as by the fall of some large and heavy body. In one instance the beam of a pumping engine broke in two, and one half fell down the shaft; it smashed every thing in its path, and filled the shaft with debris for more than 20 yards, and thus caused the death of all the men who were in the mine at the time, without exception.

A similar disaster might happen if the timber of the shaft took fire and could not be extinguished immediately. We have quoted an instance of this (No. 216).

The centre of extraction will therefore generally comprise *two distinct shafts*, instead of a single one of sufficient dimensions for all purposes, including ventilation.

This, we repeat, is a precautionary measure which should be considered *necessary*, although it is not obligatory by law in France;

and we do not allow that a fiery mine, which has to be worked on a large scale, can be considered as properly laid out, unless *the downcast and upcast shafts are entirely distinct from the surface to the very bottom.*

(**250**) The shape and section of the shafts naturally depend on the method employed for sustaining the sides, and the more or less complex duties required from them. As to shape, we have seen that round walled shafts are the best kind if they are required to last for some time. As to the dimensions, the diameter may be reduced to 5 feet ($1^m \cdot 50$), or even 4 feet ($1^m \cdot 30$), where the workings are small and the stuff is raised in small corves or buckets containing $2\frac{1}{2}$, 3, or 5 cwts of coal ($1\frac{1}{2}$ to 2, or 3 hectolitres, $5\frac{1}{4}$ to 7 or $10\frac{1}{2}$ cub. ft.).

With a diameter of 8 feet ($2^m \cdot 50$) buckets, or kibbles, holding 14 to 18 cwt. of coal (8 or 10 hectolitres, 28 to 35 cub. ft.) may be employed; large kibbles containing $1\frac{1}{4}$ to $1\frac{3}{4}$ tons of coal (15 to 20 hectolitres, 53 to 70 cub. ft.) require diameters of 10 to 12 feet ($3^m \cdot 30$ to $3^m \cdot 60$).

Of late years shafts have been made 13 ft. (4 metres) and even 14 feet ($4^m \cdot 30$) in diameter in order to use cages; but it appears useless to exceed the former of these figures as long as there is no intention of having four cages in the shaft, and when there is no necessity for keeping a large space for the return air.

The exact diameter should be fixed in each particular case, after the details of the pumps, winding machinery, man-engines, etc., which it is intended to put up in the shaft, have been studied carefully.

The necessary diameter of the shaft having been settled, there is nothing to be gained by increasing it; an *increase* in size will not facilitate the working of the machines employed for winding, pumping and lifting the men, and *always* augments the cost and *sometimes* also, in a very marked degree, the difficulties of sinking.

This increase in size would not, as a rule, be of any practical advantage for the ventilation, at least in a large mine, as the section of the shaft is generally sufficiently large, and its depth of no importance, compared with the corresponding dimensions of the great network of levels, that the current of air has to traverse between the bottom of the downcast and the bottom of the upcast shafts.

(**251**) The shape of crosscuts varies, as we have seen, according as they are timbered or walled. There is an advantage in difficult ground in making them small, so as to lessen the cost of driving and repairs.

They are then made only large enough for tramming, and here and there sidings are put in for the waggons to pass. It is thus possible to work with a width of only 4 feet 5 inches ($1^{m}\cdot30$), and a clear height of 5 feet 10 inches ($1^{m}\cdot80$).

When, however, there is no restriction arising from the difficulty of the ground, it is better to increase these dimensions, either in order to obtain a double road where the tramming is carried on most actively, or to improve the circulation of the air; sometimes also a gallery is made large for the purpose of obtaining room enough to put in a vertical or horizontal partition (*brattice* or *air-sollar*), and so forming a return air-way.

The width and height may be increased in this manner up to 8 feet ($2^{m}\cdot50$), which gives a section almost three times as large as that obtained with the smaller dimensions named above.

If the nature of the ground will not allow the drift to be kept open for the whole width necessary for two roads (even at the sidings, which are indispensable when the traffic is great), the sidings should be made by dividing the level by a median line of props, if it is timbered, or by a wall, which serves as a pier for two distinct arches, if it is lined with masonry.

Theoretically, crosscuts and levels are horizontal; but in reality they are driven with a slight inclination, in order to facilitate the drainage of the water and the tramming.

For water, a very small slope (1 or 2 in 1000) is amply sufficient.

For tramways, the gradient varies according to circumstances, which will be mentioned in speaking of the conveyance underground, from 5 to 15 in 1000.

(**252**) The site of a shaft or of a given centre of production is determined, as has already been said, by various considerations, depending on local external conditions and on the known or supposed lie of the deposit in the bosom of the earth.

A site is sought where it is easy to get rid of the rubbish derived from working in the *country* or in the deposit itself, or else, on the contrary, where the necessary stuff for filling up, in certain methods of working, can be easily obtained.

Furthermore, if the mineral is sold on the spot, the place should be easily accessible to the consumers, whilst if the products have to be exported to a distance, it should be within easy reach of existing lines of traffic (main roads, canals, sea-ports or railways).

The value of the land must be taken into consideration; unless the proprietors give their consent, the shaft must be at least 100 yards (100 metres) from their dwellings or the enclosures adjoining them.

A supply of water for steam-engines must not be forgotten, because the mine water is almost always more or less acid; the site should therefore be chosen near springs or streams, care being taken to have the mouth of the shaft above the level of the greatest floods.

Boggy ground ought to be shunned, as well as alluvial land in hollows, as it is often very watery; and serious difficulties will sometimes be avoided by sinking the shaft on the side of a hill a few yards above the bottom of the valley.

(**253**) On the other hand, we must take into consideration the general lie of the deposit, and choose the position of the shaft so as to intersect it at a given depth. In a case of this kind, the crosscuts, which fix the various working horizons, will be first of all in the hanging wall side, and lower down in the footwall side, if we wish to reduce their total length to a minimum.

However, if the deposit is thick and so nearly vertical that all the crosscuts can be made on the footwall side without becoming excessively long at an early stage of the workings, it may be thought advisable to sink the shaft entirely on the footwall side. It will thus be quite safe from dislocations of more or less importance, which the workings almost inevitably cause in the neighbourhood of the hanging wall; this will be of great advantage for the winding machinery and still more for the pumps working in the shafts.

(**254**) It is thus evident that the two kinds of considerations are essentially different, and that they will not, as a rule, lead us to fix upon *the same site* for the mouth of the shaft. From this point of view, it may said that we are by no means obliged to sink the shaft in one particular spot.

It will be necessary to study all the different conditions, usually discordant and sometimes entirely contradictory, which it appears be desirable to satisfy.

After the site has been chosen, it is always possible, in case of need, to connect it with the site that external considerations rendered preferable, by means of some suitable arrangement (a tramway at the surface, an automatic or ascending inclined plane, an adit-level, etc., etc.); in the same way, a crosscut, driven from the shaft at the proper level, may be made to intersect the deposit at the same place as the shaft would have cut it, had its position been determined solely by the lie of the deposit.

(**255**) When the position and size of the shaft have been determined, it is sunk to the depth fixed upon, and provided with the machinery necessary for the various purposes of the mine, and the deposit is reached for the first time by one or two crosscuts; the *period of first establishment* or *winning* is now closed, though of course additional machinery may be required subsequently.

Another question then presents itself, as to the system which ought to be followed in carrying out progressively *the preparatory works*, which are made in order to enable the various parts, into which the working field can be cut up, to be removed successively.

The system of division generally in vogue consists in dividing the working field vertically into various horizons or stories by a series of crosscuts; the distances between them are varied according to local circumstances, and at the point where each joins the shaft a hooking-on place or *plat* is made.

The distance between two horizons is rarely less than 8 fathoms (15 metres), or more than 27 fathoms (50 metres). The shorter the crosscuts the nearer they may be.

The crosscuts are driven out from the shaft at right angles to the strike of the deposit, or series of parallel deposits.

When the deposit is reached, a level is driven in it right and left. The levels which serve as bases to two consecutive horizons are connected by workings of some kind. The lower level serves to bring in air from the downcast shaft, and the upper level takes it back to the upcast shaft with which it is placed in communication. The preparatory works of any given horizon or story are then completed.

(**256**) Several questions now present themselves : —

1. On what scale can these preparatory works be carried out?

2. How long can the levels be made?

3. In what order ought the different superposed deposits to be worked?

4. In what order should the different horizons of the same deposit be taken?

The first question admits of very different answers according to circumstances.

It is evident that, as the shafts become deeper and more costly, we are induced to give them larger working areas, so that the charge on each ton for repaying the cost of winning may be kept within reasonable limits, by the total expense being spread over a larger output. If we take the case of a coalfield with the seams cropping out at the surface and extending to a small depth, we may suppose that the crosscuts would be driven perhaps 100 or 150 yards (100 or 150 metres) on each side of the shaft; this would come to the same thing as arranging the shafts from 200 to 300 yards (200 to 300 metres) apart, along the line of greatest dip.

On the contrary, with shafts that are very deep and expensive, either on account of the depth itself or from their traversing very watery strata, the crosscuts may very well be extended to 500, 600 or even 1000 yards (500, 600 or 1000 metres) and more; this would be the same as making the shafts 2000 yards (2000 metres) apart on the line of dip.

It may be said that everything is tending to increase this distance.

It becomes more expensive to sink the shafts, not only because they have to be deeper, as has just been said, but also because they have to be provided with more and more powerful machinery.

A larger daily output is required of them in proportion to the increased engine power, and a further extension of the working places thus becomes necessary.

It must also be remarked that, so long as the mine is provided with proper ventilating power, long crosscuts do not offer any practical difficulties, and they do not greatly increase the cost of the mineral, provided that they are furnished with good tramways, worked by horses or mechanical means when circumstances permit it. The conveyance underground under such conditions can be carried out very economically, sometimes more cheaply than a similar amount of tramming at the surface, which would perhaps be necessary if it were thought desirable to bring the produce drawn from two different pits *to the same point* .

(**257**) It is evident that the same motives which induce us to make long crosscuts, may lead us to drive long levels in each deposit from the point where it is intersected by a crosscut.

The levels may be driven for only 50 yards (50 metres) on each side of the crosscut, or the shafts can be placed 100 yards (100 metres) apart along the line of strike, if they can be sunk and provided with machinery at a small cost.

The levels may be driven 500, 600 or even 1000 yards (500, 600 or 1000 metres) on each side, in the case of deep pits provided with expensive machinery. However, a difference must be made between crosscuts and levels, in this sense, that the latter cannot always be prolonged indefinitely. They are not always, in fact, driven through such firm ground as the crosscuts; and it often happens that it costs so much to keep these levels open and in proper repair beyond a certain time, that this circumstance puts a limit to their length.

Levels along the strike in many thin seams in weak ground, such as that often met with in the Coal Measures of the North of France and Belgium, thus become very difficult and expensive to keep in repair, when they attain a length of 300 to 400 yards (300 to 400 metres) from the crosscuts.

In this case, if it has been found expedient to place the shafts more than 600 or 800 yards (600 to 800 metres) apart along the strike, the result is that the repairs are very costly, when it is desired, as it always should be theoretically, to avoid leaving any pillar between the two sets of workings which might have to be sacrificed at the end.

When the various seams are sufficiently near one another and when one of them, from its thickness and roof, is suitable for making a good tramway, we can avail ourselves of these circumstances in order to drive the levels much further. This is effected as follows : When the distance driven in the different seams is so great that it becomes difficult to keep the levels in repair, *they are shut up*, or *rather they are no longer kept in repair*, for a given distance, save in the one special seam ; here, on the contrary, for the same distance a good tramway is established, worked either by horses or machinery. It serves for all the seams, and its far end is connected with the seams by a crosscut, beyond which the levels are carried on and kept in repair.

The same artifice may be employed over and over again, and the intervals will diminish in proportion as the seams are nearer one another and the levels more difficult to keep in repair.

(**258**) The above details answer the first two questions asked in No. **256**, and it is evident that the questions cannot be answered very precisely, because, according to circumstances, the horizontal dimensions of the working area from one shaft may *very reasonably* vary from 200 to 2000 yards (200 to 2000 metres) along the dip, and from 100 to 1200 or 2000 yards (100 to 1200 or 2000 metres) along the strike, or from an area of a few acres to more than a square mile (several hectares to several square kilometres).

As to depth, there is theoretically no other limit than the depth to which the deposits extend. The longer mining goes on at any place, the greater does the depth become; and the smaller the horizontal extent of the deposit, the more rapidly will the workings be deepened.

At the beginning of this century, few coal mines were more than three or four hundred yards deep; at the present day, in some coalfields which have been at work for a long time — at Charleroi especially — there are pits of 800 to 1000 yards in depth. Some metalliferous mines have reached and exceeded these depths, and one is very nearly 1100 yards deep. As will be stated further on, there is apparently no radical difficulty, either as regards ventilation and temperature, or as regards machinery for pumping and winding, in penetrating much beyond the above limits. It may be said, in fact, that we are far from having attained the limit at which the treasures buried in the earth's crust will cease to be within the reach of human skill, on account of lying too deep or being at too high a temperature.

A working area of limited extent, which sufficed when the mine was shallow, may become insufficient when a great depth has been reached, requiring much more plant and more powerful machinery.

This explains how one is induced, in a coalfield where it was easy at first to have a great many pits, gradually to diminish their number as the depth increases, concentrating the winding upon those that are left.

For the last thirty years this principle of concentration has been seen to prevail in many coalfields, and the number of pits has grown smaller as the depth became greater, without any reduction, or even with a considerable increase, in the output of a given area.

Thirty or forty years ago people were satisfied with 100 tons per day or even less from a single shaft.

Nowadays, there is no pit well provided with machinery which does not produce at least 200 to 250; outputs of 350 to 500 are not rare with new plant, and some pits are intended to reach, and indeed have reached, 700 and even 900 tons per day.

In order to be able to keep up these large outputs regularly, it is necessary to make use of all the resources afforded by the art of mining in its present state: that is to say, to erect ventilating and winding machinery on the largest scale, to retain the power of extending the working area considerably, by making good tramways on which the coal is drawn either by horses or mechanically, to increase the rate of driving and sinking by the use of machinery, etc.

A mine laid out in this way compared with a mine of less than a century ago, stands in about the same relative position as a large engineering workshop, furnished with improved machine-tools, when compared with a workshop where everything is done by hand.

(**259**) We shall suppose that the working area has been settled and divided into stories of a certain vertical height, each of which corresponds to a set of preparatory workings and is usually designated by a number, or by the depth of the corresponding hanging-on place, or *plat*, from the surface or from some horizontal plane. We must now consider that each story or horizon will give rise to as many distinct and more or less simultaneous workings as there are deposits, and each deposit to as many successive workings as there are stories

This arrangement of workings allows us to examine the two last questions put in No. **254**.

Theoretically, the different deposits should be worked *in descending order*, that is to say, *those near the surface before those lower down.*

This rule is founded on the fact that all workings, even in thin seams where the empty spaces are carefully stowed up, necessarily produce movements and more or less important dislocations above them; and these may cause great difficulty in keeping the levels open in an overlying deposit, and give rise to a greater proportion of smalls when the seam is worked away.

This is the *purely theoretical* rule. In practice, however, provided that the lower workings have been properly stowed, and that the higher deposit is not thick and sufficiently far above the lower one, say 15 or 20 yards, it will only undergo a general movement due to the sinking of the intervening strata; for, as the stowing becomes compressed, each bed separates in succession from the one above and settles down on the one below. This general settlement causes very little breaking up, and may even facilitate the removal of seams which were originally firmly bound to the roof and floor.

In this manner, the above theoretical rule, which must be observed in the case of thick deposits, close to one another and worked by letting the roof crush in, becomes *less and less obligatory*, as the deposits are thinner and more distant, and as fewer movements of the roof are produced in the workings.

A time arrives, therefore, when we are at liberty to follow either order, and arrange the workings to suit commercial considerations; indeed, as has been just said, we may be led by technical considerations to follow the ascending order, the reverse of that laid down by the above rule.

This rule, moreover, must never be understood to mean that the workings in the lower seams should be postponed, in some measure, indefinitely. It means only that the workings should be carried on, so that the movements of the ground resulting from them, should be felt only *in a region where the upper deposit has already been removed.*

The application of this rule presupposes that the limits of this region can be determined exactly.

This cannot always be done in a very precise manner with thick deposits, worked by letting the roof crush in, as this method produces dislocations, or crushes, which often become apparent even at the surface by irregular subsidences of the ground.

In the numerous instances, however, when the old workings are filled up or stowed, the subsidences take place gradually upon the stowing, without producing violent dislocations or bending the strata.

If, therefore, we suppose that the dip and strike are uniform throughout the ground, the subsidences at each moment are limited to a cylindrical mass above the seam, having as its base the part of the underlying deposit that has been stowed.

The geometrical condition to be fulfilled in applying the theoretical rule is, therefore, this, that when this cylinder is prolonged to the deposit above, it should only meet with places already worked away.

(**260**) As to the order to be followed in the different stories of the same deposit, the opinion has been expressed that the ascending order should be adopted; firstly, because in going down first of all to a great depth any movements of the ground would not be felt at all at the surface, or only slightly; secondly, because this plan prevents water from finding its way into the workings as soon as it would do otherwise, and thus puts off the day when a special pumping machine becomes indispensable; and lastly, because, as the workings gradually rise, the water could be allowed to fill up the abandoned parts, without requiring to be pumped up.

We think, however, that these reasons are quite insufficient to justify a theoretical idea which is in no wise confirmed by practice.

From an economic point of view, it is evident that the extra expense, and especially the loss of time, that would be caused by the necessity of sinking down at once to a very great depth, perhaps in ground but little known, would more than outweigh the petty advantages, true or supposed, stated above.

We will add that the system is not to be recommended in a technical any more than in an economic point of view. The most that can be said in its favour is that, if a deposit is thin and in a nearly horizontal position, *it is a matter of indifference* whether the workings are begun above or below; but, as the thickness and dip increase, the necessity for taking the stories *in descending order* becomes more and more imperative. The reason for this is analogous to that which makes it necessary to work away the upper deposits before those that underlie them, that is to say, in order that the movements resulting from the present workings may not affect any places save those where the mineral has already been removed.

Thus, finally, the general rule ought to be *the descending order*, both for *the different stories or horizons of one and the same deposit* and for *the different deposits of the same horizon.*

Such in our opinion are the answers to be made to the four questions asked above (No. **256**).

(**261**) Summing up what has just been said, we see what are the considerations by which the limits of the working area belonging to a given centre of production are fixed; how this indefinite working area, unlimited at all events in depth, is subdivided into horizons or stories by a series of preparatory works carried out successively at different levels; and lastly, what order ought generally to be followed, either in working the different parallel deposits intersected by these preparatory works, or in working the different horizons of the same deposit.

It remains be seen how we should proceed to work one of these stories of a given deposit, and now, for the first time, we come to the question of the *Method of exploitation*, *removal* or *working away*, applicable to this deposit.

The methods of removal, contrary to what is the case in the works of first establishment and the preparatory works, depend, up to a certain point, on the nature of the deposit, and essentially upon its geometrical characters, especially its thickness and dip.

The different methods must be described in detail; because the choice, for a given deposit, and the proper and skilful application of the method chosen, are some of the most essential subjects which an engineer has to consider.

Although a great variety of methods are employed, as will be seen further on, some general remarks may be made concerning them.

(**262**) Where a deposit is sufficiently developed to be workable, *one at least of its dimensions* is always very great, or may be looked upon as pratically unlimited.

Of the two others, one *at least* is considerable, even in the case of a mass; and it is practically unlimited, like the first, in the case of a bed or lode.

In both cases we must imagine, as a rule, that if the substance of the deposit were *completely* removed, an extensive open space would be left in the ground, which could not remain in that condition.

If, therefore, the deposit is completely removed it will be necessary either to let the roof fall in, and fill up the empty space, or else to substitute a stowing for the substance worked away. Stuff for filling up, or stowing, may be obtained by picking out the sterile parts of the deposit, or taking it from some other point either at the surface or underground.

If it is necessary, or expedient, to prevent the roof from falling in and if there is no stuff for stowing at hand, or if the mineral is not valuable enough to pay the expense of stowing, it can only be partially removed. All that is done, in such a case, is to drive various sets of levels through the mass of the deposit leaving pillars between them, which are cut through as often as is thought possible without bringing about a general caving in.

There are thus three very distinct kinds of workings : —

Methods *by stowing*, in which all the deposit is removed and all the spaces left by the workings are afterwards packed full of stuff.

Methods by *pillar work*, in which after the deposit has been cut up by a network of galleries, the pillars which were originally left between the galleries are removed as far as possible whilst the roof is allowed to fall in behind.

Lastly, methods *by pillars and chambers*, in which the workings are considered as finished when the network of galleries is completed.

(**263**) The great characteristic of the methods by stowing is that it allows as complete a removal of the useful part of the deposit as could be wished, without causing any serious disturbance of the enclosing rocks.

The methods by pillar work have, theoretically, the same advantage as the filling-up methods, as far as the complete removal of the deposit is concerned; *but, in practice*, there is always a certain waste either in the quantity or quality of the substance obtained;

and the thicker the deposits are, the more marked is this waste. Besides, the movements of the ground, instead of being mere general subsidences, as they are when the empty spaces are properly stowed, become true dislocations, which increase in amount with the thickness of the deposit, and may depreciate the value of the surface, shake or destroy buildings, favour the infiltration of water into the workings, etc.

The method by pillars and chambers does not, theoretically, produce any movement of the ground, if, as is not always the case, a sufficient amount of moderation has been shown in driving the levels; but their great inconvenience is that of sacrificing a very large part, generally at least one-fourth and sometimes one-half or more, of the useful part of the deposit.

This inconvenience is so great that this method, *formerly a good deal in vogue*, is nowadays being gradually *abandoned everywhere.* It would be justifiable economically only if the merchantable value of the part sacrificed was less than the expense that would have to be incurred, firstly for breaking it down, and secondly for the stowing rendered necessary by its removal, or if it were insufficient to pay compensation for damages to the surface and extra cost of pumping, which would result if the mineral were worked away entirely.

This is an enquiry that has to be made in each case; and, except in the case of substances of little value, it will generally be found that the result of the enquiry is favourable to the employment of a method which allows the complete removal of the deposit.

(**264**) From what has just been said, it is evident, firstly, that from a technical point of view, the methods by stowing are preferable to the others, and that their superiority is all the more marked as the deposit increases in thickness and in value per cubic yard; secondly, that the methods of the second class, or pillar work, which are very applicable to deposits of moderate thickness situated at great depths, and perhaps in such cases more economical than the filling-up methods, lose their advantages when applied to thicker deposits, nearer the surface and under land of great value, or covered with dwellings, or so placed as to expose the mine to the danger of being flooded; thirdly and lastly, that the methods of the third class, imperfect in a technical point of view, are only applicable to substances of little value, or to cases where it would be impossible to obtain stuff for filling up, or to employ pillar work at any reasonable cost.

(**265**) To whatever the class proposed mode of working a given deposit may belong, endeavours should be made in applying it to satisfy, as far as possible, the following several conditions:—

1. To facilitate the breaking down in every possible way. This is done, in accordance the ideas expressed in Chapter III, by making the working places *as large*, and the holing *as deep* as possible. by adopting an arrangement of stopes which always leaves the mass to be broken down free on more than one face, etc., etc.

2. To reduce to a minimum the length and cost of the galleries that have to be kept in a regular state of repair. This result will be attained by keeping them open only just large enough for the uses for which they are intended, and, as the work proceeds, by doing away with all those that are not absolutely necessary for haulage or ventilation.

5. To render the superintendence and ventilation more easy by concentrating the workmen as much as possible in one place, instead of spreading them through all the parts of a story that is being worked. Consequently, the levels should be driven as soon as the attack of a district, or *panel*, is begun, the pillars should be worked off pretty quickly after the drivages have been made, and only such passages kept open as are strictly necessary for extending beyond this district.

This course will also have the advantage of improving the quality of the product obtained, since there is not sufficient time for the pillars to be crushed, as they would be if the pressure of the roof were allowed to act for some time over a large area.

4. To combine the working away of a story with its own preparatory works, or those of a lower story, so that when it is nearly worked out, or when its working is temporarily stopped by some

accident, such as meeting with a fault for instance, there may always be some other working places prepared, at this or a lower level, to receive the workmen. The object of this arrangement is to insure a regular and nearly constant output, and, at the same time, to preserve a certain margin for making it vary according to the demand.

(**266**) Such are the principal general considerations which we think should be brought forward in this place.

We do not yet make any mention of the arrangements to be made for underground transport, raising the mineral, ventilation or pumping. These subjects will be treated in their turn; moreover, these various operations depend upon principles and are performed by the aid of appliances which have no direct relation with the methods of working which engage our attention at present.

We shall treat the methods of working, first of all, in a general way, considering in succession a certain number of types illustrating the most important cases met with in practice, and we shall dwell upon the most essential conditions which may influence the choice of a method and the details of its application.

The most important of these conditions are :—

The thickness and the dip of the deposit, the presence or absence in the deposit of sterile substances that can be used for stowing, the greater or less solidity of the deposit itself and of the enclosing rocks especially the roof, lastly the manner, in which the useful substance is distributed throughout the extent of the deposit under consideration, which is sometimes nearly regular and uniform, sometimes essentially variable and discontinuous.

CHAPTER XI.

DESCRIPTION OF THE PRINCIPAL METHODS OF EXPLOITATION, OR THE WORKING AWAY OF MINERAL.

267. The establishment of a thoroughly complete centre of production for working a deposit or series of deposits requires, firstly, the *winning*, or the execution of a set of underground works which communicate with the surface by two orifices and are carried on to intersect the deposits in depth; and, secondly, the erection of suitable machinery for extracting the mineral as well as for the subdiary services such as pumping, ventilation, and the like.

To this centre of production is assigned a more or less extensive boundary corresponding to the importance of the winning, the capabilities of the plant and the magnitude of the proposed output; this is called its *working area;* it is indefinite vertically and is divided into as many subordinate working areas as there are deposits within the boundary.

The *winning* is followed by a series of *preparatory workings* at different levels; these divide the working area into a number of superposed tiers or stories, which are prepared and worked away one after the other, generally in *descending order.*

The above course is pursued in all cases; and one mine does not differ from another save in the extent of its working area and the vertical height of the different stories.

It is only when we come to the remunerative working of a story, *and not before*, that we have to raise the question as to the *method of exploitation* or *working away* to be adopted; that is to say, the manner in which the work should be carried out, due attention being paid to the various conditions presented by the deposit under consideration, as regards its composition and nature.

We shall proceed to describe the methods that are applicable to the most important cases which may present themselves in practice, and in doing so we shall have occasion to refer to the general remarks made in the preceding Chapter.

We shall consider in succession the methods which are suitable for deposits formed more or less after the manner of veins, and those which are more particularly fitted for deposits occurring in the form of beds, and solely, or principally, of sedimentary origin.

Although based upon the same general principles, these methods admit of certain variations in their mode of application, on account of the difference in origin of the deposits; and it is of importance that we should point out how these variations may occur.

§ 1. — Methods of working suitable for lodes or deposits of a similar origin.

(**268**) The most marked characteristic of these deposits, which is a consequence of the usually complex nature of their contents, is the fact, that the useful mineral is often more or less intermixed with, or enclosed in, sterile mineral, called veinstone or gangue.

Although the whole of the deposit may require to be worked away, the greater part of it need not in many cases be taken to the surface; and, in consequence of the increase in bulk due to its being broken up, it may more than suffice to fill up the empty space (*gunniss*, Cornwall).

The methods applied to deposits of this kind may frequently be classed among the methods of working with filling-up. They differ according to the width of the deposits.

We shall now consider a few special cases.

(**269**) FIRST CASE. — **Methods of working away narrow metal-**

liferous veins or lodes. — We understand by *narrow*, widths which do not exceed (save perhaps in a few accidental swellings) the maximum width of an ordinary mine level, say 6 ft. 6 in. to 8 ft. (2 metres to $2^{m}\cdot50$).

The width of these deposits will vary therefore from nothing, where they are pinched, nipped, or squeezed up, to 6 ft. 6 in. or 8 ft. in the widest places.

The characteristics of a mineral vein, or lode, as we have seen in Chapter I are : — a considerable dip, usually nearer the vertical than the horizontal; the presence of sterile mineral, usually sufficing and often more than sufficing to fill up the cavities produced by the excavations; regular walls and generally a solid filling-up; lastly, irregularity and discontinuity of the useful mineral which accompanies the sterile substances.

For working a deposit of this kind, we may have either a vertical shaft communicating with the lode by crosscuts at intervals of 8, 11, 14, or at most 16 fathoms (15, 20, 25 or 30 metres), or an inclined shaft which also serves to explore the lode in depth in proportion as it is extended downwards.

The lode is divided by a series of galleries at various levels, and by series of intermediate shafts (*winzes*) from one gallery to another, into rectangular blocks 8 to 16 fathoms (15 to 30 metres) high by 14, 16, 22, 27 or more fathoms (25, 30, 40 or 50 metres) along the strike.

The object of these levels and winzes is both to begin to work away the lode, and also to ascertain its nature and value at different points.

The length and height of the blocks will have to be diminished in proportion as the richer parts are disseminated more irregularly in the plane of the deposit.

This cutting up into blocks (shown in fig. 4) is carried on along the strike until either the boundary of the working area (*sett*) or the end of the deposit is reached. In depth there is no limit whatever; new levels are driven off each time that the lode is intersected by a new crosscut, and fresh winzes are sunk as the levels are lengthened.

The best plan is not to lay dow any rule for sinking these winzes at constant distances apart, but to sink them in the rich parts of the lode, in order that the mineral obtained may pay a portion of the cost of sinking, and also that they may serve the purpose of exploring the different shoots of ore.

A number of blocks, or rectangular pillars, are thus left after the driving and sinking have been completed, each being bounded by two levels and two winzes.

The principal part of the exploitation consists in removing such blocks as appear to be workable, without adhering to any particular order; in fact, the workings may be arranged either so as to ensure a regular output, or to suit it to a varying demand.

A mine cannot be said to be well laid out unless it has reserve blocks already cut out by levels and winzes, sufficient to ensure the regular output for several months, or even several years.

The difference between the two methods of exploitation practised in vein mining depends on the manner in which the blocks are removed; they are called respectively the method by *overhand stopes* and the method by *underhand stopes*.

(**270**) The method by *overhand stopes* consists in beginning the removal of a block at one of its *lower corners*.

Starting from the winze that bounds the block, a horizontal slice 4 ft., 5 ft. or 6 ft. 6 in. ($1^{m}\cdot30$, $1^{m}\cdot50$ or 2 metres) high is taken off, raising the height of the level, of course, by the same amount. The mineral broken down falls on the floor of the level, where it is picked; the sterile rubbish (*attle* or *deads*) is placed upon a firm timber stage (*stull*), or arch of masonry, which is made at the height formerly occupied by the top (*back*) of the level, and the useful mineral is carried away.

When the first *stope* has been advanced a fathom or two, a second is commenced at the side of the winze immediately above the first. The stuff broken down falls upon the attle of the first stope where it is picked; the deads are left there and the ore is thrown into the level. In course of time a third stope is commenced above the second and so on.

The block is therefore removed by a series of superposed slices parallel to the strike.

When the work has proceeded for some time in this manner, we have a series of working places each one a little behind the other, which looks like the *steps* of a staircase seen from below; hence the term *overhand stopes*. The rubbish (*attle*) under the workings forms a set of more or less clear steps like a staircase seen from above. The ore broken down from any stope falls on the rubbish of the preceding ones, and is thrown down from one stope to another, and finally from the bottom one into the level.

The stopes are carried on till they reach the winze that bounds the other side of the block; and the working away of the block is completed when the uppermost stope has been removed.

The block of lode is thus replaced by a block of deads occupying the same space; the levels and winzes that surrounded it are kept open when necessary.

The top (*back*) of the lower level is formed by the timber *stull* or arch of masonry, which carries the deads, and the bottom, or floor, of the upper level is formed by the top of these deads; the winzes are now kept open by props (*rearings*) and a lining of laths, at the ends of the pile of deads and along the lines occupied by the sides of the block of vein before the stoping commenced.

The mode of working just described usually admits of a slight variation which does not modify the principle, but considerably facilitates the work of transmitting the ore into the level beneath. It is represented in figure 205 at A, and consists in making little shafts (*mills* or *passes*) at short intervals in the midst of the deads; they begin at the top of the level and are built up gradually as the height of the pile of deads increases.

These *mills* are so placed that the miners have not to go up or down more than one or two stopes before finding a place where they can get rid of their ore. Sometimes the ore is allowed to fall directly into the level; but more often the lower end of the mill is closed by a door and the mill is kept nearly full; by opening this door the trammers can fill their waggons without trouble.

(**271**) The method of working by underhand stopes is shown in figure 205 at B; it consists in beginning the removal of the block at one of its *upper angles*.

A first stope is taken off the floor of the upper level to a depth of 3 to 5 ft. (1 metre to $1^{m}\cdot 50$.) After the first stope has advanced far enough a second stope is begun behind it, and so on.

The deads which remain after the ore has been picked out are thrown backwards on to stages (*stulls*), one of which is generally put up for every stope.

When in full operation the series of working places resembles the steps of a staircase seen from above, and the stulls on which the deads are piled up look like a staircase seen from below. The arrangement is in fact just the reverse of *overhand stoping*.

A few roadways which are maintained in the midst of the deads serve for conveying the ore to the winze, through which it is either thrown into the lower level or drawn up by means of a windlass (*tackle* or *turn-tree*) into the level above.

(**272**) Fig. 206, A and B, represents a variation which may be applied to either method of stoping; it consists in beginning the work without having previously sunk a winze. Overhand stopes are started by a *rise*, underhand stopes by a *sink;* and each time that a portion has been *risen* or *sunk* the height of a stope, new working places are commenced to the right and left hand.

The stopes gradually extend on both sides from the rise or sink, forming two wings which resemble an inverted fan in the case of *overhand stopes*, or a fan in the ordinary position in the case of *underhand stopes*.

(**273**) The two above-described methods, with a few variations which do not affect the principle, are *universally adopted*, and it is everywhere admitted that they fulfil, in a satisfactory manner, all the requirements of a good method of working away ore.

In the first place, they belong to the class of methods of working with filling up, one of the characteristics of which is that the entire mass of the deposit may be removed.

The breaking down of the ore is facilitated by the working places being arranged in stopes; the filling up can be done economically with materials obtained on the spot; only useful substances need be conveyed underground through the levels and shafts; a block can be removed very rapidly by putting on a number of workmen who can be easily superintended; there is no necessity for maintaining any other levels and winzes than those actually required for underground conveyance and ventilation. Finally, the preparatory workings, the driving of levels, sinking of winzes and the stoping away of the ore, can follow one another without intermission, and can be carried out with more or less activity, as may seem desirable, so as to ensure a regular output, as far at least as the richness of the lode admits.

(**274**) In spite of these advantages which are *common to both methods*, the choice between them is by no means a matter of indifference, and it is therefore necessary that we should point out clearly the special peculiarities of each.

If we take *the amount of timber used* as a criterion, the comparison is entirely in favour of overhand stopes, since these only require one long stull for the removal of an entire block; whilst with underhand stopes as many, or almost as many, stulls are required as there are stopes in the block. The advantage of overhand stopes becomes more and more apparent as the price of timber is higher, the width of lodes greater and the solidity of the walls less, because all these three conditions augment the cost of a single stull very considerably, and *à fortiori* the total expense which would be incurred if underhand stopes were used for removing an entire block.

This increase of expenditure is so great that no one would think of stoping underhand, any portions of the lode which exceeded 6 ft. 6 in. to 8 ft. (2 metres to $2^{m}\cdot50$) in width, the limit which we have already mentioned, even in a mine where this method was applied elsewhere.

Overhand stopes, on the other hand, may be used for working the wide parts of lodes, provided that the stuff is sufficiently strong to admit of the working face being carried the full width of the deposit. In other words, there is *an absolute limit* to the width of a lode that can be worked with underhand stopes, say for instance 8 ft., whilst the width that can be given to overhand stopes *depends on the solidity of the deposit.* This width may reach 5 fathoms (10 metres), if the one *necessary and sufficient* condition is fulfilled, that the deposit is strong enough to admit of the working face being carried 5 fathoms wide.

This does not imply that the stull must be 5 fathoms (10 metres) wide, because it would then require a huge frame-work of timber; on the contrary the deads are piled up on one or both sides, and a level of ordinary width is left on the footwall of the lode or in the middle of the deads. Cap-pieces forming the roof of the level support the deads above them and vertical *mills* are left opening into the levels. Fig. 207 shows a section of this system.

An advantage is claimed for overhand stopes over underhand stopes because they afford *greater facilities for breaking down the stuff, for stowing away the deads and for conveying the ore to the levels.*

They are considered also to be safer for the miners, where the walls are bad and do not allow the stulls carrying deads to be as firmly fixed as would be desirable.

(**275**) The above remarks are evidently all in favour of overhand stopes; and, in fact, this method is pursued in an immense majority of cases.

There are only two circumstances which can render the adoption of the opposite method desirable : — Firstly, when the substance of the deposit is weak, as in the case of what is called *a rotten lode;* secondly, when the lode contains very valuable ores, such as silver ores, especially those that are soft and friable, like Ruby silver for instance.

The first condition, viz., the necessity of having a proper degree of solidity, where a lode is to be stoped away overhand, explains itself at once, as it involves the safety of the men employed.

The expediency of working away very valuable ores by underhand stopes, is a consequence of the different manner in which the stuff is broken down and the deads stowed away in the two cases.

This point requires some further explanation. With overhand stopes, the stuff broken down falls upon a floor formed of the deads of a lower stope, and much fine ore and many small fragments would be entirely lost in the interstices, since the deads are not handled over again. Larger fragments even might be left where they had fallen without being sufficiently examined and picked over, if the workmen were negligent.

With underhand stopes, on the contrary, the stuff, as it is broken down, falls upon parts of the deposit which are still intact; and the stope cannot advance without all this stuff passing through the miner's hands. No fragment can escape his attention; and it can only be through intentional negligence or spite on his part that any piece of ore, or piece likely to show ore on being broken, can be thrown among the refuse.

This, therefore, is the *essential and characteristic* difference between the two methods of working that we are comparing.

The field for overhand stopes may therefore be extended, if precautions are taken to diminish their inferiority from the point of view just mentioned.

For this purpose, the miners must be strictly compelled to level the surface of the deads carefully when any ore is going to be broken down upon them, and to cover over the surface with boards so as to keep the stuff free from rubbish; the workmen must also be made to lift up and pick over with care everything that has fallen down, to break open any fragments likely to contain ore, and finally to pile up the deads in a regular manner, so that they form a series of well defined steps.

If care is not taken to have all these operations carried out, if, for instance, the deads behind the stopes are allowed to form an irregular heap terminated by an uneven talus, it is very certain that a *considerable* part of the useful ore is lost in the rubbish, either in the form of imperfectly picked fragments or as smalls scattered through the mass.

This last cause of loss deserves special consideration, as the ores are usually more friable than the veinstone. Losses arising in this manner may be of much importance, as the expenses of working are just the same whether they occur or not.

The additional output obtained by stowing the deads regularly, picking over the stuff carefully and breaking off rich bits of ore from lumps of refuse, must not be despised, for it is, so to say, a *net gain*. In some cases it may constitute the entire profit of the mine.

When local customs admit of it, it is very useful to remunerate the miners who are stoping away ore, not per fathom stoped, but by the quantity of ore rendered marketable, or better still by the quantity of metal contained in the dressed ore.

This system (*tribute*) is commonly practised in some parts of England, where the different working places (*pitches*) are put up to auction from time to time, and let out to gangs (*pares*) of miners who undertake the working at their own risk and peril.

This practice is undoubtedly the cause of the superior activity, intelligence and skill exhibited by the miners in the metalliferous districts where it is in vogue.

If it cannot be applied in its complete form everywhere, it is advisable that, in some form or other, part of the miner's pay should increase with the quantity of ore obtained. We consider this *indispensable*, because the precautionary measures spoken of above, involve *an additional amount of trouble which the miners would not take*, unless interested in the result, even if subjected to constant supervision which is practically impossible.

(**276**) SECOND CASE. — **Methods of working away wide veins and masses.** — We will now take the case of deposits exhibiting the same general characters as the lodes treated in the preceding example, save that their width exceeds 8 ft. ($2^{m}\cdot50$), or, more exactly, is *greater than the width that can safely be given to the working places, on account of weakness of the walls.*

We have seen that underhand slopes become unsuitable *as soon as the width of the lode exceeds 6 ft. 6 in to 8 ft.* (2 metres to 2^{m}·50), and that overhand slopes are also unfit *as soon as the strength of the contents of the lode is insufficient compared with its width, whatever that may be.*

In this last case the levels cannot be driven the whole width of the lode; they are then made either in the middle of the deposit, or on the footwall or hanging wall side, according as one of these positions offers the greatest amount of security.

The remaining width of the deposit is usually removed by working across it from one wall to the other, hence the term *crosscut method* which is applied to the system adopted for these wide deposits.

In a general way, this method consists in subdividing a block between two levels into a series of superposed slices, each of about the same height as an ordinary level, or 6 ft. 6 in. (2 metres), and then removing these slices in ascending order by a series of drivages. The width that can be given to these drivages is governed by the strength of the deposit, whilst their direction is chosen so as to be most favourable for breaking down the mineral.

When one set of drivages has been completed and packed with rubbish, another set is driven and then filled up in a similar manner, and so on, until at last the whole of the slice has been removed wherever it is workable, and replaced by a continuous mass of stowing.

The top of the original level is then stripped away and the next slice is removed as before with the filling-up instead of solid mineral as a floor. This difference *renders the breaking down somewhat more easy*, as it allows the stuff to be undercut, but it *causes more difficulty in supporting the ground*, because the floor is not perfectly firm and the mass of the deposit is somewhat shaken from sinking down slightly on the stowing.

As soon as the second slice has been removed, a third is taken and so on to the last; this is stripped off under the deads of the first slice of an upper block already worked away.

If these deads are old and have had time to settle down thoroughly, they are often as firm as, and sometimes even firmer than the lode itself; in this case the slice immediately under them can be removed without any special arrangements; the working faces may perhaps be reduced a little in width and a little more precaution taken in timbering.

In other cases, absolute contact with these deads is avoided by leaving a solid roof (an *arch of ground*) about 3 ft. (1 metre) thick; part of this may be stripped off in going back, after a drivage has been completed.

Just as in the case of overhand stopes, the ore is thrown down through *passes* into the level which is kept up in the midst of the deads.

(**277**) In working a regular lode, the principal levels may be on the footwall side and connected with one another by a small number of winzes, the chief object of which is to ensure proper ventilation.

The block between two levels is removed as follows : — A first series of crosscuts about 6 ft. 6 in. (2 metres) wide are driven out from the main level (fig. 208) leaving pillars 19 ½ ft. (6 metres) wide between them; the crosscuts are timbered as found necessary and are carried on to the hanging wall. When this is reached they have to be completely filled up with refuse, obtained in picking over the stuff, and the timber is withdrawn as far as the nature of the ground allows it. In order to keep back the deads from the level, the mouth of the crosscut is finally blocked up by a good pack-wall, made of the best pieces of rock that have been picked out.

The next thing to be done is to drive a crosscut along the middle of each pillar. When these crosscuts are completed half of the slice will have been worked away.

The other half is obtained by a third series of cross drivages, the two sides of each being formed by the deads of the first and second sets of drivages. These different sets of crosscuts are distinguished by the numbers 1, 2 and 3 in fig. 208.

A second slice may then be taken, and it is not necessary that the first slice should be completely removed before the second is begun. As soon as several contiguous drivages have been properly stowed with deads in any part of the mine, the working away of the slice above may be begun in that part. In this way two, three or even more slices, according to the output required, may be worked away simultaneously in the same block or story.

A lower story may be even begun, before the removal of the upper one is completed. However, it is advisable to finish one block before removing very much of a lower one, so as to prevent any but a story that is completely worked away from feeling the successive subsidences of the contents of the lode on the deads; especially as the movement is generally considerable when the uppermost slice is removed, because this slice is rarely completely filled up.

In a word, the principle of taking the slices *in descending order* should be adhered to so far that the exploitation of an upper story should always be *in advance* of that of a lower one.

The effect of the successive subsidences of the lode on the deads, in the parts removed, is to limit the number of slices that can be taken in ascending order, or, in other words, *the vertical height* of the stories is limited. The height of each story should diminish in proportion as the nature of the deposit renders such subsidences prejudicial, either because they threaten the security of the drivages or reduce the quantity of large mineral that can be extracted.

Ten slices for each story, or a vertical height of 11 fathoms (20 metres) is not often exceeded.

(**278**) Large lodes, suited to the crosscut method of working, often have one or more branches, and consequently large masses of the enclosing rocks (*horses*) are found in their midst, so that some of the crosscuts starting from the footwall meet with these *horses* before reaching the true hanging wall. It would be useless to remove this sterile stuff; and, therefore, after a large *horse of ground* has been explored by a few crosscuts, these are driven on to the true hanging wall of the lode. Two distinct sets of workings are then started, one on the hanging wall, the other on the footwall side of the lode. (*See* fig. 209.)

(**279**) The crosscut method is also suitable when you have to deal with a more or less irregular mass, limited on all sides horizontally, instead of a regular lode. (Fig. 210, plan and section.)

In this case the level which serves as a base to any story is a closed curve, instead of extending indefinitely along the strike, and is called a *contour level.* Its object is not only for opening out the deposit previous to its removal, but also for ascertaining the shape and size of its horizontal section.

As soon as the contour level has been made, a drivage should be put through the mass in the direction of its greatest length, or two drivages at right angles to it, and then crosscuts may be started in the manner described above, so as to remove the whole slice by degrees and replace it by deads.

As already stated, the slices should be taken one after another in ascending order. One set of levels will do for all the slices, for *passes* can be built up as the deads rise, to effect a communication between the working places above and the level below.

(**280**) THIRD CASE. — **Methods of working away wide lodes or masses not containing a sufficient quantity of deads for filling-up.** — We have already stated (No. **267**) that deposits of vein-like origin *usually* furnish a sufficient quantity of deads for filling up the excavations, because rocks occupy a very much larger space when broken up ; we also remarked that it was useless to take these deads out of the mine, indeed that it was advantageous not to remove them, firstly, in order to avoid to extra cost of conveyance underground, and secondly, in order to derive the benefits obtained by using them for filling up, the principal of which is that the whole of the deposit may be worked away.

Though this is *usually* the case, it is not so *invariably*, and in some wide deposits the deads do not suffice to fill up the excavations.

Such deposits are chiefly those that have been formed at one time by a true eruption and are filled by a nearly homogeneous mass, whereas ordinary lodes or concretionary lodes, on the contrary, have been filled at various periods by crystalline products deposited successively from different solutions or vapours.

The structure of the first is massive and homogeneous, that of the second crystalline and heterogeneous.

When, therefore, we have a deposit furnishing a small proportion of deads, either because the ore is very pure, or because, on the contrary, it is so intimately mixed with the veinstone that it is impossible to pick it underground, the mode of working may still be a modification of the second example (No. **276**) *i. e.* the method by crosscuts.

All that is required is to make up for the insufficiency or absence of deads in the deposit by procuring a supply from elsewhere. By this simple expedient, the crosscut method becomes applicable, theoretically, to *all masses without exception no matter what quantity of deads they may furnish.* All the excavations must always be filled up, save the main levels and perhaps the last slices. *If the deposit affords too large a quantity* of refuse, the excess will have to be raised to the surface, if, on the contrary, *too little*, the deficiency will have to be made up from elsewhere.

Nothing further need be added as regards the details of carrying out the work. Later on we shall speak of the various methods of procuring deads either underground or at the surface.

(**281**) Side by side with the advantages of filling up, there is a serious inconvenience when the materials have to be obtained from anywhere save the deposit itself, viz., the expense of quarrying the stuff, conveying it underground and getting it to its place. It may happen, especially in the case of ores which have a small value at the pit's mouth, that it is impossible to procure stuff for filling up sufficiently cheaply to render its employment economically possible.

In this case the *filling up* method must be replaced by the method of *removing pillars and allowing the roof to fall in.*

We may proceed in the following manner : —

The deposit, divided as before into tiers or stories, is subdivided into horizontal slices, as in the crosscut method already described; but these slices, instead of being made simply as thick as the height of an ordinary mine level, may be taken very much thicker; besides which, instead of being removed in ascending order, they must be taken in descending order, like the stories themselves.

At the bottom of each slice a few drivages are made, either a main level on the footwall with a certain number of crosscuts going out to the hanging wall, or else the slice is cut up into pillars by two series of galleries at right angles to one another.

The principal object of these drivages is to obtain some output from the mine, before arriving at the principal period of working, *i. e.* when the pillars are stripped away (*robbed*).

A part of the mine is stripped by proceeding backwards, or towards the shaft and removing the different pillars in succession. First of all they are cut away for a height equal to that of the levels and then the part remaining above, or roof, is made to fall down. As much of it as possible is removed, but of course soon after it falls the old workings crush in also.

A slice is thus removed *almost completely* for a height of 6 ft. 6 in. (2 metres) or the height of the drivages, and *more or less incompletely* for the thickness of the roof, according to the skill of the workmen and the manner in which the old workings crush in.

Of course this method occasions a general subsidence of the ground, which makes itself evident by landslips and a general disturbance of the surface, as soon as a certain number of slices have been removed.

Against the expense of procuring refuse for filling up the excavations, we must put into the scales the consequences which these subsidences of the surface entail, such as indemnities to landowners and the premature infiltration of water into the workings, as well as the inconvenience of a less complete removal of the mineral and increased danger to the miners.

It is not necessary to wait till one slice is removed, before beginning to strip the slice below. Levels may be driven through the lower slice while the one above is being stripped, and drivages may be begun in a third before they are finished in the second; but no stripping of one slice can be carried out till the slice above has been entirely worked away.

Fig. 211 shows a longitudinal and a transverse section of this method of working.

A few inclined galleries, or winzes, serve to convey the produce of any slice to the main level. These *passes* must be strongly covered over on the top when the stripping begins overhead, so that they may be kept open for working the next slice.

(**282**) This second method, which may be called the *crosscut method combined with removing pillars*, to distinguish it from the first or *crosscut method with filling up*, is varied in practice in several ways, which depend principally on the solidity or coherence of the deposit.

The width of the drivages and of the working faces during the stripping may be increased as the deposit becomes more and more solid.

The thickness of the roof will depend upon local circumstances. The greater this thickness can be made the more economical will the exploitation become; but at the same time the work may be less safe for the miners and cause a large quantity of ore to be wasted.

As extreme examples we may cite that in very solid deposits requiring no timber, slices are taken 5 fathoms (10 metres) thick, the drivages being carried to the very unusual height of 20 to 23 ft. (6 to 7 metres), and the roof being 13 to 10 ft. (4 to 3 metres) thick; whereas in deposits of a marly or clayey nature the slices are made only 6 ft. 6 in. to 8 ft. (2 metres to $2^{m}\cdot50$) thick, or simply the height of the galleries. In this last case the roof is reduced to nothing, as the deposit itself is not stronger than the filling-up of the slice above, even if this stowage has not had time enough to settle down and become packed together.

We shall see further on how the stripping may be carried on in a slice under workings that have crushed in, when a more or less thick roof is left between the old and the new workings.

(**283**) Lastly, in the case of a deposit which does not furnish any deads for stowage and will not bear the cost of their being procured specially, and where it is impossible to use the stripping method just described, the only plan is to divide each tier or story into several slices and drive galleries at the bottom of each slice, leaving a solid roof between the top of the gallery and the bottom of the next slice. *The whole working away, or exploitation*, consists in driving these galleries.

In workings of this kind, the pillars and chambers of one slice should be made to correspond exactly in plan with those above and below, so as to make them secure; sometimes also, as the slices are taken lower and lower down, the section of the pillars and thickness of the roof is increased, whilst the width and height of the galleries separating the pillars are proportionately diminished.

This system of working, which is represented in fig. 212, may be called the *method by crosscuts with solid roof and floor*, to distinguish it from the method by crosscuts with filling up and the method of crosscuts with stripping. It was formerly much used for working away the upper parts of wide deposits.

It has happened more than once that, after having reached a certain depth, the workers became anxious to obtain some of the valuable material left behind, and with this object in view cut through the pillars, stripped (*robbed*) their sides or the roof of the galleries as far as appeared compatible with the safety of the mine; but they often went beyond this point and enormous crushes, or *cavings-in*, have been the result of such imprudent workings.

Nowadays this method may be looked upon as obsolete, and only applicable to substances of very small value and sufficiently abundant in nature to make the inevitable waste a matter of no importance. We believe, however, that *there is no metalliferous deposit in which such is the case.*

§ 2. — Methods of working applicable to deposits of sedimentary origin.

(284) The essential character of these deposits, or *seams* as they are called, is the simple nature and uniform distribution of the substances which form the object of the working; so that it is not usually necessary to ascertain by a system of preparatory drivages (*fore-winning*) in what manner the valuable mineral is distributed.

As a type of deposits of this kind we shall take seams of coal which are the most important; and we shall divide them into four classes, having regard both to their thickness considered alone, and to their thickness considered in connection with their dip.

(285) First case. — **Methods of working thin seams of coal.** — Under the name of *thin seams*, we shall include those whose thickness is less than the minimum height at which it is possible to keep the working-places, or, much less than the height of the *haulage-ways*, or *roadways*, which serve those working-places. This thickness may vary from 10 in. or 12 in. ($0^{m}\cdot27$, $0^{m}\cdot30$), (the lowest limit that has been reached in working coal, as far as we know) to 2 ft. 3 in., 2 ft. 7 in. ($0^{m}\cdot70$, $0^{m}\cdot80$) or a little more.

Under such circumstances, it is necessary to cut the roof or the floor, either along the whole face, or, at any rate, in the roadways; and the rubbish from this source, together with that produced by the partings of the seam when there are any present, furnishes sufficient materials for stowing, which is a prominent feature in the working of thin beds.

To this class we shall also refer those beds which, although not requiring the roof or floor to be cut, to make room for the miners, are yet worked with a filling-up, or stowing, derived principally from partings of sterile matter in the seam itself, from the fall of a false roof, from the enlargement of the roadways, or lastly, in case of need, brought from somewhere else.

The type of the system applicable in this case is the *long-wall* method of working.

This method, which is represented in plan in figure 213, consists in driving a level, or heading, along the strike of the seam from the point where the preparatory works have reached it, or in any direction, if the bed is nearly horizortal. This *main level*, *bottom level*, or *mothergate*, is formed by driving forward a *stall*, or *wall*, of sufficient width to giving stowing space for the refuse resulting from the cutting of the haulage-way and the return air-way; those two passages are made at the two opposite sides of the wall, or the former may be made through the middle of the stowing, while the latter is at the rise side.

After the heading has advanced far enough, a *face* is measured off along the return air-way and driven forward in a given direction; when it has farther advanced by an equal distance, a second face is taken similar to the first and driven in a parallel direction; after another advance, a third is taken, and so on.

The entire system of walls presents the appearance of a broken line, and recalls, except in scale, the arrangement of stopes made use of in working away lodes.

Each wall has an air-way at the right hand and left hand side, to insure the circulation of the air, which enters by the level and finds its way along the walls successively. Other galleries, made through the stowing serve each wall for haulage purposes, and lead into a common trunk which is a branch of the principal roadway.

The rubbish is thrown behind and employed for advancing the face of the stowing at a short distance in the rear of the working face; the blocks are picked out for the purpose of building the pack-walls which maintain the haulage-ways through the goaf (*gob*, *waste*).

The whole of the walls are advanced to the boundary assigned to the *panel*, or district of working; and when one wall has arrived at the limit, it is replaced by another setting out from the main level which has continued to advance.

The same process is carried on until the limits of the panel have been reached everywhere, both towards the strike and rise of the bed.

(**286**) If the seam is quite horizontal, or has a scarcely appreciable inclination (*pitch*), the direction of the principal gallery as well as of the walls, is quite arbitrary. They may then be cut in such a way as to render the process of breaking down the coal as easy as possible; and the faces can be advanced parallel to the cleat, that is to say, the principal road is made *parallel*, and the ordinary roads are made *at right angles* to the cleat.

If there is no distinct cleat, and the pitch of the seam is rather more decided, the principal galleries, and the walls, may be driven in a diagonal direction intermediate between the lines of strike and rise, the object being to give a favourable gradient for haulage.

When the pitch is still more pronounced, say from 15° to 20°, the idea of giving a favourable slope, both to the main haulage road and to the others, may be abandoned; for the inclination favourable to haulage then becomes sensibly parallel to the strike, and, consequently, the ordinary roadways would intersect the level at too acute an angle.

In this case, one of two systems may be followed : either the principal roadway may be made level while the others follow the line of greatest slope, the walls going straight to the rise ; or, on the contrary, the main roadway may be made on the line of greatest slope, while the ordinary roadsways follow the strike, and the faces of the walls are then parallel to the line of dip.

The haulage along the level roads is done by ordinary means, and on the rise headings by means of self-acting inclines.

(**287**) The choice between the two systems is by no means a matter of indifference. The haulage is least liable to interruptions when the ordinary methods of tramming are employed in the principal roadway; as it is not expedient to have the haulage along the levels and the extraction from the pit both dependent on one large self-acting incline which receives the mineral from a series of levels. It is, therefore, better to have the common roadways following the line of greatest pitch than to have them in the direction of the strike. They are then more easily kept in repair ; for, when it is necessary to cut the roof or the floor, a roadway following the line of greatest slope is less liable to have the sides falling in, than one along the strike, since the pack-walls on the rise side of the latter, and the *benches* of the roof or floor, are apt to slide or fall into the roadway under the action of gravity. Lastly, a roadway which opens into a wall going direct to the rise serves every part of the face better than one opening into a wall following the strike, as the workmen have less trouble in moving (*carting*) the coal along the face to the tram-waggon, or *tub*. Walls going towards the rise are therefore usually preferred.

(**288**) The dimensions of the walls are very variable. As we have mentioned in No. 285, the width of the leading wall is determined by the condition of the empty space being able to contain all the rubbish resulting from partings in the coal, from a false roof, or from cutting the roof and floor so as to make the necessary space for haulage and ventilation. In England, the extreme width is as much as 120 to 180 yards (100 to 150 metres) and more, in places where the seams are nearly horizontal, where the coal is produced in large solid pieces, and the roof is very good. Widths of this extent are favourable to supervision ; they facilitate the breaking down of the coal either by hand or with the aid of hewing machines ; the loading of the tubs is also more easily managed : for each wall is of sufficient importance to have a line of rails carried along the face, by which the tubs are brought to the fillers, and dragging out the coal in *sleds* or *boxes* (*carting*) is rendered unnecessary.

These great widths are not, however, applicable to thin seams which are friable and have a bad roof, and more especially, if they have a considerable pitch. Indeed, the last circumstances would make it difficult to keep in repair the network of roadways which should branch from a common trunk, and open upon a face of this extent, so as to facilitate the removal of the coal.

Between the superior limit of 170 to 180 yards, and an inferior one of 6 to 8 yards (6 to 8 metres), every intermediate dimension may be met with, *suitable to local conditions*. A very convenient system, often to be seen in operation, is to have all the walls working towards the rise, of a width of 16 to 18 yards (14 to 16 metres) and each served by a small self-acting incline. The incline is lengthened every two or three days as the wall advances.

(**289**) Arrangements can be made for limiting the length of the ordinary haulage roads as the workings become extensive. They are similar to those already indicated in No. 257 for curtailing the length of roads to be maintained in a number of parallel beds.

When there is a series of parallel roads (fig. 214), extending from the same level to a great distance towards the rise, a new level is made at a higher position, and by this means the parts of the ordinary roads comprised between the higher and the lower levels are cut off, with the exception of one or two which are turned into good self-acting inclines. Similarly, when the ordinary roadways are levels and have advanced to a certain distance from the self-acting incline, a new incline can be made nearer to the faces, and in this way the parts of the roadways between the new and old inclines are suppressed.

(**290**) Walls with their faces parallel to the face of the level are not applicable when the pitch is too great; and it may be said that the theoretical limit has been reached when the coal *will slide on the floor of its own accord;* the working then becomes difficult and dangerous for the workmen, especially in a wide face, and the tendency of the coal to slide towards the pack-wall and mix with the stowing makes the throwing out (*picking*) inconvenient. Walls of this kind are further unsatisfactory in beds in which fire-damp is given off either from the bed itself or from the goaf, for the fire-damp rises to the highest part in virtue of its lightness, and collects along the face, or, at the very point where most of the men are concentrated.

In a case of this kind, walls parallel to the line of greatest pitch are employed; they are opened out successively as the heading is driven towards the rise; they are thus a little in advance of each other forming a series of steps, and present the same appearance as the stopes established in a vein for working out any *bunch* of valuable mineral. There is this difference, however, between the case of a vein and that of a bed, that for working the latter the system can be at once applied to every *district* or *panel;* and that exploratory workings are unnecessary on account of the uniformity of composition which, as we have already said, characterises the bed in contradistinction to the irregularity of yield, which is the normal condition of a lode.

(**291**) It will be seen, from what has been said in Nos. 285 to 290, that the system of working thin beds, considered in a general manner, consists in taking out the mineral without previously exploring it with a network of galleries; progressing further and further from the shaft, and making the necessary roadways through the stowing behind the faces, so that they may all arrive at the limits of the district or panel, at the same time that the working out of the district is completed. It will be seen further, that the same system is applicable to all thin beds under the following conditions: In horizontal or very slightly inclined beds, the walls may be advanced in *any direction;* they can be driven with advantage at *half-slope* in beds whose pitch is more pronounced; they will be conveniently driven towards the rise where the pitch is sufficient for the establishment of self-acting inclines; and lastly, they should be driven in the direction of the strike for every pitch greater than the angle of repose of the coal on the floor of the working.

(**292**) The system of walls following the level has another advantage in a case of frequent occurence, viz., when the pitch is always considerable but variable in amount from point to point on the line of strike.

A certain number of walls having been established at first over a space represented by a given vertical height, and each wall being served by its own roadway parallel to the level, as the inclination varies nothing is changed over the whole system except the *length of the faces*, which *increases* or *diminishes* in proportion as the inclination *diminishes* or *increases*. In this way, for example, we pass naturally from a high inclination to a *flat*, or inversely, as the corresponding bend is encountered successively by the various levels.

(**293**) Walls following the level have, as we have said, an inconvenience, resulting from the fact, that the road which serves any one of them is naturally placed at the lowest point, in order that it may not be necessary to raise up the coal in filling the tubs; under these circumstances, transporting the coal along the face is troublesome, and may become dangerous in vertical or nearly vertical seams. In this case, the workmen, instead of standing on the floor of the bed, are supported above one another on stages, which also retain the broken down coal until it becomes expedient to throw it down from stage to stage to the lower end of the wall.

This inconvenience is remedied by substituting a *larger number* of stopes in the height of a panel, or working area, for a *smaller number* of straight walls; the stopes are similar in height to those employed in working lodes, that is to say, they are not over 6 ½ ft. and each is occupied by a single workman. The arrangement is then altogether like that of overhand stopes in the working of a lode, even to the dimensions of the walls. The broken down coal is also thrown into *mills*, or *passes*, which lead to horizontal roads made in the stowing. The latter lead to a self-acting incline which connects them with the main level.

This arrangement is represented in figure 215, which should be compared with figure 151 in which a straight wall is represented.

When a highly inclined part of the bed is encountered, it should be worked either by upright walls, each of which corresponds to an ordinary wall in flat working, or by a series of stopes in which the workmen stand successively above and behind each other. We should have, for instance, 5 or 6 upright walls, or 20 to 25 or more stopes.

For reasons already given, the stopes may, in general, be considered preferable to the upright walls. There is perhaps only one circumstance under which the latter would be preferable, or could even become necessary; viz, when the air-current is weak and the the mine makes much gas, which it would be difficult to dislodge from the numerous angles formed by the stopes, whereas it could be easily swept along the upright wall, thanks to its lightness.

(**294**) We have supposed hitherto, that the roadways leading from walls following the strike opened upon a self-acting inclined plane which brought the mineral to the principal level.

Often, however, in reality, this self-acting incline has no actual existence, and the loaded tubs are conveyed down sloping or diagonal roads by the *putters* (*hauliers*, or *drawers*) who return with the empties.

This arrangement, represented in fig. 216, may be regarded as necessary, when the inclination is too slight to allow of self-acting inclines being employed; it is often retained also, even when these inclines can be made.

It is perhaps desirable that self-acting inclines should be more frequently constructed; and, indeed, they are coming into more general use. Such an incline is made in the direction of the greatest inclination, in a gallery which is shorter and requires less repairing, even for an equal length, than a diagonal road (*See*, No. **287**). It is much easier for a putter to manipulate a break than to convey a loaded tub down the incline and bring back an empty one.

We are of opinion that this system will be more frequently employed in future than it is at present; and we shall again refer to it when treating of haulage. It appears evident to us that self-acting inclines should be made wherever their use is *practicable;* and that, if the system is little employed at present, it is supplanted by an unjustifiable extension of that of diagonal roads which is quite often enough the only one the inclination of the bed admits of.

Although such is the state of affairs, we should remark that the common system of diagonal roads admits of the simplification in the maintenance of galleries indicated in No. **289** (fig. 214) for roads towards the rise.

A new diagonal roadway, which serves all the faces, cuts off the whole of the old roadways between itself and the last diagonal one, except the principal level and the return air-course (*See*, fig. 216).

(**295**) SECOND CASE. — **Methods of working seams of medium thickness.** — Among beds of medium thickness, we include those whose thickness is about the same as the height of an ordinary mine gallery.

It should be understood that neither the bed itself, nor the false roof (*clod*) which it may possibly have, furnish any stowing, or, at any rate, very little; and that the amount of roof or floor worked away is far too small to serve for a filling-up and thus to form a notable feature in the method of working.

On the other hand, it should be understood that, if the thickness is greater than the height usually given to the galleries, any coal left on the roof is comparatively thin.

In fine, the thickness in question may be stated to vary from 3 ft. to rather more than 8 ft. (less than one metre to $2^{m}\cdot50$).

(**296**) Generally speaking, it may be said, in the first place, that the methods of working thin beds may be applied to the beds just defined; this is accomplished by having recourse to the well-known resource of supplying the deficiency of stowing produced at the faces and in ripping the roadways, either by leaving suitable spaces between the pack-walls, or by bringing the required materials from other parts of the workings.

This is not simply a theoretical idea; on the contrary, it is essentially practical and of frequent application.

Thus, for instance, in many of the English districts, the long-wall system is extended to beds of from 3 ft. 3 in. to 4 ft. 3 in. (1 metre to $1^{m}\cdot30$) in thickness, and even to thicker beds in which the sterile materials are quite insufficient to form a complete filling-up. The available materials are then built along the sides of the haulage ways and air-courses; and in the interval between the pack-walls there are large empty spaces which remain open when the roof is good, and fill up with fallen roof in the contrary case; if necessary, the roof is even brought down by blasting in these spaces, and they are used as quarries when the insufficiency of stowing materials is very great.

The advantages of easy supervision and economical working are thus obtained, while, at the same time, the quantity of stowing materials employed is reduced to what is strictly necessary.

The system is, therefore, quite applicable in the conditions in which it is employed; that is to say, when the beds are of medium thickness, consist of hard coal, are nearly horizontal, have a good, roof, and furnish only a small quantity of sterile matter.

There are other conditions of frequent occurrence, however, in which the long-wall method is applicable; for instance, all the varieties of long faces, walls following the rise or the strike, overhand stopes and their varieties of upright walls, *are applicable to beds of medium thickness* when the filling-up can be sufficiently well done.

These arrangements have their own peculiar advantages which we have already mentioned; viz, they favour a tolerably complete removal of the coal, and cause less derangement in the upper seams and at the surface.

On the other hand, they have one inconvenience which may sometimes be so serious as to exclude the employment of the system altogether, that is to say, the increase in the cost price, which the stowing entails.

(**297**) The method which is properly adapted to beds of medium thickness is *the formation and stripping out* (*heading*, *drawing back*, *stoping*) *of pillars* without stowing; and undoubtedly the largest proportion of the coal which comes into the market is worked in this way.

Considered in a general manner, it consists in driving two series of galleries which intersect at a given angle, having large pillars between them; then, after all the drifts in a district have been completed, the pillars are taken out, beginning at the further end and allowing the roof to fall in the rear.

The working of a district is finished when the removal of the pillars has retreated backwards to the point from which the preparatory drifts first set out.

The system is very easy to imagine and describe, but it may be misapplied; it is, therefore, of great importance that its true principles be properly understood, as well as some of the details of its application.

Many people consider that the period of making the drifts belongs to the regular working; consequently, they form a network of galleries of large dimensions, in order to facilitate the breaking down of the coal, and leave square or rectangular pillars which are made as narrow as possible.

In this manner they push the workings towards both the rise and strike of the bed, until the extremity of the panel has been reached; then the pillars are taken out, beginning at the end furthest from the shaft.

This system has two principal objections : firstly, it is necessary to keep up a great and increasing network of galleries until the pillar working has been begun; and, secondly, the pillars that were first formed are the last to be removed. It follows that many of the pillars are gradually crushed by the pressure of the roof, and produce an unusually large quantity of small coal when they are worked; or the floor of the mine rises up (*creeps*), obstructing the galleries, and causing considerable expense for ripping roadways when the pillars have to be taken out.

On the other hand, if, in order to avoid these objections, a network of narrow galleries were rapidly cut to the boundary of the field, leaving only a few very large pillars; and if the work of removing these pillars were not begun until after the boundary had been reached, a long period would intervene during which the working would be expensive and the number of available working-places very limited.

Thus the time when the work began to be remunerative would be greatly delayed.

(**298**) The best system seems to be a combination of these two methods : that is to say, a network of narrow galleries with very large meshes is driven gradually towards the boundary of the working area, the narrow galleries forming roadways and air-ways, and the various meshes of this network are taken out separately as speedily as possible, leaving only the narrow galleries requisite to communicate from one panel to the next.

In this way the length of the galleries, and the mean time during which they have to be kept in order are diminished; and, since the blocks are removed soon after they are formed, the coal is obtained in the very best condition as to quality.

In principle, it may be said that, as soon as any particular panel has been opened up, the question should be asked whether the blocks can be removed without hindering the development of the other panels, and if an answer can be given in the affirmative, *they should be removed at once.*

This system constitutes the method of working by *long blocks* with *pillar and stall;* the other is the ordinary method of *bord and pillar*, or *post and stall.*

The first expression is intended to indicate the fact that the pillars are only cut across at long intervals when it becomes necessary for haulage and ventilation; the second, that a more complete working out of the whole district is begun from the first, with the view of making this a productive period of itself.

(**299**) The method of working by long blocks with pillar and stall is certainly the best.

For example a network with large meshes is traced out comprising a series of levels at distances of 50 yards (50 metres) apart, joined to each other by headings at distances of 100 yards (100 metres) apart : both kinds of galleries are made only large enough to serve the purposes for which they are intended; they are a kind of preparatory works by means of which the blocks which they surround are attacked, while by their further extension other similar blocks are being won.

The removal of each block can be effected from the two headings between which it is situated, one half being worked from each heading. A series of levels (*stalls*) are driven into the block from each heading; they are narrow at first, and are then suddenly enlarged to the greatest width which the nature of the bed, and the limited time they require to remain open, permit of. The corresponding stalls from each side meet in the middle of the block, which is thus divided into a number of longitudinal pillars whose thickness also depends on local conditions.

In this manner a series of pillars is formed 100 yards (100 metres) long; these are removed in descending order, being attacked at the middle point and stripped backwards towards the heading.

When one of these blocks has been worked out, the narrow levels and headings remain protected by safety pillars, which are not worked out until the panel has been exhausted; they are prolonged towards both the rise and strike, and serve to trace out similar blocks which are removed successively in the same way.

Fig. 217 is a plan of the general arrangements of working by long blocks : the various details given above will be found on the figure.

It will be seen that, while one block is in course of being worked out, those beyond it, towards both the rise and strike of the bed, are only in the first stages of development or working.

(**300**) Long blocks may be taken out in two different ways : but it does not appear to us that experience has yet shown which is the best; indeed, one system or the other should be preferred, according to local circumstances.

The stalls, and the pillars between them, may be made of medium size; or, on the contrary, the stalls may be made as wide as possible, leaving thin pillars between them, whose principal object is to sustain the roof temporarily, and thus to act like the side props of a frame of timbering.

The second system, which may be called the English method, can only be employed when the roof is good, the coal firm, and the removal of the pillars is rapidly proceeded with. We are constrained to believe that this system furnishes the greatest proportion of large coal, and is least expensive as far as timbering is concerned.

(**301**) Under less favourable conditions, the stalls are made of smaller dimensions than the pillars; they may be 4 to 5 yards (4 to 5 metres) wide, for instance, while the pillars between them are 6, 8 or 10 yards (6, 8 or 10 metres) thick.

One of these pillars which we may suppose to be 8 yards (8 metres) in thickness, and of a length equal to the distance between the headings less twice the thickness of the protection pillar, is begun at the middle point and worked off backwards towards the headings.

A beginning is made by cutting a *thirling* 4 or 5 yards (4 or 5 metres) wide through the pillar, until it reaches the falls of roof caused by the removal of the pillar to the rise of the one in question. After this first opening has been made, the rest of the pillar is worked off in one of two different ways : either a succession of more or less contiguous crosscuts (*rooms*) are driven towards the rise, or two walls are driven in opposite directions along the line of strike.

The crosscuts are often quite contiguous to each other, and then the workmen have the solid coal which has to be removed by the next succeeding crosscut on the one hand, and the fallen roof of the preceding one on the other. Each crosscut is driven up as far as the fallen roof in the stall above. If part of the coal has been left on the roof during the upward progress of the crosscut, it is stripped off with picks or by blasting, as well as possible, at the time the timber is removed; or it falls of its own accord.

If it is not necessary to leave a top-coal for the purpose of keeping up a false roof, the whole thickness is taken down in the first working.

Sometimes the crosscut, in course of being worked, is separated from the last completed one by a thin barrier of coal, 1 yard or so in thickness, which is removed, as well as possible, when the place is abandoned. This system, which reminds us of what we have just called the English method, is represented in figure 218; the face requires to be cut (*shorn*) on both sides, instead of only on one side, but this arrangement may be more advantageous when the pressure of the roof is very great, besides, more large coal is obtained, and less timber is required.

Faces driven towards the rise are limited in application to flat or only slightly inclined seams. When the pitch is such that the coal slides on the floor under the action of gravity, they become very objectionable, more especially after they have pierced into the fallen stall above

(**302**) Walls parallel to the dip are *applicable in any case*, but become *a necessity* for high *inclinations;* they are driven forward, and timbered in the rear of the face, in such a way as to regulate the falling of the roof (*See* fig. 219). Care must usually be taken not to retard the falls too much, lest too great a pressure be thrown on the face, crushing the coal, increasing the quantity of smalls, and causing more expense for timber; besides, when the fall at length begins, it is not easily prevented from extending to the very face. Accidents may sometimes arise from this cause, although a movement of this kind generally gives sufficient warning beforehand to enable the workmen to retire in time ; the face, however, is completely blocked up, and time must be expended in opening it again.

This accident should be prevented, if possible; and the broken ground should be kept at a nearly constant distance from the face. When the unbroken roof extends too far back, and the pressure at the face becomes excessive, the distance to which the broken ground should extend is marked off; an additional row of props is then set up between those already placed at this boundary (*See* fig. 219), and all the timber beyond it is drawn out. If necessary a few shots are then fired in the roof just behind the boundary line, so as to bring it, down, and limit the falls to the proper distance behind.

When the pitch is very great, the wall cannot be driven in the whole width of the pillar, since the broken rock from the fallen stall above would slide into the working-place, and threaten the safety of the miners. It is necessary under these circumstances, to leave a thin pillar of coal at the rise side of the wall, and to remove it, as far as possible, at a short distance in the rear of the face.

An upright wall may also be replaced by overhand stopes. The men then support themselves on stages which rest on the props or on special timbers put in for the purpose (*See* fig. 220).

(**303**) In summing up what has been said regarding the removal of pillars, it will be seen that the arrangement of working-places may vary, according to the rule already given for the long-wall workings of thin beds : that is to say, when the seam is horizontal or nearly so, the blocks may extend in any direction whatever, and may therefore be laid out so as to facilitate the breaking down of the coal by keeping the faces parallel to the cleat. When the pitch is considerable, a double condition has to be fullfilled : to make the haulage as easy as possible without, at the same time, forming pillars with very acute angles, and this leads to the arrangement of galleries parallel to the strike and dip. In other words, the blocks are made *parallel either to the strike or dip of the seam.* It will be apparent, moreover, that the latter are not practicable when the dip is very great, that is to say, equal or superior to the angle of repose of the minerals; aud hence they must be laid out *parallel to the strike* when that limit is surpassed.

The pillars into which the blocks are divided may be removed, according to circumstances, either by a succession of crosscuts driven through them, or by two faces cut longitudinally ; in fine, the latter system is necessarily employed in the case of blocks parallel to the strike, in highly inclined seams.

(**304**) THIRD CASE. — **Methods of working thick seams of coal which are nearly horizontal.** — Under the name of *thick seams*, we shall include those whose thickness is considerably greater than the height of the ordinary roadways, varying from a minimum thickness of 8 to 10 feet ($2^{m}\cdot50$ to 3 metres) to that of the thickest beds known, which are as much as 50, 60, 100 feet (15, 20, 30 metres) and more.

The working of these thick seams more particularly concerns French engineers, since they occur most frequently in France; or, at least, they furnish the greater part of the supply of that country.

For reasons which will be given further on, we will distinguish the case of beds which are nearly horizontal from that of beds which are nearly vertical.

We shall consider the former case first. In principle, the *method of working by long blocks with removal of the pillars*, which we have described in the last division, may be applied to thick seams; but with this difference that, after the working of the bottom part of the seam has been completed, the upper portions have to be stripped down in the same working-places in which the pillars are removed.

This stripping down of the top-coal is always a delicate work;

for it should be done in such a way as to cause the beds of coal to fall, without bringing on an immediate fall of the roof above them. and to allow time for taking away the broken coal, before it is covered by the falling roof.

Figure 221 represents such a system of stripping, employed in a stall following the strike. It is supposed that the top-coal is taken down in two stages, by shots which are fired after the props which served to keep it up have been removed.

The work thus presents the appearance of overhand stopes.

In general, this method of breaking down cannot be employed without causing a certain waste of coal, which is lost under the falls of roof; and this waste is greater, according as the seam is thicker, the coal more friable, and the roof more brittle.

It would be difficult to apply this system to a seam of greater thickness than 16 or 17 feet (5 metres), that is to say, with a top-coal thicker than 8 to 10 feet ($2^{m}\cdot50$ to 3 metres).

(**305**) In mines in which the coal is sufficiently firm and the roof sufficiently strong, and in localities where it is easy to procure props of great length, this method of removing the coal could be somewhat modified. A series of contiguous crosscuts are made, taking the whole height of the seam by a system of stopes, which allow at least a better selection of the coal, and cause less waste, if they are not more economical otherwise. After the coal has been entirely removed, the roof of the working-place remains supported by a series of long props reaching from the floor to the roof; the empty space is bounded on one side by the fallen roof of the preceding crosscut, at the rise side by the falls in the level-course stall above, and on the two remaining sides, by the pillar in course of being taken out and the lower, still untouched pillar.

Several rows of properly stayed props are now set up along these two faces and in front of the roadway; then all the props beyond these rows are removed, so that they may be used over again. Those props which cannot be taken out are weakened by cutting them with an axe. That part of the roof which is no longer supported soon falls in a mass.

After it has fallen, a new crosscut is commenced alongside the last; the fallen roof is kept back by the props; and, although it has not quite settled down, the stones cannot run into and encumber the new crosscut and the roadway.

This system, which is represented in figure 222, is applied with much ability by the Silesian miners. They show great fearlessness in taking out the props, or cutting them with the axe, until the last moment where the cracking of the roof, which usually falls in one piece, warns them that the fall is imminent.

The next crosscut is not begun until this fall has taken place, as it facilitates the work.

If the roof were of such a nature that it fell immediately after the props were taken out, this work could be carried on from a distance, by means of a long chain. The props are then drawn out by means of a winch, or screw-jack, or some other apparatus erected in a place sheltered from the falls (*see* fig. 223).

Such a system of taking out timber is favourable to the safety of the miners, and allows of the crosscuts being made wider.

The method of removing pillars, which we have described above, is only limited by the length of the props which can be procured in the district, provided they do not become too heavy to be handled by the workmen.

It may be applied to beds of 16 to 17 feet (5 metres) and even more in thickness, if a part of the coal, which is mostly lost, be left for a roof.

(**306**) A similar system can also be applied to beds of much greater thickness, if the firmness of the coal and roof allow timbering to be dispensed with. It is in this way, for example, that the *ten yard coal*, or Dudley thick coal, which is horizontal and 30 feet (9 metres) thick, is worked on a large scale in Staffordshire.

Some thick beds of anthracite are also worked in the same way in the United States; these beds are remarkable for the firmness of the coal, which resembles that of building stone, and for the soundness of the roof.

In reality, the system followed amounts to a division into large blocks, with this distinction, that the galleries which separate the pillars constitute the principal part of the working; they are made very large, having a height equal to the thickness of the coal, and as great a width as the firmness of the ground will allow.

The pillars are mostly lost, the process of stripping being confined to cutting through them in several places. Their principal and essential use is, in reality, as we have said above when treating of the English system, to support the roof of the great galleries, or, in other words, to serve as kind of supporting walls.

In Staffordshire these galleries or chambers (*sides of work*) are thirty yards (30 metres) wide, and sometimes as much as 50 (45 metres), while the pillars between them are only about 8 yards (7 metres) thick. The roof of the gallery is, besides, supported by one or sometimes two rows of small pillars called *men-of-war;* these are ranged in a line along the axis, or parallel to it, and are made of the size judged to be necessary; for example, 9 yards (8 metres) square and 12 yards (11 metres) apart.

The working presents a series of overhand stopes; the undercutting is done at the floor, and the different beds are removed successively in ascending order.

The breaking down of the coal by this method is very economical but at the same time dangerous, and accidents frequently happen. Besides, if the beds part from each other too easily, a great waste of coal may ensue, because the thick partings of stone which occur in the seam, often fall solidly as immense sheets and cover up the coal from the lower beds before it can be removed. This coal, buried under the rubbish, heats and takes fire easily; and on this account, it often happens that, instead of the boundary pillar being partly taken out, the gallery itself has to be abandoned prematurely and all the openings into it securely built up.

(**307**) The same system of working is pursued in the United States, with this difference, that the beds next the roof are attacked first, so that the chamber is cut out by underhand stopes.

This method of working is favourable to selecting the coal properly, and to its complete extraction. Besides, it is less dangerous for the workmen, and, on the whole, appears to us to be preferable to the method followed in Staffordshire.

In both countries, the floor of the gallery in the rear of the faces remains encumbered, to a greater or less height, with rubbish, or small coal, which is sometimes partly left behind. It would be difficult to carry a tramway over this mass of rubbish without incurring much expense in turning it out of the way. It is, therefore, better to cut a narrow gallery along the middle of the pillar and put it into communication with the faces at short intervals by means of crosscuts. The coal which is worked at the face is then removed by the nearest crosscut.

The system described in the last two numbers is represented in plan, in figure 224.

(**308**) The system of great chambers, employed in Staffordshire and Pennsylvania, seems to be defective in so far, that the useful mineral is not wholly removed; but, apart from this defect, which appears to be inherent to any system of working thick seams without filling-up, we may consider it, as it is practised in England and still better in Pennsylvania, to be, after all, the most economical way of working with long pillars subsequently taken out, when the seams are as much as 24 to 30 feet (8 to 10 metres) thick, as they are in these localities.

This method costs the least for working the coal and supporting the roof.

At the same time, even taking into account the imperfectly worked pillars which are left between the stalls, it will be perceived that the actual loss of coal is not at all excessive, especially when the system of underhand stopes is employed; and that it is not, perhaps, more than it would be, in applying this method in another way to seams of eqnal thickness.

(**309**) This method, however, has many essential defects in whatever manner it is applied. These are:

A certain waste of coal increasing with the thickness of the bed, all other things being equal;

The risk of conflagrations which are an almost inevitable consequence of this normal waste, and sometimes lead to another still greater waste when it is necessary to abandon whole districts for the purpose of isolating them ;

Lastly, the subsidence of the surface, and sometimes the danger of inundation which may be brought about by the falls of roof; these defects increase with the thickness of the bed, and diminish as its depth from the surface becomes greater.

(**310**) In order to make these defects disappear, or at least to lessen them, an artifice is adopted of which we have not yet spoken, it can, moreover, be applied to all thick beds which have a well marked stratification.

Its consists in treating the seam as if it were composed of a number of separate beds, joined together, but requiring to be worked separately.

The difficulty arising from very great thickness is thus diminished ; and the question to be solved is how to work a certain number of superimposed beds whose individual thickness can be regulated, while at the same time *they are very near each other*, or even *in immediate contact.* This may be done in two different ways :

The different slices may be regarded as seams of medium thickness which can be subdivided into great pillars to be afterwards taken out, and then they are worked in descending order ; the, first slice is worked out like an ordinary seam ; and the second, and those following, have the falls produced by the upper workings for a roof.

This arrangement subdivides the extent of the fall without diminishing its total height ; but it diminishes the waste of coal, since the part to be stripped down from the roof may be reduced as much as we desire.

On the other hand, the different slices may be regarded as seams of medium thickness, which have to be removed while their place is *completely filled with stowing*, in such a manner as greatly to lessen the movements of the ground, and completely to prevent loss of coal.

In this case it is usual, though not necessary, to take out the different slices in ascending order, rising upon the filling-up of one bed, in order to work the next above it.

These two methods of working are known by the names of the Blanzy and Rive-de-Gier methods, from the names of the localities in which they were first practised.

The Blanzy method might be called : *a method of working by slices without filling-up ;* that of the Rive-de-Gier : *a method of working by slices with filling-up.* In the former case, the complete removal of the coal makes it necessary to take the slices in descending order ; while, in the latter, the employment of stowing does not necessitate any particular order, and there may be special reasons for adopting one or the other.

On the one hand, the ascending order might be preferable, from the consideration, that it is usually more convenient to have the stowing underfoot than overhead.

On the other hand, the reverse order might be desirable, owing to an easy inflammability of the coal which might give rise to the fear that fire would break out in the upper beds, when they settled down on the stowing of the beds below them.

The Blanzy method corresponds to cross-working with removal of the pillars ; the Rive de Gier method to cross working with filling-up, mentioned in No. 280 ; and, to continue the analogy between thick seams and masses which contain little or no dead-stuff, it is expedient to add, a method *by slices with solid floors and without removal of the pillars*, corresponding *to the method of pillars and chambers with solid roof and floor* described in No. 283.

The last is similar to the Blanzy method, but differs from it in this respect, that the working terminates when the first drivages are completed, and the pillars of each slice, together with the solid floor between the slices, are entirely sacrificed.

We can only call attention to this system, which may be regarded as obsolete and generally inapplicable, for the reasons already given in No. 283.

(**311**) The method of working by slices without filling-up, and taking out the pillars, was applied to a seam 50 feet (15 metres) thick at Blanzy. The bed was divided into three nearly equal slices, which separate from two principal beds of stone, presenting easily distinguishable partings.

The three slices were worked by the system of long blocks like distinct seams, and the advance drifts were arranged in such a way that the lowest levels and the levels of each story were in the same horizontal planes, while their headings to the rise were directly above each other (*see* section figure 225).

There was no difficulty in this arrangement, since a short cross-cut in the seam itself could fix the position of these drifts exactly.

The working out of these slices was effected according to the methods described in Nos. 299 and 301 : the coal was divided into blocks by narrow headings driven in the direction of the strike and and rise; then wide, level-course stalls were driven through each block leaving a long pillar between every two; and lastly, the pillars were taken out in descending order, beginning at the middle point and working them backwards to the headings. The removal of the pillars was conducted in the manner described in No. 304.

When the upper slice had been worked away, the middle one was taken next, and, lastly, the lowest.

(**312**) It was formerly thought necessary to allow a considerable time, two or three years, for example, to elapse, between the time of taking out one panel, and the corresponding one below it, in the case of two superposed seams. This was done for the purpose of allowing the broken roof to settle down and solidify, so as to make the working of the lower panel more easy, since it had the goaf of the upper one for a roof.

It was found, however, at Blanzy that this was not necessary, and that the working out of the lower blocks could be proceeded with, below even recent stowing, more regularly, and with less danger to the workmen, than under the solid roof itself; for it was then possible to regulate the fall of roof behind the working faces of the pillars, so that irregular and excessive pressures, which might sometimes take place under a solid roof, could be avoided.

A system was, therefore, adopted, whereby the three corresponding blocks were worked out almost simultaneously; with this restriction, that the removal of the long pillars, which corresponded to each other in each slice, was proceeded with in such an order that the upper ones were rather in advance of the lower.

The pillar working, contemplated as a whole, thus presented the appearance of underhand stopes; while each great stope itself consisted of a few overhand stopes, on account of the method of removal.

(**313**) This method had, further, another advantage in regard to spontaneous ignition, to which the Blanzy coal is liable.

The complete working out of a bed, of even 16 feet (5 metres) only, cannot be effected without considerable loss of small coal which is buried under the falls of roof.

This coal, mixed with inflammable shale from partings in the coal, or from the roof, had a certain communication with the air through the spaces in the falls, and was in very favourable conditions for heating gradually and then taking fire.

It was thus possible that, when the work of removing the pillars in the lower part of the seam was being proceeded with, the incandescent rubbish could fall into the working places.

Since the heating takes place only by slow degrees, there is not time for it to increase to a dangerous extent, if the pillars of the second slice are removed sufficiently soon after those of the first. The falling down of the rubbish has then a cooling effect, such as would be produced if it were turned over and exposed to fresh air.

Consequently, the dead-stuff does not get heated to incandescence, except in those panels from which all the coal has been removed, and where the fire may smoulder without danger.

This system was first employed by M. Harmet thirty years ago; and, at the time, it was considered to be a very important improvement.

It diminished, but did not entirely prevent the loss of coal; it reduced the danger from fires, and produced the coal at a low cost price. But there still remained the disadvantages inherent to working thick seams by the method of drawing back pillars without filling-up, which as already stated are the following : an inevita loss of coal; irregular subsidence of the surface; the sacrifice of higher still unworked beds; and lastly, however much care may be taken, the work is dangerous for the men, and there are always certain chances of fires, or at least of a heating, which may sometimes necessitate the abandonment of a few of the pillars, and sometimes of whole blocks, before the working out is completed.

Indeed, even at Blanzy where the method was orginated, a method with stowing has been substituted.

We believe, however, that the Blanzy method could be advantageously applied in localities were the surface is of little value and the coal not inflammable; for it is evidently very economical.

(**314**) The method of working by slices, with stowing, requires the slices to be thinner than those that can be worked without stowing. In the former case, the thickness is determined by the height at which dead-stuff can be easily put in place while the men are standing on the floor; in the latter, on the contrary, the thickness is limited by the height of the beds that we choose to strip down as top-coal, at the same time accepting a certain proportionate waste of coal as an unavoidable contingency.

The usual limit is that of the height of the ordinary roadways 6 to 8 feet (2 metres to $2^{m}\cdot50$). We may suppose the lowest slice to be taken at a thickness of $6\frac{1}{2}$ feet (2 metres), and that, treated like an ordinary bed, it may be worked either by the bord and pillar or the long block method. When the pillars are to be removed, any process may be adopted, so long as the condition is fulfilled of filling up the empty space completely, instead of allowing the roof to fall.

We may even suppose that, instead of forming pillars or long blocks, the long-wall method can be employed without cutting any advance drifts, and that the requisite stowing is brought from another part of the mine or from the surface.

In fine, it may be said that, considered in a general way, the slice is worked out in the manner considered most suitable, with no other necessary condition, except that it must be completely filled up so as to prevent any possible fall from taking place.

A second slice is worked on the top of the filling-up of the first, and in the same manner; a third succeeds the second, and so on.

The system is represented in figure 226 which should be compared with the preceding figure. In each of these figures the numbers indicate the order in which the slices are to be taken.

Figure 226 supposes that the fifth slice is being worked; that the bed is 39 feet (12 metres) thick, and that it has been divided into six slices each 6½ feet (2 metres) thick.

(**315**) The number of slices is theoretically indeterminate. The stowing of one slice that has been worked out, does not fully support the slice above, until it has been squeezed together somewhat. Thus a certain subsidence takes place in the upper parts of the bed; the total extent of the sinking increases proportionately with the number of slices worked out, and is all the greater for a given number, if the filling-up has not been done well.

This movement, if not too great, facilitates the working of very hard coal; but it decreases the proportion of large coal, and increases the quantity of timber required. It may happen, besides, that, in subsiding, the mass breaks up and becomes fissured to such an extent as to allow it to heat, or even to become incandescent as if it were a mass of small coal.

These circumstances, and especially the last, limit the number of slices, and, consequently, the thickness of the bed that can be worked by this method.

We are of opinion that the limit of the number of slices would be ten, and the limit of the thickness of the seam 65 to 80 feet (20 to 25 metres). This would not prevent the system from being applied to beds of still greater thickness, however, if necessary; or even to beds of any thickness, if the total height were divided into several stories which could be taken successively in the descending order, and each worked in slices, in ascending order.

In a bed of 100 feet (30 metres), for example, two stories could be taken of 50 feet (15 metres); or, if the coal were very friable and easily inflammable, even five or six divisions could be made, and then each could be worked in 2 or 3 slices of 6 or 8 feet (2 metres to $2^{m}.50$) each.

(**316**) In applying this method, the long pillars are usually formed in the first place, and these are taken out, either by a series of contiguous crosscuts, each of which is completely filled with stowing before the next is begun, or by level-course walls in which the stowing follows closely behind the face.

The crosscuts are sometimes filled up in proportion as they advance, only a narrow space being left betwixt the coal and the stowing.

This arrangement is a good one, when the beds that form the roof are not solid enough to allow of the space remaining open during the whole time it is being worked (*See* fig. 227).

When the crosscut is partially filled up in this manner, it is evident that the face may be opened at the upper end of the pillar and worked downwards to the stall.

In the latter case, the passage which communicates with the working-face is one that has been left when the preceding crosscut was filled up (*See* fig. 228).

These arrangements, which require the filling-up to be sustained by a pack-wall, at least on one side, cost rather more than when the filling-up is simply thrown in with the shovel; but the work is better done and the stowing rammed closer to the roof; so that, in this way, falls are prevented, which would be *actually dangerous for the men* at the time, would be *a difficulty in the working of the next slice*, and, with certain coals, would increase the danger from fire.

(**317**) We have already said that, when this method is employed, the slices are usually taken in the ascending order; it is not necessary, however, to wait till one slice has been completely worked out before beginning the next; since, if this were done, the output would sometimes suffer greatly.

On the contrary, it is necessary to attend to the principle of distinct panels in each slice, these panels being worked out as rapidly as possible; after this has been done, the working of the next slice can be begun immediately, on the filling-up of the last.

In this way, it may be seen, how the working out of the first slice may be going on in one panel while the working out of the second, third, or even of a higher slice may be going on in the adjoining one.

The only result is a rather greater complication in the arrangements for hauling the stowing materials.

On the other hand, by working out the different slices of one panel rapidly, a considerable advantage is obtained, especially with easily ignited coals : that is to say, the fires are avoided which might ensue, if the dislocated upper beds were allowed to rest for a long time on the stowing.

The last system may be called the vertical.

(**318**) In the foregoing description we have supposed the bed to be horizontal, and then the superposition of one slice above another would be absolute, so to say; so that the galleries of the second slice could be made by heightening those of the first, at the same time that they were filled up to a certain height with stowing. If, however, the seam has a considerable inclination, horizontal divisions may be made as we have indicated elsewhere in figures 225 and 226; the levels of the first slice will be on the floor of the bed, and those of the succeeding slices will be made, not by *heightening*, but by *widening* towards the roof, those of the preceding slices.

The work of filling up may be much facilitated by taking advantage of this medium inclination. For, while the coal is being removed through the lower level, dead-stuff is shot in from an upper one, which is kept open at its lower side with this object.

If the pillars are removed by level-course walls, the filling-up can be kept parallel to the front of the face, which is usually in the direction of the dip; and the dead-stuff may be allowed to take its natural slope, if the solidity of the roof is sufficient.

If these faces are cut towards the rise, on the other hand, each is filled up completely before the next is begun. In this way the arrangement can be varied as in the case of nearly horizontal seams, advantage being taken of the inclination only for the purpose of bringing the dead-stuff to its place, as much as possible by the action of gravity; although, of course, there must always be some rehandling, in order to fill up all the space exactly.

The limitation of slices parallel to the seam, by two horizontal planes, is, therefore, applicable to both systems of working : with slices and removal of pillars *without stowing*, or with slices and filling-up.

In reference to the system of working with stowing we should say, that this method of ending the slices can be conveniently employed, whenever the seam is neither quite horizontal nor much inclined.

In the first case, the widening would be useless, since it would not open out any new layers of the seam ; in the second case, the working of a slice which had the stowing of a lower one for its floor might be very troublesome, if the inclination of the bed were greater than the natural slope at which the stowing would lie.

The last remark naturally leads us to the consideration of those cases in which thick seams are nearly vertical.

(319) FOURTH CASE. — **Methods of working thick and nearly vertical seams of coal.** — We have already discussed the methods applicable to thick horizontal seams.

According to the first order of ideas, *the thickness of the seam is, so to say, left out of account*, and long blocks are formed in the same way as in working a bed of medium thickness; sometimes little importance is attached to the first drivages, the principal work being reserved for the stripping down of the coal left on the roof when taking out the pillars ; sometimes, on the contrary, large stalls are made at the first with only thin pillars between them ; and of these a large proportion must be sacrificed, while the process of removing them is always a more or less incomplete one.

This system is evidently impracticable in the case of a nearly vertical seam; because, with narrow headings cut at the floor of the bed, the best coal could not be ripped from the roof in the usual way; and with large stalls, the intermediate pillars, which would then be horizontal partitions, would not have any degree of solidity.

(**320**) In another order of ideas, *taking the thickness of the seam into account*, it is divided, in imagination, into a series of superimposed layers of little thickness, and these are worked, *sometimes* by the pillar and stall method without stowing, and *always in descending* order, *sometimes* with complete filling-up, and then generally in *ascending* order.

The first method is not absolutely inapplicable to vertical beds; but the removal of the pillars, which is always difficult in steep seams, becomes particularly so with a *bad roof* which consists of the fallen roof of the slice above.

The second method would be equally difficult, on account of the *bad floor* formed of the stowing of the slice below.

Thus, we are finally compelled to seek new methods, applicable to those cases in which the *seam is thick* and at the same time *much inclined*.

It is necessary to introduce some new principle, and this is done by modifying the arrangement considered in No. **310**.

For this purpose, the seam is divided into *horizontal, or nearly horizontal slices*, altogether independent of its dip; that is to say, we substitute a method of *cross-working* for the usual system of workings *in the plane of the seam*.

The seam is thus divided into a number of *stories*, whose height is arbitrarily fixed; then, in each story so formed, the number and thickness of the individual slices can be regulated.

The stories are taken in descending order; but it remains to be seen in what order the different slices of each story are taken.

(**321**) Each slice can be compared to a horizontal seam of given thickness, and represents, in plan, a great rectangle, whose length is indefinite, and whose breadth is the horizontal thickness of the bed.

It may be said, in general terms, that the two distinct methods described above (Nos. **310** *et seq.*) for the case of slices *parallel to* *the stratification*, in sensibly horizontal beds, are applied in working out these slices.

The question of working thick, vertical, beds is thus solved in principle.

Methods similar to those of Blanzy, or Rive-de-Gier, can be adopted; the former (crosscut method of working with subsequent pillar working) proceeding with the slices *necessarily* in descending order; the latter (cross-working with filling-up) proceeding *generally* in the inverse order.

These methods are similar to those already described in No. **280** *et seq.* for metalliferous masses.

Indeed, it may be imagined in a general way, that there is no *geometrical difference* between a wide *lode* furnishing only a small quantity of *deads*, and a *thick seam of coal which is nearly vertical;* and, consequently, that the same system of working may be applied to both. What has been said, therefore, in No. **280** *et seq.*, in regard to thick lodes, may be repeated in reference to the seams of which we are treating.

Thus, in making use of stowing, the crosscut method properly so-called can be applied; and without stowing, the crosscut method with subsequent removal of pillars.

Lastly, in case of need, a crosscut method with solid roof and floor can be employed: without either removing the pillars or putting in stowing.

The last method is, however, theoretically imperfect, for the reasons already given in No. **283** and repeated in No. **310**.

There are, therefore, in fact only the two methods to be considered.

(**322**) The method of forming and removing pillars without filling up, is applied by cutting a principal level along the floor or roof of the seam, and this serves as a base from which stalls are driven transversely with pillars between them. These workings are made about 6 ½ feet (2 metres) high, but the width of the working-places, and the thickness of coal left to support the stowing of the slice above, which we suppose to be already worked out, depend on the firmness of the coal itself.

When the coal is friable, the stalls may be 6 ½ feet (2 metres) wide, and the top-coal 10 feet (3 metres) or more thick; but when it is hard, the former may be as much as 10 ft. (3 metres), or more, wide, and the latter may be reduced to 3 ft. (1 metre).

The work of removing the pillars and top-coal is begun at the boundary of the panel and continued backwards by one of the methods indicated in No. **301**; the whole slice is treated as if it were a long pillar, of a breadth *equal to the horizontal thickness of the seam*, formed in a bed of the same thickness as *the height of the stalls and top-coal together*, and with a bad roof.

The coal may be removed, for example, by a series of contiguous crosscuts, separated from each other by narrow pillars 3 to 5 ft. (1 to 1 ½ metres) thick. Each crosscut is driven across the whole thickness of the seam, and the top-coal is stripped out backwards towards the starting point; while, at the same time, as much as possible of the narrow side-pillar is taken out (fig. 229).

The stowing of the slice above falls immediately, when the top-coal is taken out; in case of need, it may be kept from running forward and encroaching on the working-face, by building pack-walls here and there. It then lies at its natural slope behind the face of the head-coal, and the workmen engaged in taking down the latter stand on it. In this way the work is carried backwards to the principal gallery, and then a pack-wall is built across the end to protect the next working-place.

While the pillar workings of one slice are being carried on, the crosscuts, or even the pillar workings, of the slice below, or even of a third slice, may be proceeded with, provided that the points at which pillars are being taken out, are kept one behind the other in the various slices, so as to form a series of underhand stopes similar to what was described in No. **312**.

(**323**) In the second method described in No. **321**, cross-working with filling-up, the various considerations referred to in

No. **314** *et seq.* are applicable, and some additional details may be given in this place.

Where the coal is easily broken and inflammable, the height of the tiers has been reduced to 20 feet (6 metres), comprising three slices of 6 to 7 feet (2 metres); each slice is taken out by a series of crosscuts from floor to roof, which are carefully filled up as they are made.

The crosscuts are driven from various points in the principal level at the same time, and not merely at the two extremities; this is done in order to multiply the number of working-places, and obtain a sufficient output.

It might happen, in spite of the reduced height of the stories, that fire should break out in the second or third slice; and, in order to localize it, a stopping would have to be built in the principal gallery, so that all the places beyond would be lost.

To avoid an occurrence of this kind, a second level is driven in the solid rock of the floor, parallel to the principal one, and communicating with it at short intervals by means of crosscuts a few yards in length. The principal level then connects the working-places, and the stone drift serves for haulage. If these arrangements are made, a fire which breaks out at any point is at once isolated, by building two stoppings in the principal level, between two consecutive crosscuts; and, consequently, the whole of the workings can be reached, except those between the stoppings, which are naturally kept as near together as possible.

The stone-drift and the crosscuts entail a considerable extra expense, and this system is not applicable unless the ground is fair; it should be remarked, however, that the stuff resulting from this work can be usefully employed as stowing, so that the drifts may partly be looked upon as quarries; and a sum ought to be deducted from their cost, equal to that which would have been incurred in getting the same quantity of stuff from somewhere else.

This system is represented in figure 250; the numbers in this figure have the same signification as those on fig. 208.

(**324**) One general character of the crosscut methods of working, either by simply removing the pillars, or with filling-up, is that the slices have only a limited superficies relatively to slices parallel to the plane of stratification. It is as if we had only one pillar with a breadth equal to the horizontal thickness of the seam, instead of a series of parallel pillars. Owing to this circumstance the daily output is inconveniently limited; but this inconvenience may be, in some measure, provided against in various ways.

In the first place, if the thickness of the seam were suitable, two principal levels could be driven, one next the roof, the other next the floor; and, besides these, there might be a third in the middle ot the seam. In this way each crosscut between floor and roof would consist of four places, all in operation at once : one starting from each level at the floor and roof, and two from the middle level.

(**325**) Another way of augmenting the output consists in increasing the thickness of the slices, making them more on a par with those employed in cross-working with removal of pillars : for example, 15 to 20 feet (5 to 6 metres).

A slice 16 feet (5 metres) thick may be taken out by means of one level at the floor by which the coal is taken away, and another at the roof, 16 feet (5 metres) higher up, by which the dead-stuff is brought forward (figs. 251 and 252). The coal is removed by a series of crosscuts, 6 ft. (2 metres) high at first, running from the roof to the floor; having arrived at the floor, they are put into communication with the level for supplying dead-stuff, by means of a narrow passage, and, if necessary, a small triangular pillar is left to support the floor of this level. The stuff is thrown into the narrow passage and runs down until it takes its natural slope: the workmen stand on it while taking down the 10 ft. (3 metres) of top-coal, and work backwards from the floor towards the roof; they have thus to handle only so much of the dead-stuff as is required to fill up the space, and jam it against the bottom of the next higher slice.

(**326**) Working-places driven across the seam are not usually in such favourable circumstances for getting the coal as those driven parallel to the stratification; this is partly on account of their position, and partly, because they have to pass through the partings or beds of stone which are sometimes of considerable thickness in these large seams.

The seams themselves may be regarded as if composed of a number of seams of ordinary thickness, which have come closer together, on account of a gradual thinning out of the strata between them.

When it is considered preferable, the stalls can be driven along the strike, (fig. 232), and then, instead of being crosscuts at right angles to the level, they set out from a common crosscut, and are carried forward parallel to the level.

If, at the same time, the slice has the thickness mentioned in the preceding No., and it is intended also to bring forward the dead-stuff at the top, then the arrangement does not essentially differ from that described in No. **318**.

That is to say, there is a *geometrical identity* between slices parallel to the stratification and limited by *two given horizontal planes*, and a horizontal slice *comprised between the same two planes* and worked by a succession of stalls parallel to the stratification.

(**327**) **Resumé of the four preceding cases.** — What has been said regarding the methods of working applicable to coal seams, may be considered to apply also to other stratified deposits.

The methods differ, as we have seen, according to the richness of the deposits.

It cannot be said, absolutely, that any one of them is superior to all the others in a technical point of view, since they are not all applicable under the same circumstances.

We have already discussed the respective merits of the methods applicable in a given case; and it remains for us to compare the various methods among themselves, in regard to their relative economy.

In making this comparison, we shall leave out of the question the influence of the absolute value of the mineral contained within a given space; and we shall suppose the total thickness to be always the same, both when considering the case of a very thick seam, and that of a certain number of thinner seams.

(**328**) These premises being made, it may be said, regarding seams of the first class, that working them is, for several reasons, not *relatively* very advantageous: in the first place, the work of breaking down is costly; partly, on account of the constrained position of the workmen under a very low roof; partly, because a given amount of holing, or kirving, produces only a small quantity of coal; and, lastly, because the roof must be taken down in the faces themselves to make room for the men when the seams are very thin, and this becomes an important part of the work.

In the second place, the work of cutting roads for haulage and air-courses becomes very expensive. The cost of maintaining a network of these passages will form a relatively larger item as the output diminishes, or, in other words, as the seam becomes thinner; stowing the stuff produced in cutting the roads becomes difficult, especially when the faces follow the strike; and the timbering is costly, more particularly in steep measures.

In fine, working thin seams with filling-up may be regarded as decidedly expensive; and the cost price of the mineral increases considerably, when we pass from a flat to a steep working.

(**329**) The position is quite different in seams of medium thickness in which the roof does not require to be cut for head room, either in the working places themselves, or in the roadways leading to them.

In regard to beds of this kind, it may be said, that the cost of breaking down the coal, compared with that in thin seams, varies almost inversely as the thickness of the coal, all other things being equal.

The expense of filling up disappears, and that of making and maintaining haulage roads is reduced in an important degree.

The falls of roof, resulting from a total removal of the mineral, lead to a subsidence of an entirely different kind from that which takes place in a seam which is packed with dead-stuff; they are accompanied by a crushing of the rock which increases its bulk; while, on the other hand, when the roof settles down gradually on pack-walls and stowing, the same increase does not take place, and, in course of time, the subsidence is apparent at the surface. The consequence is, that seams of medium thickness, *at a sufficient distance from each other and from the surface*, can be worked out entirely, *without filling-up*, with perhaps less damage to the surface than if the space had been carefully packed.

Every condition tending to reduce the cost price to a minimum, is therefore present.

The majority of the coal workings in England are carried on under such favourable conditions; and this fact accounts for the superiority of these mines, in which the normal cost price of the products is less than in most mines of the continent, notwithstanding the high rate of wages.

If we leave out of account the exceptional, and probably transitory, state of matters which have affected the coal trade for the last eighteen months (1872-73), we may undoubtedly assume, that English colliery owners can sell their produce at the mine *at a profit*, at a much lower figure than the *cost price*, at most of the mines in Belgium and the North of France.

When the thickness of strata which separate the seams from each other is not great enough, regard being had to the thickness of the seams themselves, then, removing pillars without filling-up in medium sized seams, and taking out pillars and head-coal in thick seams, are accompanied by certain inconveniences which have been already pointed out. These are: dislocation of the superincumbent ground; breaking up of the upper seams; an increase of the quantity of water to be pumped; and damages at the surface for which the land-owner has to be compensated. Moreover, in those cases where the working of head-coal is on a large scale, or, in other words, where the seam is very thick, a loss of mineral takes place, and there is always a danger of standing fires which sometimes cannot be extinguished.

The employment of a filling-up is to be recommended in such cases, notwithstanding the increase of cost price; and this is all the more urgent, since it prevents great dislocations of the strata although not a gradual settling down.

(**330**) When the thickness of the seam is so great that it cannot all be taken out in one working, we have seen that, if it is nearly horizontal, it may be treated as if it were composed of several seams, each to be worked separately.

These different slices should be taken in descending order, if the method of removing pillars without filling-up be employed; and they may be taken in an arbitrary order, but usually ascending, if stowing is employed.

The employment of a filling-up is to be recommended all the more, in proportion as the total thickness of the seam increases; indeed, this method is being gradually adopted; and it is found that the diminution of surface damages, of the cost of working, and sometimes of timbering, together with the increased quantity of mineral obtained from a given area, the fewer chances of accident to the workmen, and the less probability of standing fires, are positive advantages, which more than compensate for the cost of procuring, and filling in, the dead-stuff.

(**331**) Lastly, if we consider the thick, nearly vertical seams, which should be taken out by a method of cross-working, we have the same kind of motives as with horizontal seams, to decide the question as to whether a method of removing pillars and head-coal without filling-up, or with filling-up, should be adopted; and, indeed, the use of stowing is becoming more and more preferred in both cases.

There is, however, this difference between the two cases, other things being equal, that nearly vertical beds are less easily worked than horizontal ones; the principal reasons being the increased cost price of working, and the fact that the smaller horizontal extent of the slices does not admit of so large a daily output at a given level.

(**332**) From what has been said, it may be concluded that, when a certain quantity of coal has to be worked out of a field of given area, this will be done to more advantage if the beds are horizontal than if they are nearly vertical; and if the total thickness of coal be 33 ft. (10 metres), for example, it will likewise be worked to greater advantage if the coal is contained in five or six seams, each 5 to 6 feet (2 metres or rather less) thick, than if it were composed of a large number of thinner seams : for instance, fifteen seams each 2 ft. 3 in. ($0^{m}\cdot65$ to $0^{m}\cdot7$), or one seam 33 feet (10 metres) thick.

If it were desirable to specify these advantages more precisely with the aid of figures, as far as that can be done when such variable elements, as those on which the cost price depends, enter into the calculation, we might perhaps state the matter thus :

1. *Thin beds worked with filling-up* (*long-wall*), are those in which the cost price varies most, according to the thickness of the seam, its dip, the nature of its roof, etc. They can seldom be worked for less than 6s. to 7s. 2d. (7^{f},50 to 9 francs) per ton, if they are horizontal; or from 7s. 2d. to 8s. 9d. (9^{f} to 11 francs), if they are vertical.

2. *Beds of medium thickness worked without filling-up, by the pillar and stall method.* When these seams are in the most favourable conditions as regards dip, facility of breaking down the coal, and solidity of roof, we do not consider that, in any district, their produce costs less than 4s. (5 francs) per ton at the present time, taking into account the redemption of, and interest on, capital invested, as well as the actual costs. This cost, which is altogether exceptional, will always be higher when any of the above circumstances are less favourable : for instance, if the quantity of timber required is great, if the seam is much intersected by faults, if it is nearly vertical, etc.; and in these cases the cost will usually be 4s. 10d. (6 francs) per ton, or even more.

The employment of a complete filling-up, instead of allowing the roof to fall, may perhaps lessen the cost somewhat, in regard to some of the principal items of expense, especially timbering; but a general increase of cost may be reckoned upon, varying from 5*d*.

to 10*d.* (0^{f},50 to 1 franc) per ton, according to circumstances.

3. *Thick seams.* We consider that horizontal beds, in which the coal is firm, is not inflammable, and has a good roof, can be worked by the method of long blocks with removal of the pillars, either with or without a previous division into slices, with the same economy as beds of medium thickness as far as the ordinary working expenses are concerned. But they are inferior to the latter class, inasmuch as they cannot be taken out so completely, and their working causes greater damage to the surface; for reasons already given, however, especially in No. **313** — the above-mentioned method of working them is seldom employed.

Under ordinary circumstances, they are worked with a complete filling-up, either in slices parallel to the stratification, or horizontal ones; and the cost price of the coal varies between 5s. 7d. and 6*s.* 5d. (7 to 8 francs) per ton for horizontal seams, and from 6*s.* to 7*s.* 2*d.* (7^{f},50 to 9 francs) for vertical seams.

(**333**) We give these figures only as approximately mean values applicable at the present time (1873); but they are not intended to dispense with a special calculation in any given case; and we think that, under special circumstances, it would be well to take the values higher than those we have given : for example, if the establishment of the colliery has required a large outlay, if the expenses of pumping are heavy, if the richness of the deposit is very irregular, if the nature of the roof is such that it requires much timber, etc.

It may be estimated that, of the two hundred and odd millions of tons of coal produced in the world annually at the present time, at least two-thirds of the quantity are produced by seams of medium thickness, one fourth by thin seams and the rest, about 8 per cent, by thick seams.

These figures give a means of calculating a mean price if desired. Allowing, for instance, 5*s.* 2 ½*d.* (6^{f},50) per ton for the first; 7*s.* 7*d.* (9^{f},50) for the second; and 6*s.* 4 ¾*d.* (8 francs) for the third class of seam; we obtain a general mean of 6*s.* 0 ¾*d.* (7^{f},57) which is, however, too general to be of any service to the miner.

Lastly, we would add that these prices are understood to mean the cost of the coal at the mouth of the pit, and apply only to the present time. They cannot but increase with the lapse of time, and that somewhat rapidly, on account of the increase in the rate of wages, the price of timber, and of all other kinds of materials.

Excepting, however, at times of crises, the cost prices will increase less rapidly than the selling prices; because, whatever may be done to meet it, the increase of output will not be able to keep pace with the increased demand. This growing insufficiency will have an inevitable effect; it will cause a special rise of prices, beyond what the gradual depreciation in the value of money would require. (*See*, No. **72**.)

§ 3. — Appendix on the employment of stowing.

(**334**) In the two preceding sections we have seen the importance of the *rôle* played by stowing in the methods of working applied to mineral deposits which occur in the form of lodes, masses, or beds.

Without reviewing all the details, we shall recall the following facts : Sometimes the necessary quantity of stuff is produced by the working itself, being obtained either in the deposit or from the rocks which enclose it; at other times, it has to be obtained either partly, or wholly, from other parts of the workings, to make up for its insufficiency, or absence, in the working-place. Filling-up, which is useful in a general way, may be said to be indispensable in thick seams which have to be entirely taken out, if we wish to avoid the various inconveniences which arise, when methods of working out without filling-up are resorted to, especially the loss of a certain, often important, part of the useful mineral, which is all the greater when the pillars are not removed at all. Lastly, filling-up has no other drawback than a certain augmentation of the cost price, often more apparent than real; and this drawback will become less and less in regard to certain substances, and assuredly in regard to coal, when compared with the superior interest that will arise in avoiding the waste of a material which, as we have said, is becoming more sought after every day.

It is important, therefore, that we should give some particulars regarding the mode in which the service of procuring and using filling-up materials can be economically organized.

(**335**) In the first place, dead-stuff is produced at the working face by picking out sterile matters from among the useful mineral which is the object of the working (*veinstone*, *deads*, *attle*), in metalliferous deposits, partings of shale (*clod*) and sandstone in coal seams.

It is also produced from the roof, or floor, either when a false roof is taken down, or when stone is cut to make the working-place wide enough or high enough for the miners; or to make its dimension suitable for a haulage way or an air-way.

The advantage of rubbish obtained in this way is that it is produced, as it were, on the spot, and may be said to cost nothing, in this sense, that it costs less to stow it in the workings than to haul it to the pit-bottom, raise it to the surface, and dispose of it there.

Rubbish produced in the workings in coal seams has sometimes this disadvantage that, being principally composed of more or less bituminous or pyritous shales, it is apt to oxidize slowly, become hot, and even ignite spontaneously if allowed to remain long in a heap without being turned over. Cases are not uncommon, in which spontaneous ignition has taken place in old workings (*goaf*) filled with rubbish.

Any shale which is liable to ignite spontaneously should be drawn to the surface, or, at least, buried amongst non-inflammable substances.

(**336**) If dead-stuff cannot be obtained at, or near, the working-face, it must be brought from some other part of the mine, or from the surface. This is done in various ways.

Thus, in a long-wall working, circular empty spaces, surrounded by strong pack-walls, are left at certain places in the goaf; at first they are well timbered and put in communication with the face by one or more haulage ways (fig. 255). When the timber is drawn out, the roof breaks up and falls; a bell or dome-shaped space is formed, which becomes a rubble quarry from which the stuff is carried away through the haulage ways mentioned above.

If the dip of the deposit is considerable, a crosscut is driven into the roof at a convenient level; a wide space is opened at its end, timber being used while it is being formed; the timber is then withdrawn, the roof falls, and the stones are carried away through the crosscut as they are required. (*See* fig. 234.)

It may have been possible to work off a slice next the roof taking out the pillars without filling-up; and afterwards, when the rest of the bed is being worked by a series of cross stalls, the fallen roof of the first slice can be obtained at the end of each working-place when it reaches the roof, and can then be used as filling-up.

If the deposit is intersected by faults filled to a greater or less extent with crushed stuff, then any gallery driven until it cuts one of these faults may become a source from which stowing materials can be obtained. The end of the gallery next the fault is strongly timbered; a short rise is made to the height of a few yards and then enlarged, the rubbish falls and can be drawn away at the bottom (fig. 235).

Lastly, when any preparatory work is done in the enclosing rock (*country*), such as that shown in fig. 230, the resulting stuff can be employed in filling up.

If a supply of dead-stuff cannot be obtained from the sources we have indicated, or if it is necessary to supplement that supply, the requisite quantity is brought from the surface.

Bituminous or pyritous shales, which had to be taken to the surface originally, may be sent back into the mine after they have been burned in heaps in the open air.

Slag (*cinder*) and other refuse of metallurgical processes, easily worked sandy or clayey substances, or even solid rock obtained by extensive blasting operations can also be employed.

The last case is very applicable to a seam worked at a short depth below the surface, when it can be combined with a partial opencast working of the same bed. Thus, the *overburden* which is removed in the process of opencasting, can be used for filling-up underground; and then it costs only the expense of haulage and filling in, if the cost of removing it from the top of the mineral be put down to the account of the opencast.

(**337**) Dead-stuff sent from the surface must be lowered into the mine and conveyed to the working-place. We might suppose it to be let down the winding shaft, and then its weight would to some extent act as a counterpoise to the useful mineral which was being raised; the power of the winding engine could, therefore, be reduced accordingly.

Practically however, this is an unimportant advantage, when we consider the powerful winding engines that are now made use of; and it would not compensate for two difficulties which are inherent to such a system.

The first is making the two services of winding mineral and letting down dead-stuff strictly uniform; whereas the former ought to be quite independent, and capable of being carried on with the greatest possible rapidity.

The second is that, since the useful mineral should descend from the working-places to the pit-bottom, the latter is, from the first, the lowest point of the workings; and, consequently, if the stowing were introduced by the same shaft, it would require to be *hauled upwards* to where it was required.

Thus, in a general sense, the winding shaft and its machinery should not be employed for letting down dead-stuff.

It should be introduced by special shafts sunk vertically from the surface, being either thrown into them, or let down by self-acting machinery.

From the outset, the stuff should arrive at the *highest point* of the slice in course of being worked; and should only have to *descend* in order to reach the working-place.

When local conditions are favourable, the arrangements for this service should be made in the following way: the waggon which is loaded with mineral at the working-place *descends* to the bottom of the winding shaft; it is then raised to the surface, emptied, and conveyed to the rubble quarry where it is filled with dead-stuff;

from this point it is taken to one of the rubbish shafts; it is let down to the bottom, and from thence *descends* to the working-place, where, after being emptied of its contents, it is again filled with useful mineral.

This arrangement was successfully adopted on a large scale by M. Graffin, director of the Grand-Combe mines in the Department du Gard.

The local conditions which have been ingeniously taken advantage of, are such that, during their whole circuit, the waggons are assisted by the action of gravity, except while they are being raised in the winding shaft; they descend from the working-places to the bottom of the shaft; from the top of the shaft to the rubble quarry; from the rubble quarry to the top of the rubbish-shaft; from the top to the bottom of this shaft; and thence to the face, from which they set out filled with coal, and to which they now return filled with dead-stuff.

This arrangement avoids confusion at the pit-bottom and in the haulage ways; it permits of these galleries being made narrow and at a small cost; it makes the haulage very economical, since it is only in one direction; and the inclination of the roads can be made sufficiently steep to cause the waggons to descend alone under the action of gravity.

(**338**) It is usually allowed that every cubic yard excavated in coal will furnish $\frac{3}{4}$ ton of the mineral (1 statute ton per 36 cubic feet — 1 metric ton per cubic metre). Theoretically we ought to have 18 cwt. per cubic yard (1200 kilogrammes per cubic metre) as the density of coal is about 1·2. The difference is caused by the refuse picked out, and by the inevitable loss of small coal produced in breaking down, and above all, in hewing.

When the excavations are carefully packed it is usual to allow four fifths of stowing, *i. e.* 28·8 cub. ft. per ton (8 hectolitres per metric ton) of coal extracted; the difference of 7·2 cub. ft. is due to the unfilled spaces left for haulage ways; to the fact that the stuff is not always tightly rammed in up to the roof; and, lastly, to this, that by a well known phenomenon — the sinking of the roof in places that are not immediately filled up — the dimensions of the space are somewhat reduced.

Allowing that the stuff worked for the purpose of being used as stowing increases 50 per cent in bulk when broken; it will be seen that if we extract one ton of coal we must introduce the rubble produced by 19·2 $\left(\frac{2}{5}\times\frac{4}{5}\times 56\right)$ cub. cubic feet ($\frac{8}{15}$ metre per metric ton) of solid rock into the workings.

From these data we may obtain the approximate cost per ton, due to the employment of this method of filling up.

Let it cost 10d. to quarry 56 cub. ft. of solid rock (1 franc per cub. metre) and 5d. ($0^{\text{f}},50$ per cub. metre) to convey this quantity to the working-places and fill it in ; the cost of stowing per ton of coal excavated will be $\frac{2}{5}\times\frac{4}{5}(10+5)=8$d. $\left(\frac{8}{15}(1+0,50)=0^{\text{f}},80\right.$ per metric ton$\left.\right)$.

This is not an abnormal figure; and it represents, very nearly, the expense that would be actually incurred, under ordinary circumstances.

APPENDIX.

EXPLANATION OF THE PLATES.

Plate I. — Figures 1 to 10.

FIG. 1. — No. **10.** — This figure shows what is meant by the *dip* and the *strike* of a deposit, which, considered independently of its thickness, is compared to a curved surface coinciding either with the roof or floor.

AB being the horizontal trace of this surface, the tangent MM' at the point m is the *strike* (*bearing*) at that point.

The horizontal trace of a vertical plane at right angles to MM' at m gives the projection P_1P_1' of *the line of dip* and the point of the arrow indicates the *direction of the dip.*

Turning this vertical plane round P_1P_1' as a hinge, the curve CD is the trace of the deposit on the vertical plane, the tangent PP' to the curve CD is the line of dip, and this dip is measured by the angle $P_1mP = P_1'mP' = \alpha$, that this tangent makes with the horizontal plane.

FIG. 2. — No. **10.** — This figure shows how the direction of the dip and strike may be defined at any given point with regard to the N. and S. meridian, whether the true or the magnetic meridian.

We obtain all the possible positions of the line M*m*M′ of the preceding figure by varying the angle N*m*M′ from 0 to 90° towards the East or towards the West, or from 0 to 180°, if it is agreed to count all the angles in the same sense (from North to South passing by the East for instance).

The dip and the strike will be shown, at the same time, by varying the angle of the straight line mP_1, *drawn in the direction of the arrow*, from 0 to 360°. Thus, for instance, by saying according to the figure, that the dip is an angle α, and that the line of dip is directed at 305°, it will be understood that the deposit strikes N. 35° E., or E. 55° N. and dips towards the West at an angle α.

Fig. 3. — No. **15**. — Example of a bed with *partings*, that is to say, one in which the useful substance is divided parallelly to the stratification by thin, more or less continuous beds *a*, *b*, *c* of sterile matter.

Fig. 4. — No. **15**. — Example of a seam *splitting*, that it to say, of a single seam changing into two distinct seams which have to be worked separately, in consequence of the gradual development of a parting.

Fig. 5. — No. **16**. — Example of a *beaded* seam, showing a series of *swellings* or *pockets*, separated by *nips*.

These irregularities might be contemporaneous with the deposition of the seam; but in all cases where they have been accompanied by changes of level, or where the alterations in thickness occur sufficiently suddenly to make the want of parallelism apparent to the eye at a given point, they are posterior to the deposition and should be attributed to movements of the rocks causing unequal pressure on the mineral while in a more or less plastic state.

Fig. 6. — No. **16**. — Example of a *trouble* in a seam, that it to say, when the roof and floor are no longer regular and where the

substance of the seam itself is more or less altered. This trouble is produced by elevatory movements causing inequalities of pressure, and breaking or crushing the seam and the enclosing rock.

Fig. 7, 8, 9. — No. **16**. — Examples of effects produced by a fault due to elevation. All the shades may be observed between a clean sharp fracture such as AB (fig. 7) and a simple bending (fig. 9), where the rocks were sufficiently plastic to be simply bent and drawn out in the direction AB without breaking.

Fig. 10. — No. **16**. — Example of the irregularity known as a *want*, *balk*, *wash-out*, or *fault of erosion*. This is a change of thickness produced, not by the thinning out of the whole of the layers composing the seam, but by the removal or suppression of the upper layers from erosion subsequent to the deposition.

Plate II. — Figures 11 to 21.

Fig. 11 and 11 *bis*. — No. **16**. — The object of this figure in to point out the different alterations which may have been effected by atmospheric agencies, either near the outcrops or near fractures, or *faults*, which often cut up the ground and afford access to these agencies.

Fig. 12. — No. **17**. — Example of the *folds* and *contortions* that may be exhibited by a series of beds of sedimentary origin.

A special seam such as MN makes a *saddle* or *anticlinal* at A, and *troughs* or *synclinals* at B and D. The reason that the saddle no longer exists at C is because it has been removed by subsequent denudation, we have what may be called an *anticlinal in the air*.

Fig. 13. — No. **17**. — Another example of folds and contortions in which the undulations of the preceding figure are replaced by

more or less clearly defined sharp angular bends, and the beds elevated in certain places at an angle of more than 90°.

Points such as A and B corresponding to the saddles and troughs of fig. 12 are here called *hooks;* parts such as AB and CD take the name of *flats*, parts such as AC where the seam is overturned, the roof being below and floor above, are called *rearers*. When a hook is neither exactly horizontal, nor even exactly straight, as is usually the case, it is said to *pitch*, or have an inclined axis.

Two dotted vertical lines on the figure are supposed to represent a shaft in elevation. They show how such a shaft may intersect the same seam several times, where there are flats and rearers. The figure shows three of these intersections; sometimes there are four, five, or even more of them.

FIG. 14. — No. **19**. — Example showing how a fracture, or fault, when accompanied by a change of level, must usually remain more or less open in consequence of the more or less marked unevenness of the line of fracture.

FIG. 15 and 16. — No. **20**. — The object of these figures is to show that, if a fissure has for a time remained open and accessible to the vapours or solutions coming from the interior of the earth, its filling-up ought to present a more or less clean crystalline structure and a banded arrangement more or less symmetrical, either as regards the walls, or as regards fragments of these walls which may be included in it.

FIG. 17. — No. **20**. — Example of a *very compact* vein in solid ground.

FIG. 18. — No. **20**. — Example of a *disseminated* or *scattered* lode in weak ground; fragments of the walls falling in after the formation of the fissure have produced a sort of breccia, occupying a zone o a certain width, and having its various fragments enclosed by the veinstone and ores which have been deposited in the open spaces.

Fig. 19. — No. **24**. — Example of a *bed-vein*, that is to say, a deposit which has been formed in the same way as a true lode, but parallel to the stratification, because the fracture was formed along the line of least resistance presented by a plane of bedding.

Fig. 20. — No. **24**. — Example of a *step-vein*, produced by the stratification being *nearly* parallel to the line MN along which there was a tendency for a fracture of the ground to be produced. This fracture has been deflected locally at the points A and B and has followed the direction of the stratification for a certain distance A*a* and B*b*; so that a broken line MA*a*B*b*N′ takes the place of the straight line MN.

Fig. 21. — No, **24**. — Example of a *contact-vein*. This deposit is interposed between two different rocks, which are simply placed side by side and not closely welded to one another. The plane of contact is evidently a line of least resistance or a joint of easy separation. A deposit of this kind is, therefore, formed by the same mechanical action as the *bed-vein* of figure 19, or the steps A*a* and B*b* of the *step-vein* in figure 20.

Plate III. — Figures 22 to 34.

Fig. 22. — No. **31**. — Figure serving to establish the geometrical consequences of *Schmidt's* rule, or the rule of the *obtuse angle*, which consists in this, that when a fracture or fault has been produced and has been accompanied by a relative movement of the hanging wall and foot wall of the fault, this movement is generally comparable to a *sliding*, in which the hanging wall has been shifted *downwards on the foot wall* along the line of greatest dip.

The result has been that, excepting the case where the deposit is at once vertical and at right angles to the plane of the fault, the two parts of the deposit separated by the fault are no longer prolongations one of the other, and have been *thrown* or *heaved* with regard to one another.

We distinguish :—

The throw along the slope or dip of the fault, represented in projection by OD′, and in true size by OD′ rotated so as to be horizontal.

The vertical throw, equal to DD′;

The horizontal throw along the fault, equal to OS;

The horizontal throw perpendicular to the strike of the deposit, equal to OE;

The shortest distance in the plane of the fault, equal in true size to OF;

The absolutely shortest distance at right angles to the plane of the deposit, equal to OG;

The throw gives rise in plan to a sterile space comprised between the two parallel lines TOV,T′D′C. (*See* the text of Nos. **31** and **32**.)

Fig. 23. — No. **33**. — The object of this figure, which is analogous to the preceding one, is to show that it is not always possible by more inspection to determine the direction in which one ought to turn, after having worked along the strike of the deposit MO, in order to find the point S. It is evident that, in certain cases, a mere variation in *the amount of the dips* suffices to change the *direction to be followed*, making it either OS_1 or OS_2.

It is easily seen that, in the case of dips arranged as shown in the figure, the direction will be OS_2 with a *sufficiently flat* fault and a *sufficiently steep* deposit, and OS_2 with the inverse conditions of a *nearly vertical* fault and a *nearly horizontal* deposit. (*See* the text of No. **33**.)

Fig. 24. — No. **34**. — Example of a case where Schmidt's rule *gives no indication*, the two parts of the deposit separated by the fracture not being at all parallel to one another. The fracture in this case is not due to elevation, but to a sharp fold which the rocks were not plastic enough to bear without breaking.

Fig. 25. — No. **36**. — This figure and the following ones up to figure 34 inclusive, give some examples of the various aspects afforded by the geometrical representation of deposits subjected to the various disturbances already defined.

A series of successive troughs and saddles, or flats and rearers, which have no pitch, or, in other words, the axes of which are not inclined, present a series of parallel lines A′B′C′ if cut by a horizontal plane.

Fig. 26. — No. **36**. — If these same folds and contortions have a certain pitch in any direction, the above parallel lines are replaced by converging lines, and the smaller the pitch the more acute are the angles made by them; they are joined by *curves* or cut one another at *acute angles*, according as the strata have been more or less sharply bent.

Figs. 27 and 28. — No. **36**. — These figures, which ought to be compared with figure 25, apply to the case where the pitch or inclination of the axis changes, and there is consequently a place where it is horizontal. In figure 27 it is supposed that the axis rises on each side of the horizontal part, and in figure 28 that it dips down on each side. The closed curve A′B′ of figure 27 is a *basin* in which the bed exists *below* the horizontal plane; the closed curve B′C′ of figure 28 is, on the contrary, a *hog's back* in which the bed exists above this same plane.

Figs. 29 and 30. — No. **36**. — These two figures correspond respectively to the preceding figures 27 and 28; they suppose that, instead of having wavy troughs and saddles, the beds are bent into flats and rearers separated by hooks, which are generally formed of rectilinear parts joined by sharp curves. The seam exists *below* the closed perimeter A′B′ of figure 29 and *above* the closed perimeter B′C′ of figure 30. The closed lines A′B′ of figures 27 and 29, and B′C′ of figures 28 and 30, are respectively accompanied by the indefinite lines C′ (figs. 27 and 29) and A′ (figs. 28 and 30).

It is thus seen, as already stated, how conditions which can be easily defined geometrically may give rise to somewhat complicated figures with which the mind should be made familiar. (*See* text of No. **36.**)

FIG. 51. — No. **36.** — Horizontal projection of a working area comprised between two given levels A′B′C′, $A_1B_1C_1$, which are carried along two rearers and a flat separated by hooks having a certain pitch. (*See* also text of No. 36.)

FIG. 52. — No. **37.** — Appearance produced on the horizontal plane in the case where a fault beginning at a point M goes on increasing in amount of throw. The barren space is then shown, not by two parallel lines as in figure 22, but by two diverging lines MN and MN′.

FIG. 53. — No. **37.** — Appearance produced on a horizontal plane by a fault whose throw is not constant, but begins at a point M, increases gradually, and then dies away at N. Instead of these being two parallel lines as in fig. 22 or two diverging lines as in fig. 52, the sterile space corresponding to the throw is enclosed by two lines which diverge for a time from the point M, then run nearly parallel for a certain time and finally converge to another point N.

FIG. 54. — No. **37.** — Appearance produced on the horizontal plane by a fault of given throw affecting a deposit which, instead of being plane, exhibits a series of folds and contortions formed before the fault. The two intersections MN and M′N′, made in the two parts of the deposits by the plane of the fault, are formed by the same curve having slipped a certain distance parallelly to itself. The result is that the barren space included between these two curves exhibits appearances of successive swellings and pinchings, and in certain places might be replaced by parts of the deposit, which, instead of being lost, would appear repeated upon itself. We again state that the mind should be

made familiar with all these complications; and it must be understood that figures apparently very complicated may result from the combination of elements susceptible of a simple geometrical definition.

Plate IV. — Figures 35 and 36.

Fig. 35. — No. **43.** — This figure and those following it to 46 inclusive represent certain given deposits which come under the head of beds, lodes, or masses. They are briefly described in the text as examples.

Figure 35 represents in particular the seams of the Mons coalfield, which is in some measure a standard one on account of the large number of seams it contains, their regular variation in quality according to depth, and their remarkable peculiarities.

The figure is a section at right angles to the average strike of the seams.

Proceeding from South to North we distinguish :—

The region of the rearers and flats;

That of the southern measures;

The trough or synclinal formed by the basin considered as a whole;

The region of the northern measures.

This coalfield is remarkable, in spite of the generally even surface of the ground, for bearing the impress both of violent elevatory movements, and also of an enormous amount of denudation. (*See* the text No. **43.**)

Fig. 36. — No. **44.** — Section of the Liége coalfield, which, like the preceding one, is an expansion of the great carboniferous zone which stretches out from the Straits of Dover to the right bank of the Rhine. This section illustrates certain analogies and differences between the Liége and Mons coalfields. (*See* the text No. **44.**)

Plate V. — Figures 37 to 39.

Fig. 37. — No. **45**. — Section of part of the Newcastle coalfield. This coalfield differs essentially from the preceding ones, for the seams are fewer in number and the total thickness of coal is less; the superficial extent, however, is greater (and this more than makes up for the smaller richness per acre); and, lastly, the individual seams are thicker, more regular and more easily worked.

The only important disturbances are faults, one of which has a throw of 90 fathoms and, at the time of its formation, must have produced a difference of level at the surface which has since been entirely obliterated by an enormous amount of denudation.

Fig. 38. — No. **46**. — This figure is a section of the coalfield of the Grand'Combe, the most important, on the whole, of all those in the South of France, below the latitude of Saint-Étienne.

Like many of the French coalfields, it is distinguished from the Franco-Belgian coalfield by the smaller number and greater individual thickness of the seams.

The seams are generally pretty regular, although affected in one place by a disturbance, which exceeds in importance those mentioned hitherto. We refer to the great fault, accompanied by a fold, which brings together the Upper and Lower Coal Measures on the Eastern side of the coalfield, and on which the other smaller disturbances seem to depend. (*See* the text No. **46**.)

Fig. 39. — No. **47**. — Section of the Ronchamp Coalfield (Haute-Saône). This section is given as an example of a coalfield limited in extent of richness, compared with the preceding ones, but still having a great local importance. The somewhat sporadic character of its coalfields, scattered about in a great number of places and individually only of secondary

or local importance, is a feature which forms an essential difference between central and Southern France and Northern France and the adjoining countries.

Plate VI. — Figures 40 and 41.

Figs. 40 and 41. — No. **48**. — The figures show a section and a plan of the system of lodes worked in the Maria-Adalbert mine near Przibram (Bohemia). (*See* the text No. **48**.)

Plate VII. — Figure 42.

Fig. 42. — No. **49**. — This figure shows on a small scale the whole of the lodes near Freiberg in the Erzgebirge. This very complicated system includes a large number of lodes which are arranged according to three mean directions, and in which, by the careful and persevering study of several generations of engineers, eight distinct periods of filling-up have been recognized. Some of these periods seem to be very modern. (*See* the text No. **49**.)

Plate VIII. — Figures 43 to 47.

Fig. 43. — No. **50**. — This figure represents, on the same scale as figures 40 and 41, Fowey Consols mine in Cornwall.

Comparing figures 40 and 43 we learn from these two examples, which may be fairly considered as standard ones, what is the general arrangement of a system of lodes developed in a normal manner. (*See* Nos. **45** and **50**.)

Fig. 44. — No. **51**. — This figure and the two following ones refer to examples of massive deposits. Figure 44 gives two horizontal sections of the deposit of coal at Montchanin, forming a

mass of remarkable size, which ought to be looked upon as a swelling out of a number of seams which, on the whole, have a beaded arrangement, as shown in figure 5.

FIG. 45. — No. **53**. — Section of the deposit of spathose iron at Stahlberg. This deposit is an example of a massive mode of occurrence very characteristic of lodes of spathose iron, for instance, in the Pyrenees, the Atlas, etc.

FIG. 46. — No. **54**. — Section of the iron ore deposit at the Fort of Saint-Pancré (Moselle). The deposit is formed by a series of masses or pockets, filling more or less irregular cracks or spreading out at the surface. These masses, like the preceding deposit, were formed by a process analogous to that by which lodes are produced, whilst the Montchanin mass (No. **51**) and the Mokta mass (No. **52**) are true beds as far the mode of formation is concerned. Figure 46 shows the different cavities laid open in course of working. It is evident, in spite of their being scattered about, that they are arranged according to certain definite lines. (*See* the text of Nos. **51**, **52** and **54**.)

FIG. 47. — No. **76**. — This figure is intended to illustrate the theory of *Artesian wells* which are formed by sinking bore-holes until they encounter a subterranean water-sheet lying between two beds which are relatively impermeable.

The facts are entirely in accordance with this theory, and all their details are explicable by applying to them the most simple rules of hydrostatics and hydraulics. (*See* Nos. **70** to **79**.)

Plates IX and X. — Figures 48 to 58 and 59 to 75.

FIG. 48. — No. **82**. — This figure and the others following it to figure 98 represent the various parts of the special apparatus of the borer.

Figure 48 — The *fork* joint.

Fig. 49. — No. **82**. — The *screw* joint which is preferable to the foregoing, although it does not allow of the rod being turned in both directions.

The preference is due to the absence of separate pieces (bolts and nuts), and to the fact that the joint can be made more quickly and can always be screwed up tightly so that it keeps firm, even when the rods have been more or less strained by the work. In both figures (48 and 49) a shoulder is shown just under the swelling of the joint, which serves for the purpose of holding any length of rods in the bore-hole by means of a key. (*See* description of figure 94, further on.)

Fig. 50. — No. **82**. — A joint for wooden rods; these rods are often prefered to iron ones on account of their comparatively lighter weight, especially when submerged in the water which fills the bore-hole.

Fig. 51. — No. **83**. — Œynhausen's sliding joint. By this joint the rod is divided into two parts, one above and the other below it; the latter carries the tool and is alone subjected to the shocks of boring.

Fig. 52. — No. **84**. — Kind's free-fall instrument: the tool is detached and falls to the bottom of the bore-hole as soon as the rod begins to redescend under the action of gravity.

Fig. 52 *bis*. — Is another free-fall instrument designed by M. Escher. (For description of figures 52 and 52 *bis*, *see* the text No. **84**.)

Fig. 53. — No. **84**. — Degousée and Laurent's free-fall instrument, which acts when the ascending rods reach a given height above the bottom of the bore-hole; this height is constant during any one boring operation: but can be varied every time the tool is let down from the surface, by adjusting the height of the *dead weight* which determines the disengagement of the head of the tool.

Fig. 54. — No. **84.** — M. Dru's free-fall instrument. In this case the tool is disengaged when the top of the rod strikes against a spring which suddenly arrests its upward motion.

Fig. 55. — No. **85.** — Guide for keeping the rod vertical and preventing it from rubbing against the sides of the bore-hole.

Fig. 56. — No. **85.** — Parachute for retarding the descent of the rod in the event of its accidentally escaping from the workmen while being drawn up, or let down, in the bore-hole.

Fig. 57. — No. **86.** — Swivel-head for the top of the rod; it allows the rod to be turned while boring with the chisel is going on, so that a round hole is cut, even with a simple cutting blade.

Figs. 58 and 59. — No. **86.** — Rather more complex arrangements than the foregoing; with these it is possible to keep the top of the rod always at the same height while the hole is being deepened, until there is room to add a short piece of rod. In figure 59 an arrangement is shown, by means of which the amount of progress can be measured accurately at any time.

Figs. 60 to 63. — No. **87.** — Various forms of the *chisel*, which is the principal tool by means of which the hole is deepened.

The *simple* chisel, figure 60, is suitable for boring holes up to a diameter of 10 to 12 inches ($0^{m}\cdot25$ to $0^{m}\cdot30$), and more.

The *step* chisel, figure 61, is suitable for hard rocks, and for diameters of 10 to 20 inches ($0^{m}\cdot25$ to $0^{m}\cdot50$), and upwards.

The *double* T chisel, figure 62, assists in keeping the hole circular, but is difficult to repair.

The *compound* chisel, figure 63, which is indispensable for bores of 20 inches ($0^{m}\cdot50$) and upwards; it has the advantage of being quickly and easily repaired whatever the diameter of the hole.

Figs. 64 and 65. — No. **88.** — Broaching bits, or rounding tools, which serve to dress the sides of the hole, and to enlarge it wherever it has become contracted by the swelling or pushing out of certain kinds of ground.

Figs. 66 and 67. — No. **88.** — Enlarging tools; these serve either to enlarge a hole which has become more contracted than it was when first bored, or to continue a boring below the bottom of a tube, of a larger diameter than the tube itself.

Figure 66 shows the tool closed for passing through the tube; figure 67 shows it open and ready to act, either from above downwards, or from below upwards, according to the case. The arms are opened by pulling up the cord to which the wedge is attached; and they are closed by means of the contrivance described in No. **101**,

Fig. 68. — No. **88.** — Screw augers which act in the same way as enlarging tools by a slow rotatory motion accompanied with percussive movements; they are used for traversing beds of slightly agglutinated sand.

Fig. 69. — No. **88.** — Stone-breaker which is employed for the purpose of crushing or driving into the side, any fragment of a tool, or of hard stone which has fallen from the side, such as a large flint.

Figs. 70 to 72. — No. **89.** — Wimbles, or clearing tools; they are turned round like a carpenter's auger.

Figure 70 represents the *wimble-scoop*, or auger, which is suitable for débris which are ordinarily plastic.

Figure 71, the *clay auger* which serves to clear out very plastic debris, or even to cut the clayey ground which produces them.

Figure 72, the *wimble with auger point*, which is suitable for debris of a sandy consistency. (*See* the text No. **89.**)

Figs. 74 and 75. — No. **89.** — Type of clearing tools which are let down into the bore-hole by means of a cord and filled by giving them a quick up-and-down movement. These are the *sludgers with ordinary valves*, and the *sludgers with ball valves.* They do not clean the bottom of the hole so effectually as wimbles in plastic ground ; but the operation is performed much more rapidly, as they are let down by means of a cord which runs into the hole in a continuous manner, and not by means of the ordinary boring rod.

Fig. 75. — No. **89.** — A clearing tool in which a valve and an auger are combined; it is therefore applicable to sandy ground which the wimble could not easily retain.

Plate XI. — Figures 76 to 91.

Fig. 76. — No. **90.** — Verifying tool, which serves to authenticate the nature of the ground which has been passed through at any depth, after the operation of boring has been completed. (*See* the text No. **90.**)

Figs. 77 to 79. — No. **90.** — Collection of tools for obtaining cores, that is to say, pieces of the rock passed through by the boring.

Figures 77 and 78 represent the tools by means of which a groove is formed at the bottom of the hole, inside of which a longer or shorter core is preserved.

Figure 79 represents the tool by means of which the core is broken off and brought to the surface after the necessary marks have been made on it to enable it to be placed in a position parallel to that which it occupied before being detached, and in this way to determine, not only the nature of the stratum, but also its dip and strike in the interior of the earth. (*See* the text No. **90.**)

Fig. 80 and 81. — No. **92.** — Examples of tools used for seizing rods which have remained in the hole in cases of accident.

The *claw*, or *crow's foot*, (fig. 80) may be employed when the breakage has taken place at a short distance *above* one of the joint swellings; the *bell-screw may be used* in every case, but is *necessary* when the breakage has taken place a little *below* a swelling. The text of No. **92** gives details of the manner in which these tools are used.

Fig. 82. — No. **92**. — *Wad-coil*, or *spiral worm*, which serves to lay hold of the sludger-cord if it happens to fall to the bottom of the bore-hole by accident.

Fig. 83. — No. **92**. — *Pinching-hook* which *may replace* the claw and the bell-screw, and which *necessarily replaces them* when the breakage has happened at a distance from a joint-swelling, and the rod turns round easily, not being jammed in the hole.

The first circumstance excludes the use of the claw, and the second, the use of the bell-screw.

Fig. 84. — No. **93**. — All the details of a temporary tube joint made with bolts and nuts. (*See* the text No. **93**.)

Fig. 85. — No. **93**. — Tool which may be employed for making the foregoing joint for temporary tubes by means of cold rivets.

Figs. 86 and 87. — No. **95**. — Tools used for putting in a *partial lining* of tubes in the bore-hole at any desired depth. The first tool is freed from the tube by turning it round so as to unmake a bayonet joint; the second by drawing away the stay which holds its branches open by means of a string, whose free end has been retained at the surface while the tubes were being let down. (*See* the text No. **95**.)

Figs. 88 and 89. — No. **95**. — Tools used for forcing down a column of tubes which extends to the surface, partly by blows partly by turning it round at the same time.

Figure 88 represents a kind of ram, or monkey, which gives the blows on a block fitted into the top of the tube; figure 89 a handle by means of which the tube is rotated backwards and forwards. The blow and the rotatory movement should be simultaneous.

Fig. 90. — No. 95. — An arrangement by which the blow of the ram represented above (fig. 88) is made more effective, or even replaced entirely, by a continuous pressure. This arrangement, which allows of great pressure being employed, is necessary when the column of tubes is very long and bulky.

Fig. 91. — No. **96**. — Kind's tube-drawer or *shuttle*. This instrument acts by wedging itself firmly against the sides, after it has been let down to the desired point in the column that has to be drawn. The cylinder which surmounts the tube-drawer, having been previously filled with sand, is raised by means of a cord, and then a strong tension is put upon the rope by the engine.

Plate XII. — Figures 92 to 100.

Fig. 92. — No. **96**. — Alberti's tube-drawer, or *wedging tube-drawer*, acts on a similar principle to the foregoing, except that the wedging against the sides is effected by a series of wooden wedges instead of sand.

Fig. 93. — No. **96**. — Example of an apparatus called a *tube-cutter*, which serves to cut the column into several lengths which are drawn up successively in the event of the column being too long, or too firmly held, to be drawn up in one piece. This tool is employed in conjunction with one of the preceding.

Fig. 94. — No. **98**. — Retaining key (*nipping-fork*, *tiger*) is placed on the boring-floor for supporting the rods which hang in the hole during the successive operations of joining and disjoining

the different pieces when a tool is being let down into, or drawn out of a bore-hole.

Fig. 95. — No. **98**. — Large *wrench*, or *spanner*, for joining and disjoining the rods.

Figs. 96 and 97. — No. **98**. — *Drawing-cap*, and *grips*, by means of which the different lengths of rod are successively suspended to the engine rope, and the system of rods is lifted or let down in lengths which are regulated by the height of the pulley-frame.

Fig. 98. — No. **99**. — *Brace-key*, or *tiller*, which is used for turning the rod during the process of boring. (*See* the text No. **99**.)

Fig. 99. — No **108**. — This figure and those following it, as far as 104 inclusive, represent the complete surface arrangements necessary for starting and continuing a boring with the different special apparatuses already described, and represented in figures 48 to 98.

Figure 99 is a very simple erection applicable to a boring of little importance. The operations are performed entirely by hand, and therefore neither the operation of boring nor the lifting and letting down of the rods can be done quickly.

Fig. 100. — No. **108**. — Represents the erection required for boring with the rope.

It was employed in one of the mines near St-Etienne.

We already know that one of the advantages claimed for it, by the partisans of this method of boring, is the simplicity of the erections required, arising from the fact that the weights to be handled, either during the operation of boring or bringing up the tool, are not of much importance. This explains the small height of the pulley-frame and the unimportant character of the apparatus for boring and for drawing up the tool.

Plate XIII to XVI. — Figures 101 to 104.

Figs. 101 to 104. — No. **108**. — The four plates XIII to XVI represent the machinery and plant set up for important borings; these are essentially distinct from those to which figures 99 and 100 refer, both on account of their magnitude and the nature of the operations.

They were erected at the following places:

Figure 101, for the well at Passy, by M. Kind.

Figure 102, for the well of M. Say's large sugar refinery in the Boulevard de la Gare, by M. Dru.

Lastly, figures 103 and 104, for the two large wells which are being sunk at present for the Municipality of Paris, the former at La Butte-aux-Cailles by M. Dru, the latter at La Chapelle by MM. Degousée and Laurent.

In figure 101 (Pl. XIII) the drums which carry the flat ropes for handling the rod are seen at A both in plan and elevation. They are worked by a horizontal steam-engine with one cylinder. The flat ropes, which are guided by rollers, pass over pullies placed at such a height that the rod can be joined and disjoined in lengths of 98·4 feet (30 metres).

B is the boring beam or lever which is actuated by a special steam cylinder, to the piston of which it is joined by a chain. The elastic spring which limits its stroke is shown in the figure.

C is the winch for the rope of the sludger; it is turned by a steam-engine through the medium of an endless chain. The sludger-rope passes over a pulley D carried in a frame moving on a vertical spindle which allows it to be turned aside to make room for the flat ropes. It must be understood that the drums are disconnected from the engine when the winch is being used; and *vice versâ*.

The well which was intended to have a finished diameter of $23\frac{1}{2}$ inches ($0^{m}\cdot60$) inside the permanent wooden tubing, was originally begun with a diameter of 3 ft. $7\frac{1}{4}$ in. ($1^{m}\cdot10$).

A depth of about 460 yards (420 metres) was reached in ten months; but subsequently the work was much hindered by the occurrence of accidents.

Figure 102 represents:

1. A, the windlass for handling the rod; two chains are wound upon it in contrary directions and to these the rod is suspended indirectly. A fixed block with four sheaves is placed at the top of the shearlegs, and the end of each chain is fastened to a movable block with one sheave which carries the hook to which the rod is suspended. The tension on each chain is thus reduced to one third of the weight to be lifted. The windlass is worked by a horizontal engine with one cylinder through the medium of endless bands.

2. B, the boring beam, which receives its motion from a special steam engine by means of a connecting rod attached to the piston. The upward stroke of the lever is limited by an elastic spring, and the downward stroke by a stop, or buffer-block, against which it strikes, the shock producing the disengagement of the tool. (*See* fig. 54 and No. **84.**)

3. C, the windlass for the sludger, carrying a wire rope.

The same transmission of the power by means of belts is used at pleasure, for putting either of the windlasses, A or C, in motion, by simply moving a pinion by means of a disconnecting lever.

The direction of the motion is changed by means of two belts, one with its bands parallel, the other with them crossed.

Figure 103 represents the same general arrangements as figure 102, except that the various apparatuses are on a larger scale, the well having been begun with a diameter of 6 ft. 6 in. (2 metres). and with the intention of sinking it to a great depth.

Figure 104, in which the same letters refer to the same parts of the apparatus, presents some different arrangements.

Thus, the windlass carries only one chain which is arranged in such a way that the tension on it is only equal to one-half of the weight to be raised.

The work of boring is performed by the same engine that raises the rod. The lever is worked by means of a connecting rod and flat crank pierced with a series of holes, which allow of the radius being varied according to the height of stroke that may be desired. The tool detaches itself when the crank is at its lower dead-point, or the boring rod at the top of its stroke. (*See* Nos. **84** and **99**.)

The boring was begun at the bottom of a pit 6 ft. 6 in. (2 metres) in diameter.

Figures 104 to 104 are taken from the *Bulletin de la Société d'encouragement* (1856), the *Portefeuille économique des machines* (1864), and the *Annales industrielles* (1869), to which we would refer for more minute details than our present space will allow.

Plate XVII. — Figures 105 to 120.

Fig. 105. — No. **112**. — These figures and the following ones, up to 132 inclusive, refer to the tools and processes employed in breaking ground.

Figures 105 represent different kinds of picks, with one or two points, employed in working loose ground. (*See* the text of No. **112** for details relating to the shape, weight, handles, etc., of these tools, all of which details have their importance.)

Fig. 106. — No. **112**. — Shovels employed for filling.

Fig. 107. — No. **113**. — Wedge and mallet used for facilitating the removal of ground with the pick when a deep cutting has to be made.

Fig. 108. — No. **113**. — Elevation and vertical section of a cutting arranged in steps, or *stopes*, for the removal of a considerable quantity of loose ground by means of the tools shown in figures 105 to 107.

FIG. 109. — No. **114**. — Picks for soft ground.

A. Ordinary pick.
B. Rock or stone pick.
C. Poll pick.
C′. Schrämhammer.
D. Double-pointed or English pick.
E. Rivelaines.
F. Various forms of the eye of the tool.
G. Various forms of the point of the tool (for the details *see* text of No. **114**).

FIG. 110. — No. **114**. — Wedges and sledge for completing the work of breaking down begun with the pick.

FIG. 111. — No. **114**. — Plug and feathers used near Liége for breaking down rocks which have been undercut with the pick, in places where blasting cannot be used on account of fire-damp.

FIG. 112. — No. **115**. — Gads and sling (used in the *Schlägel-und Eisenarbeit* of the Germans).

FIG. 113 to 114. — Nos. **117** to **119**. — Tools used for blasting in hard rocks.

A. Borers, or drills.
B. Hammer for single-handed boring.
B′. Sledge (mallet) for boring two or three-handed.
C. Jumper for boring holes without the hammer.
D. Scraper.
E. Needle, or pricker.
F. Tamping bar, or stemmer.
(*See* the text Nos. **117** to **119**).

Fig. 114 represents crowbars for dislodging rocks after a blast. The picks B and C, fig. 100, are often used instead of crowbars.

Fig. 115. — No. **119.** — Cartridge joined to safety fuse.

Fig. 116 to 117. — No. **121.** — Various arrangements which have been proposed for diminishing the quantity of powder required in a hole, or chamber, of given height. (*See* the text of No. **121.**)

Fig. 118 and 118 *bis*. — No. **122.** — Tool proposed for enlarging the chamber occupied by the charge. This tool includes a special enlarging apparatus, the arrangement of which is shown in figure 118, and an apparatus for clearing the hole (fig. 118 *bis*). These tools can only work in a hole of tolerably large size. Their object is rational enough; it is to obtain a working chamber of a given diameter, without having to bore the hole of this diameter for its entire length.

Fig. 119. — No. **124.** — Geometrical figure serving to explain the influence of the dimensions of the hole on the useful effect, referred either to the work of boring, or to the expenditure of powder (*see* the text of No. **124**).

Fig. 120. — No. **125.** — Geometrical figure which shows the advantage of firing two holes simultaneously (*see* the text of No. **125**).

Plate XVIII. — Figures 121 to 125.

Fig. 121 and 122. — No. **131.** — Arrangements employed for breaking down very tenacious, or hard, rocks by means of fire.

The figures show the arrangements adopted to drive an end, enlarge a working place, and make a rise.

The treatment with fire is sometimes only a preparatory operation, which has to be completed by blasting with powder.

Fig. 123. — No. **132.** — Guibal's cartridges, for substituting hydraulic pressure for the action of powder.

The figures represent the whole of the apparatus and the details of the little caoutchouc bag, the ends of which are turned round and form two self-closing hydraulic joints.

Fig. 124. — No. **133**. — Arrangements for cutting away soluble rocks by means of water.

Fig. 125. — No. **134**. — Example of an open working where the rock is solid enough when in place, and jointy enough when broken down. to make it advantageous to break large quantities at once.

Plate XIX. — **Figures 126 to 132**.

Fig. 126 to 128. — No. **135**. — Examples of levels driven in solid rock free from joints.

Fig. 126 gives a cross and longitudinal section of a small level driven by the ordinary blasting methods.

The longitudinal section shows the arrangement of the *end* and the *bottom stope*, the object of which is to allow a larger number of miners to work simultaneously, and at the same time to facilitate the work.

Figure 127 is the same level, with the modification which may be made when dynamite is used.

Figure 128 is the section of a large tunnel, showing the drift at the top of the arch, the two lateral enlargements, and the two underhand stopes.

The numbers marked on this figure indicate the order in which the above works are carried out.

Fig. 129. — No. **136**. — Example of a shaft sunk in rocks of the same nature as that of figures 126 to 128.

The section shows an arrangement which has the same object as the *end* and the *bottom stope* of figure 126.

Fig. 130. — No. **137**. — Example of long-wall working in a bed of coal.

We can distinguish :—

At A we have the elevation of the working face showing the different holings, separated in front by small pillars of coal which are left in order to prevent the coal from falling too soon, the two vertical cuts, and, lastly, the holes bored in the roof for breaking down the coal by means of wedges or blasting.

B shows a plan of similar long face proceeding towards the rise.

B′ shows a plan of similar long-wall workings with the face *parallel* to the cleat of the coal, and *oblique to the direction* in which it is driven.

Fig. 131 and 132. — No. **138**. — Examples of workings in very thick beds of coal. Fig. 131 shows underhand stopes and figure 132 overhand stopes. (*See* the text of No. **138** for the comparison between these two kinds of workings, each of which has its well-marked advantages and disadvantages).

Plate XX. — Figures 133 to 136.

Fig. 133. — No. **150**. — This figure and the following ones, up to figure 144, refer to the subject treated in Chapter VI. (Application of machinery means to breaking ground.)

Fig. 133 shows the auger with which holes are bored by a rotatory movement in soft rocks, such as the gypsum of the neighbourhood of Paris.

Fig. 134. — No. **149**. — Lisbet's boring machine, acting by rotation like the auger shown in figure 133, but adapted for drilling holes in rocks harder than gypsum. This boring machine is suitable for soft beds and shales in the coal measures, where it effects a decided saving of time in boring holes for

blasting. The harder the rock the smaller is the advantage obtained by the use of the machine (*see* text of No. **149**).

Fig. 135. — No. **150**. — Leschot's boring machine. This apparatus has the advantage over all machines which use steel augers, that it can act by rotation in hard and siliceous rocks. The tool is hollow and has the end in the form of a crown set with black diamonds. This hollow shape diminishes the work very considerably because it leaves a solid core in the axis of the hole, which can easily be got out afterwards.

Unlike Lisbet's borer, Leschot's machine is especially suitable for very hard rocks.

Fig. 136. — No. **151**. — Design of the coal-cutter proposed by M. Gay, suitable for soft rocks, such as coal, certain iron ores, sulphur marls, etc., etc. It acts by a rotatory motion against one of the sides of the undercut, which it gradually widens at every turn of the tool. The weight which causes the tool to press against the side of the cut is not shown in the figure.

Plates XXI and XXII. — Figures 137 and 138, and 139 to 141.

Fig. 137. — No. **153**. — Delahaye's coal-cutting machine, acting by percussion, and capable of undercutting or boring holes.

The object of this machine is to relieve the workman from the unnecessary fatigue which he undergoes in the usual mode of working, from having to support the weight of the tool, from mass of the tool being too great and its requiring to be wielded at too great a velocity.

Figs. 138 and 139. — No. **155**. — These figures, and the following ones up to 144, refer to the use of prime movers, other than human power, for carrying out the work of breaking ground.

Fig. 138 and 139 show some coal-cutting machines which have been gradually coming into use in England during the last few years.

Fig. 138 gives a general view of Carrett and Marshall's machine which is driven by hydraulic pressure.

Fig 139 shows Jones and Levick's machine, driven by compressed air.

These machines are principally used in coal mines; but they are also applied in the Cleveland iron mines.

In order to ensure success, it is necessary that the seams should be regular, sufficiently thick, tolerably strong, and have a roof firm enough to allow them to be worked by the long-wall method, without requiring the props too near the working face.

Where these conditions are absent, and it is a rare thing to find them all combined in French Collieries, it is not practicable to use these machines.

It is probable that they might be employed with advantage in the iron mines of the East of France, as they are in similar mines in the Cleveland district.

(*See* the text of No. **155**).

Fig. 140. — No. **158**. — Leschot and Perret's boring machine. The tool works on the same principle as the one shown in fig. 155, save that it is driven mechanically, by means of a small rotatory water-pressure engine.

The figure shows the engine, and the mode of transmitting the movement to the tool.

The introduction of water-pressure allows the hand machine to be simplified very considerably, as the parts for effecting the advance of the tool can be dispensed with. The tool is merely kept against the bottom of the hole by the constant pressure of the water, which can be regulated by means of cocks to suit the varying hardness of the rocks. The bottom of the hole is kept clean by letting a small jet of water pass down the hollow rod which carries the tool, so as to wash out the mud formed by the action of the diamonds on the rock.

FIG. 141. — No. **160**. — Sommeiller's boring machine employed in driving the Mont Cenis tunnel.

The figure shows a plan and section of the model finally adopted, after numerous improvements had been added successively.

It is perfectly automatic in every way; but it would be found somewhat long and heavy for levels of ordinary dimensions.

The cylinder A simply drives the boring tool, and a small separate engine B, the speed of which can be regulated at pleasure, actuates all the accessory parts of the machine by means of the long shaft MN.

At C there is a kind of cam which acts on the valve-rod and regulates the entry of air into the cylinder A.

D shows the ratchet wheel which gives the rotatory movement to the tool by means of an excentric.

At EE′ we have the mechanism for effecting the advance, consisting of a fork connected with two rods *f*, a clutch *m* sliding on a feather on the shaft, T, of the ratchet wheel G, and an endless screw V, which is loose on the same shaft. The two rods are subjected to a constant strain forwards from a piston in the valve-chamber, and they would move if the fork were not pressed down on the teeth on the top of the guides by a spring. However, when the piston has arrived at the very end of its course the buffer *t* strikes a stop on the fork and raises it. As soon as it is released, it is pushed forwards, the rods *f* drawing the clutch *m* with them and thus effecting a connection between the endless screw V and the ratchet wheel G. This, it will be recollected, is always in action, consequently V begins to turn, and in so doing worms the whole apparatus forwards by means of the teeth on the inside of the guides, until the fork is stopped by another tooth of the rack.

When the machine has to be drawn back in order to change a tool, the air is shut off everywhere and the pawl of the ratchet wheel G disconnected. A toothed wheel, F, is slipped along the shaft MN and put into gearing with F′. The latter gears into a third toothed wheel and is thus connected with the clutch *m*. The little engine B is now set to work again, the clutch *m* is moved so as to engage with the screw V, and, consequently, when the shaft MN turns, the screw V revolves also, but in the reverse direction, and soon draws the boring cylinder back along the guides.

The arrangement, which renders the percussion independent of the other functions of the machine, gives Sommeiller's perforator a peculiar character, which complicates it somewhat, but has several advantages, and facilitates the working very appreciably.

Thus, the apparatus adapts itself very well to different kinds of rocks, which may require varying rates of speed for turning the borer, and varying degrees of force in striking the blow.

It would have been easy to derive the movement of all the auxiliary parts from the reciprocating motion of the main piston, as, indeed, has often been done in other machines of the same kind.

Plate XXIII. — Figures 142 and 143.

Fig. 142. — No. **161**. — The stand on which the above-described machines are mounted.

The figure shows the stand arranged to receive 8 perforators. The number was subsequently increased to 14.

The stand is a kind of long carriage which carries the supports for the machines in front. These supports are composed of nuts which can be made to go up or down, by turning the large screws V, carried by one of the upper or lower girders. From each nut there projects, externally or internally, a screwed arm; on this there is another nut with a hole in which the end of the perforator is fixed by means of a bolt. This second nut can be moved along the arm, and consequently the perforator can be inclined at various angles.

A system of screws V′, similar to the screws V, serves by means of other nuts to carry the front ends of the perforators. The arm projecting from each nut is not screwed, but is furnished with a slot in which a fork is fixed by means of two bolts; this fork carries the two guides of the perforator.

It is easy to see that by moving the nuts on the vertical screws, and the points by which the perforator is fixed on the arms, the apparatus may be placed, within certain limits, in a desired vertical plane, and have a certain inclination given to it in this plane.

There are two compartments on the carriage behind the machines; one of them carries the air-pipe, which supplies the separate india-rubber hose of each machine, and serves also to hold the spare tools, the other is used as a workshop for any small repairs which can be done on the spot.

There are two other mechanisms on the stand; one serves to move it by hand so as to bring it precisely to the desired distance from the face; and the other serves to fix it firmly in the position which has been chosen.

The first consists of a system of cog-wheels and a hand-wheel, by means of which the hinder axle can be turned round slowly.

The second is placed upon the front wheels which are not connected, and serves to lower the stand relatively to these two wheels, causing it to turn round the axis of the hind wheels, and making two claws, with which the front ends of the lower girders are provided, bite into the ground.

The above-described stand is 29 ft. 6 ins. (9 metres) long 3 ft. 6 $\frac{1}{2}$ in. ($1^{m}{\cdot}08$) wide and 6 ft. 2 $\frac{3}{4}$ in. ($1^{m}{\cdot}90$) high. It weighs 7 $\frac{3}{4}$ tons (8000 kilogrammes). This great weight is advantageous as regards the stability of the whole machine, which has to withstand the great reaction of the borers when at work.

Fig. 143. — No. **162**. — This figure shows the Z shape which is considered to be the best for the bits of borers driven me-

chanically, so as to ensure the holes being made thoroughly round, and not triangular as shown at B (*See* the text of No. **162**).

Plate XXIV. — Figure 144.

Fig. 144. — No. **166**. — MM François and Dubois' boring machine. This is the latest form of perforator that has been made. It is simple, and easily used.

This machine as a whole recalls that of Sommeiller, from which, in fact, it is derived.

It differs fundamentally from it, however, by the arrangements for distributing the air and rotating the tool, which are quite special, although entirely automatic as in Sommeiller's machine, and by the arrangement for feeding the perforator forwards along its frame, which is done by hand.

The distribution is effected by means of an ordinary slide-valve fixed to two pistons A and A′ of unequal diameters. There is a small hole in the larger of these two pistons, A′, which allows the pressure of the compressed air to become the same on both faces. Consequently, the slide-valve moves in one sense or the other (from right to left or left to right) according as the pressure of the compressed air is, or is not, acting on the outer face of A′.

The pressure caused by the air which passes through the little hole is at once nullified when a tappet fixed on the rod of the main piston opens a valve into the chamber which communicates with the outer face of the piston A′.

The rotation of the borer is effected by the alternate action of two cams which are lifted by two small single-acting pistons under each of which compressed air is delivered in succession.

Lastly, the advance of the borer is effected by means of a little wheel moved by hand in proportion as the hole is deepened.

The length of the stroke of the borer may thus be varied to any desired extent below the maximum; and this makes the machine suitable for rocks of different degrees of hardness.

The number of blows is regulated by the area of the small hole which traverses the piston A′; the larger this hole the more quickly is equilibrium established between the two faces of the piston, and the more rapidly is the borer brought back after having struck the bottom of the hole.

The figures on plate **XXIV** represent the machine as a whole, as well as in detail; they also show the stand, which resembles that used with the Sommeiller machines at the Mont Cenis, although it is more compact, much lighter, and fit for work of less importance.

Plate XXV. — Figures 145-151.

Fig. 145. — No. **176.** — The timberman's axe: the tool specially employed by the timberman who ought also, however, to be more or less familiar with the use of miners' tools.

Figs. 146 and 147. — No. **178.** — These figures represent a prop set up in a working-place, for the purpose of supporting the roof.

The expedients employed for allowing the prop to be easily driven into its place will be remarked in the figures; it will be seen that these arrangements give a certain amount of elasticity to the system, which, if need be, allows a slight movement of the roof to take place without causing an immediate breakage of the prop.

Fig. 148. — No. **179.** — A cast-iron prop employed in English mines in those working-faces in which the supports in the rear of the face are withdrawn, either at the time of filling up, or when it is desired to regulate the fall of the roof. These props are often made in two pieces, as represented in the figure, so that they may be easily loosened and removed.

Fig. 149. — No. **180.** — Details of the props used in several mines

in the department of the Nord, instead of ordinary timber props or the cast-iron ones of figs. 146 to 148. (*See* the text of No. **180**.)

Figs. 150 and 151. — No. **181**. — Complete timbering of a working-place by means of *props* supporting *poles*, which, in their turn, support *laths*, when the friable nature of the roof renders their employment necessary.

Fig. 150 represents a nearly horizontal face; figure 151 an upright one : both are being carried on along the strike, that is to say, following the level course; and, consequently, in both cases the face is parallel to the dip.

It will be seen that, in the case of the upright face, there are poles both on the roof and floor of the bed. It is often necessary to resort to this expedient in highly inclined seams when the floor is friable.

Plate XXVI. — Figs. 152-159.

Fig. 152. — No. **182**. — This figure represents a transverse and longitudinal section of a gallery completely timbered with frames, or sets, (*see* the text of No. **182**, where the names of the various pieces which compose the frame are given, as well as some details about setting them up).

Figs. 153 and 154. — No. **183**. — Method of strengthening the ordinary frame by struts placed horizontally, or by props placed vertically, when it is necessary to increase the height or width of a gallery for some special purpose, such as, reserving a compartment for drainage or ventilation, making a siding for haulage, etc.

Fig. 155. — No. **183**. — Two examples of the forms which the timbermen should give to the joints, according to the direction in which the principal pressure is to be expected.

No. 1 is most suitable, when the principal pressure is downwards; No. 2 when it is a side thrust. (The general principle to be observed is that as much advantage as possible should be taken of the entire section of that piece which has to resist a compressing force acting on its ends.)

Fig. 156. — No. **183.** — Timbering of a level maintained under stowing, in a lode with solid walls.

It will be observed, in this case, that, for the reasons pointed out in No. **177**, the cap, or stull-piece, to which the set is here reduced, is not exactly at right angles to the plane of the lode.

Figs. 157-159. — No. **184.** — These figures show in plan, as well as in transverse and longitudinal sections, examples of spilling through bad ground, varying from a state of mere looseness (fig. 157) to that of a running, or almost liquid mass (fig. 159).

The principle of this operation, of which the details have been given in No. **184**, is always to endeavour to keep back the ground, as much as possible, so that no more may be excavated than corresponds to the section of the finished gallery together with the space occupied by the timber.

Whatever is excavated above this quantity is *useless* as regards the result to be attained, and even *essentially injurious*, inasmuch as it tends to set the ground in motion, and so to render the work more difficult and repairs more costly.

Plate XXVII. — Figures 160-169.

Fig. 160. — No. **185.** — Temporary timbering of a shaft which is to be walled afterwards. (*See* the text of No. **185.**)

Figs. 161 and 162. — No. **186.** — Permanent timbering for rectangular shafts: in the first figure the frames are shown to be at a short distance apart, and to be composed of square pieces; in the second they are close together and composed of round timber.

Fig. 163. — No. **186**. — Joint between a *wall-plate* and a *bunton*, or *dividing;* showing how a bunton may be joined to a frame so as to weaken each of them as little as possible, and at the same time to take advantage of the entire section of the bunton which has to resist the pressure of the ground. (*See* Nos. **182** and **186**.)

Figs. 164 and 165. — No. **187**. — Timbering of a shaft in running ground. These figures are vertical sections parallel to the longer and shorter sides of the shaft.

The principle of the operation is the same as that pointed out in the case of figures 157-159, that is to say, to endeavour to keep back the earth as much as possible, and not to remove more than is necessary for the execution of the work.

Fig. 166. — No. **191**. — Combination of timbering and rubble walling, for a gallery which has to be maintained through the stowing.

New timber is used for the caps, and old timber for *bonds* to tie the building across its entire width, or for *sleepers*, or *sills*, which serve to distribute the pressure of the caps equally on the side-walls. (*See* the figure and also the text of No. **191**.)

Fig. 167. — No. **192**. — Walling of an ordinary gallery with side-walls of stonework and a brick arch.

Fig. 168. — No. **193**. — Geometrical outline of a curve drawn with several centres to form the section of the walling of a gallery. The semi-profile BCHD is drawn by means of three circular arcs BC, CH, HD, which touch at C and H and the centres of which are respectively at the points O, O′, O″.

As to the invert, if it is desired to make it a circular arc, touching the arc BC at B, its centre will be at the point O''' the intersection of BO with DD′; but if instead of having a correct union of the two curves it is thought better to have an arc of a given radius D′D″, its centre will be at O^{iv} the point of intersection of a perpendicular raised from the middle point of BD″ with the line DD′ as before.

Fig. 169. — No. **195.** — Immediate walling of a gallery in bad ground with the aid of frames and laths of iron.

The figures give a longitudinal section of the gallery, and the principal details of the frames and the laths employed in the process of driving. (*See* the text No. **195.**)

Apart from the difference in scale, and the variations of detail which this difference necessitates, the system of direct walling resembles the process adopted by Brunel in making the Thames tunnel.

Plate XXVIII. — Figures 170-184.

Figs. 170-180. — No. **196.** — Examples of walling in various headings or levels.

The walling is arranged so as to suit the circumstances under which the galleries are supposed to be driven.

Fig. 170. — A gallery in a narrow vertical lode with solid walls; the caps or collars of figure 156 supporting the stowing are here replaced by an elliptical arch, whose springers are cut in the walls more or less obliquely, according to the hardness of the rock and the amount of pressure to be supported.

Fig. 171. — One of the walls is here supposed not to be firm enough to furnish a foundation for the arch, but rather to require to be supported itself.

Fig. 172. — Both walls are here supposed to be tender.

Fig. 173. — The gallery is supposed to be used as a water-level; it is completely walled, and the invert forms a channel for the water, at the same time preventing it from oozing into the more or less permeable substance of the lode. A line of planks, nailed to crossbeams, or spreaders, above the level of the water, forms a roadway along the gallery.

Figs. 174 and 175. — These are somewhat similar to figure 171. In the former the lode is supposed to be friable and the footwall weak, and in the latter the hanging wall is supposed to be weak.

Fig. 176. — The foundations are made in the foot-wall, as the lode itself and the hanging wall are both supposed to be unreliable.

Figs. 177 and 178 represent other methods of solving the difficulties referred to in describing the preceding figures; they may be suitably applied to cases where the lode is either very thick or nearly vertical, and then they avoid the necessity of seeking too far for a foundation.

Fig. 179, like figure 170, refers to a narrow, nearly vertical, lode with solid walls; there is this difference, however, that, in this case, the walls are supposed to be *extremely hard*, and they are cut only at intervals for the purpose of making a foundation for isolated arches between the walls, which in turn serve to support segments of arches stretching longitudinally.

Fig. 180 represents the same arrangement carried out at the floor of the gallery under consideration : it may be very conveniently employed when it becomes necessary to remove the ore from beneath it and at the same time to preserve the floor perfectly intact either for the purposes of haulage or to form a water-course.

Fig. 181. — No. **198.** — Ordinary walling of a shaft : the strata are supposed to be firm enough to admit of the wall being built in a series of successive cylinders, placed one below the other in descending order, and each sustained by a suitable foundation-crib.

Fig. 182. — No. **199.** — The strata are supposed to be less compact than in the preceding case so that even a wedged crib resting on a ledge cannot give sufficient support to the masonry. It then becomes necessary to tie the carrying cribs to some higher points of support. One arrangement for this purpose is shown in the figure. The various brackets which project into the

shaft and furnish the points of support consist of long wooden beams which are sunk into the ground or rock surrounding the shaft, in such a way that it is impossible for them to be drawn downwards, unless the ground in which they are imbedded can descend in a mass.

Figs. 183 and 184. — No. **201**. — These figures refer to the case where the ground to be sunk through is quite loose, so that the shaft has to be walled at the same time that it is deepened.

The method of effecting this consists in erecting a cylinder of masonry on a crib armed with a cutting shoe (called a drum crib) at the bottom of a previously timbered excavation, and adding to the top of this cylinder in proportion as it descends into the earth.

The various portions of the cylinder require to be well bound together to prevent the masonry from getting disjointed in consequence of the friction to which its outer surface is exposed.

For this purpose, wooden cribs bound to each other by tie-rods are inserted between the courses at intervals and planks are nailed on their external faces stretching from one to the other, so as to form a continuous casing which prevents contact between the earth and the masonry.

This system is employed in Silesia and Westphalia even for pits of large diameter. (*See* the text No. **201**.)

Figures 183 represent the work in two stages of progress : in one, a new crib has just been put in, together with the wooden casing which binds it to the preceding one; in the other, the masonry has been built to the top of the casing, and steps are being taken to cause the cylinder to sink.

Fig. 184 show the details of a drum-crib on a larger scale; the arrangements may be varied in several ways.

Plate XXIX. — Figures 185-190.

Fig. 185. — No. **205.** — Ordinary junction of two galleries. To avoid the necessity of groined arching, the height of the principal gallery has been increased, and the arch of the branch pierces its side wall only.

Fig. 186. — No. **206.** — Plan and section of a pit-bottom, plat, or hooking-on-place in a timbered shaft. The landing is supposed to be of such a width that it can be timbered with ordinary frames.

Fig. 187. — No. **207.** — The wooden frames of the preceding figure are here replaced by two thick side-walls of good masonry supporting longitudinal wooden sleepers which in their turn carry the ends of a series of caps formed of T-iron or heavy rails. The caps are slightly curved as shown in the figure, and suitably tied to each other. A lagging, or lining, of light mine rails laid above the caps is employed when necessary.

Fig. 188. — No. **208.** — Other arrangements which may be adopted at the pit-bottom; it is of the first importance that this part of a mine should be as safe as possible.

The figure represents a wooden arch; the pit-bottom sidings are arched over by a series of similar arches which form a discontinuous lining of great solidity and can accommodate themselves better than ordinary masonry to those slight movements which cannot always be obviated.

Fig. 189. — No. **208.** — A pit-bottom in a circular walled shaft.

This figure shows the arrangement formerly employed in the department of the Nord and in Belgium, when the products of the mine were raised in large buckets, filled at the pit-bottom, and emptied at the surface.

Fig. 190. — No. **211.** — Represents a chamber for a water-wheel, erected in a lode for the purpose of winding or pumping. Numerous examples of this arrangement are to be found in metalliferous mines, especially in Germany. The one represented in the figure is that of an overshot wheel. The chamber is a space of lenticular form situated perpendicularly to the strike of the lode. The rock is supposed to be sufficiently solid to stand without walling. The only masonry required is between the walls of the lode in the plane of each side of the chamber, and in this masonry spaces are left to receive the plumber-blocks which support the journals of the wheel.

Plate XXX. — Figures 191-193.

Fig. 191. — No. **211.** — Chamber of a water-wheel similar to the preceding but in less compact ground, which requires to be completely walled. It will be remarked that the side-walls are not planes but slightly cylindrical so that they may be better able to resist the thrust of the rock towards the open space.

Fig. 192. — No. **219.** — Cross-section of a large tunnel through loose ground. The whole space is completely timbered with props of ordinary dimensions, which are tightened up and held in place by means of suitable tie-beams.

At this point the tunnel is ready for the walling, the templets for the invert, and the lower part of the side-walls being shown in position.

Fig. 193. — No. **221.** — Figures 193 represent the various stages of the work to be done in enlarging a tunnel; — for example, one that has been originally made for a single line of railway and requires to be enlarged so as to admit a double line.

A. Original section of the tunnel; the scaffolding on which the work of enlarging is done is shown in position, although the work itself has not been commenced ;

B. Ripping the top and side of the old tunnel to make room for the new arch ;

C. Building the new arch, one side of which rests either directly on the rock, or on sleepers, and on the other on the side-wall of the old masonry ;

D. Widening at the level of the rails, after the arch has been completed and the safety scaffolding removed, in order to prepare for underpinning the new arch on the side which rests on the rock. If it is thought desirable, the old side-wall may be removed afterwards, and a new one supporting the arch built in its stead.

This method of enlarging admits of the railway service through the tunnel being continued uninterruptedly during the progress of the work. (*See* the text No. 221.)

Plate XXXI. — Figures 194-198.

Fig. 194. — No. **226.** — Plan, section, and details, of ordinary wooden tubbing resting on a wedging-crib. The object of tubbing is to form a water-tight lining, which diminishes the flow of water into a shaft while it is in process of sinking, and finally shuts it off, when the lowest section has been built upon an impermeable bed.

Fig. 195. — No. **229.** — Details of cast-iron tubbing in section. It is sometimes quite necessary to employ cast-iron instead of wooden tubbing, on account of the difficulty, or even impossibility, of getting pieces of timber of the proper quality and dimensions.

Fig. 196 and 197. — No. **235.** — Method of sinking shafts by means of compressed air; this application was first made by M. Triger and is hence called the Triger system.

Fig. 196 is the first arrangement made by M. Triger. (*See* No. **235**.)

Since that time the system has been often employed, both by M. Triger himself and by other engineers, for sinking shafts in watery ground, for the foundations of piers of bridges, lighthouses, quay walls, etc., etc.

The device upon which the system depends, considered in a general way, consists in placing an air-tight tube, closed at the upper end, over the point where the workmen are engaged, and maintaining a pressure of air in its interior, sufficient to prevent the influx of water at the bottom : it is in fact equivalent to a diving-bell.

This method of sinking is independent of the *quantity* of water; and its applicability is only limited by the *maximum pressure* which the workmen can sustain (about 5 atmospheres).

Fig. 197 shows the arrangements employed in the neighbourhood of Liége, in sinking large shafts through thirty or forty feet of the very running and watery alluvium of the Meuse. (*See* the text No. **235**.)

Fig. 198. — No. **236**. — System proposed by M. Guibal for traversing wet, running, ground situated at a great depth from the surface.

In principle, this system amounts to the employment of a shield, or cutting prism, for sinking shafts, similar to that employed by Brunel for cutting the Thames tunnel. The shield and its sheath are forced downwards by means of hydraulic presses, which take their bearing on the bottom of the last ring of tubbing; this ring itself being fastened to the one above by means of wood-screws. The movement of the shield is facilitated by operating on the bottom through the equilibrium pipe with suitable tools.

When the shield has descended far enough, a new ring of tubbing is placed under the last, and fastened to it in the manner just described.

Plate XXXII. — Figures 199-203.

FIGS. 199 and 200. — No. **236.** — These two figures show parts of the Guibal apparatus in detail. Fig. 199 is the water-tight joint which should be formed between the end of the sheath and the outside surface of the tubbing, so as to prevent water from flowing into the chamber at the point where the presses are worked, and where the rings of tubbing are put in when required.

Fig. 200 represents the expanding tool employed for loosening the sands through which the shield has to pass.

It will be observed that the systems of Guibal and Triger are both independent of the *quantity* of water, since it does not require to be pumped out. Guibal's system is, besides, independent of the pressure, unlike that of Triger; on the other hand, however, the latter system gives much better facilites to the workmen, within the limits of pressure in which it is available, for avoiding accidents and performing every necessary operation. The workman is, in fact, in actual contact with the ground, and can attack it directly; whereas according to Guibal's system he is separated from it by a shield, and can only reach it by means of a long rod traversing the narrow central column which rises above the natural level of the water.

FIGS. 201 to 203. — No. **239.** — System employed by Kind and Chaudron for sinking shafts in watery ground. Considered in a general way, this system consists in making a bore-hole of large diameter with ordinary tools and in the usual way, except in so far as certain modifications are required to suit the great diameter; then, after the hole has been finished and well cleaned out to the bottom, a water-tight metallic lining, provided with a water-tight joint at the bottom, is let down into it. This system, like the two preceding, is independent of the quantity of water, and like Guibal's system independent of the pressure; but it offers much greater facilities than the latter in case of accident, or if the ground happens to be hard.

In fine, its application is beset with all the difficulties of boring while, at the same time, it offers all the facilities presented by that process.

It seems, however, that the large diameter has a tendency to diminish the difficulties and increase the facilities. It is, therefore, a practicable process and will probably be much employed in the future. (*See* the details, Nos. **239-243**.)

Plate XXXIII. — Figures 204 to 208.

Fig. 204. — No. **269**. — This figure and the following ones, up to those of plate 40 inclusive, refer to *modes of working away* mineral.

Figure 204 exhibits two vertical sections of the deposit, at right angles to and parallel to the strike, showing the system of levels and winzes, which serve for exploring an ordinary lode and dividing it into blocks.

Fig. 205. — No. **270**. — In this figure two distinct methods, are shown viz., *overhand stopes* and *underhand stopes*, by which the different blocks of the preceding figure may be worked away in any order. (*See* the text of No. **274** which describes the characteristics of each of these methods).

Fig. 206. — No. **272**. — This figure shows how a block may be attacked by one or other of the above methods, by beginning with a *rise* or a *sink* at any point in a level without a winze having been sunk there.

Fig. 207. — No. **274**. — Application of the method by overhand stopes to a lode of any width, with this condition that the firmness

of the deposit is sufficient to allow the stopes to be carried the full width of the lode.

Fig. 208. — No. **277.** — When the above condition is not fulfilled, that is to say, when the working face cannot be maintained for the whole width of the deposit, the stuff must be taken away in slices, and each slice removed by a series of contiguous drivages.

This arrangement characterises what is called the *crosscut method* or method of *cross-working.*

It is shown in plan and section in figure 208.

It consists in removing a block by a series of superposed slices taken in ascending order, the different superposed blocks, on the contrary, being taken in descending order.

The numbers on the plan indicate the order in which the successive crosscuts are made; they are filled up in succession so as to permit an entire slice to be removed methodically.

The series (1), by which the operation is begun, removes one quarter of the deposit; series (2) another quarter, and, lastly, series (3) the half which remains in the middle of the filling-up.

It is readily understood that this manner of removing a slice, may be, and ought to be, varied according to circumstances, if, for instance, it is more advantageous to carry the drivages along the strike, etc., etc.

Plate XXXIV. — Figures 209 to 212.

Fig. 209. — No. **278.** — This figure in some measure completes the preceding one. It shows a plan of cross-workings in which it is supposed that the lode has a considerable mass of sterile rock (a *horse*) in it, which it is best to leave undisturbed. The drifts starting off from the main level are seen to stop at this sterile portion, with the exception of one crosscut which is

driven through to explore it and enable the workings to be resumed on the other side.

FIG. 210. — No. **279.** — Application of the crosscut method to a more or less irregular mass.

The main level of a regular lode is here replaced by a *contour level* which follows all the windings of the deposit, so as to determine and circumscribe its horizontal section.

The next thing to be done is to drive several horizontal levels in the deposit itself, which serve as starting points for the cross drivages by means of which the slices are removed. The crosscuts may be driven in any direction and can be multiplied as required.

The first slice having been worked out and the excavations filled up (with the exception of the principal levels), the next higher slice is taken, then a third and so on.

The figure supposes that the sixth slice is being worked; the five preceding ones are completely filled up, save the principal levels of the first slice, with which the sixth is in communication by means of *passes* left in the filling-up of the four intermediate slices.

FIG. 211. — No. **281.** — Working of a very large mass which furnishes little or no stuff for filling up. The method employed is still that of *working by crosscuts*; but, instead of filling up the empty spaces, the roof is allowed to fall in. The ground between two main levels is removed in successive slices in descending order. Each slice is made as high as a level with the addition of as much of the roof as can be taken away. The cross section shows several slices cut up by levels below an horizon where everything has been removed. The longitudinal section shows how the different slices ought to be taken in going back towards the shaft. The workings in any slice ought to be behind those of the upper slice, and in front of those of the lower one.

FIG. 212. — No. **283.** — A method of working a large mass which

cannot be filled up economically and from which it is not intended to remove the pillars.

The mass is divided into a series of slices, each of which is worked by cross drivages of less height than the thickness of the slices, so that a solid rib or floor of mineral is left between every two sets of workings.

The drivages must be so arranged that the pillars of one slice are exactly above those of the slice below; and as the workings become deeper the thickness of the floor and the width of the pillars should be increased, while the width of the drivages is correspondingly diminished.

This method is now considered antiquated and applicable only to some very special cases, where the value of the mineral is so small, stuff for filling-up so expensive, or the surface worth so little, as to render other modes of working unremunerative.

Plate XXXV. — Figs. 213 and 214.

Fig. 213. — No. **285.** — This figure represents the long-wall system of working coal, which is applicable to thin, nearly horizontal seams.

The faces are opened one after the other from a level or heading, and a new face is begun on the rise side, every time the heading has advanced by a given distance.

We thus obtain a series of contiguous faces, which stand in retreating order and are gradually extended towards the boundary of the field of operations.

Fig. 214. — No. **289.** — Is a variation of the preceding arrangement, being a system of faces of moderate width progressing towards the rise, and each served by a small self-acting incline. The machinery for the incline is moved forward at intervals of two or three days as the face advances.

A cutting-off level parallel to the original level is shown here.

It is opened when the inclines have become of great length (*see* the text of No. **289**), and thus the length of roadways requiring to be kept in repair is reduced. This arrangement is suitable for beds whose inclination is considerable but not excessive (for example 15° to 20° at the most).

Plate XXXVI. — Figures 215-216.

Fig. 215. — No. **293**. — A face of work divided into a series of overhand stopes; this system is applicable to a highly inclined seam in which the faces necessarily follow the strike.

Fig. 216. — No. **292**. — Long-wall workings with the faces progressing along the strike of the bed; the diagonal gallery or cross-heading shown in the figure takes the place of the self-acting inclines.

The cross-heading cuts off and shortens the levels which serve the faces, thus *laying off* that part of each level included between itself and the last cross-heading for which it has been substituted.

This artifice diminishes the length of galleries to be kept in repair, each diagonal playing the same part with regard to the one before it that the cutting-off level of fig. 214 does with regard to the original level.

The arrangement of faces represented in fig. 216 is called *flat slopes*.

It is particularly suitable to seams whose inclination, though well marked, varies from point to point between somewhat wide limits: the various roads which terminate at the bottom of each slope then preserve their level, but the length of the slope itself varies with the degree of dip.

Plate XXXVII. — Figure 217.

Fig. 217. — No. **299**. — Example of working by long pillars applicable to seams of coal of medium thickness.

It will be remarked in this figure how a district of the workings is first divided into blocks, by means of a number of galleries following the strike and rise of the bed and extended gradually towards the boundaries of the field; then, how each block is divided into long pillars and worked off separately, while others beyond are only in process of being formed (*See* No. **295** *et seq.* for general considerations regarding the working of seams of medium thickness.)

Plate XXXVIII. — Figures 218-223.

Fig. 218. — No. **301**. — Stripping or working off the long pillars of the preceding figure by a series of crosscuts which may be either immediately contiguous, or, as indicated in the figure, separated from each other by small barriers which check the crush; these barriers are removed, as well as possible, when the faces are abandoned, and the timber is drawn so as to allow the roof to fall.

Fig. 219. — No. **302**. — Stripping by a face progressing in the direction of the strike; or, more precisely, by two faces starting from the middle of the pillar which is being taken out and proceeding in contrary directions (*see* also fig. 217).

Fig. 220. — No. **302**. — Stripping-off faces in a highly inclined seam. The face is driven along the strike, but instead of being straight it is a broken line like overhand stopes fig. 215, in order that the men who are placed one behind the other may be able to work without constraint. The highest stope pre-

vents the rubbish of the workings above from running down into the faces; it is taken out in the rear of the faces so as to let down the roof.

In the absence of filling up rubbish, as in fig. 215, the men support themselves on stages by means of the props with which their places are timbered.

Fig. 221. — No. **304**. — This figure and those following it relate to the working of thick seams; that is to say, seams which are thicker than the height of an ordinary roadway. Let us suppose that a block has been divided into long pillars, as described above, by means of galleries of ordinary dimensions at the floor of the seam. The next proceeding is now to take out these pillars to the full height of the seam, and to rip down the top-coal left in the galleries for a roof.

Fig. 221 represents the application of the system described above. The lower part of the seam is first removed by faces progressing along the strike, and the top-coal is stripped down in the rear. The roof is allowed to fall after the top-coal has been taken down, but the fall should be so regulated that the distance from the face to the goaf always remains about the same.

Fig. 222. — No. **305**. — Figure 222 represents another method of working off thick seams; it is employed in districts where thick timber can be easily obtained. The coal is worked off by a series of contiguous rise faces which are arranged in the form of underhand stopes from the floor to the roof. After the entire stall has been surrounded by rows of props, whose object is to keep back the rubbish and hinder it from running first into the adjoining face, and afterwards into the face to the dip, the whole interior of the stall is stripped of its props and the roof allowed to fall in.

A is a plan of the stall after the roof has fallen and before a new stall has been begun alongside.

B is a section of figure A in a vertical plane passing through the axis of the gallery next below the block that is being stripped off.

C is a similar section made while the stall is still timbered and just after it has been finished.

D is a section in a vertical plane passing through the axis of the stall while it is in course of being worked.

(*See* the text of No. **305** for details of this process of removing pillars).

Fig. 223. — No. **305**. — The tools and arrangements for drawing timber from a stall such as we have just described, without endangering the safety of the men.

Instead of being removed with the axe in the usual way, the timber is drawn out from a distance by means of chains, and the necessary strain is obtained by using a screw-jack or suitable levers. This method is suitable when the consistency of the roof is such that the removal of a prop causes the immediate fall of that part of the roof which was supported by it.

Plate XXXIX. — Figures 224-229.

Fig. 224. — No. **306**. — Method of working the Staffordshire thick seam or *ten yard coal*. It consists in driving a series of very large galleries of the full height of the seam leaving some square pillars along their axes for sustaining the roof.

These galleries constitute nearly the whole working, the long pillars which separate them, and the square pillars which keep up the roof are looked upon as almost entirely lost. This method requires a firm coal and a good roof, and if these two conditions are amply fulfilled it may be economical without being too wasteful, or too dangerous for the workmen (*see* the text of Nos. **306** and **307**). It will be remarked that little galleries, by means of which the haulage and ventilation are carried on, are preserved in the interior of the pillars at the floor of the seam. If the figure be compared with that of plate XXXVII (fig. 217) it will be seen that the little galleries correspond to the preliminary network by which the district of workings is divided into blocks, whilst the large galleries, of which we have just spoken, may be regarded as equivalent to the work of subdivision into pillars and subsequent stripping out of each block.

Figs. 225 and 226. — Nos. **310-315**. — Illustrate the principle pursued in working a thick seam regarded as if it were formed by the union of several seams of moderate thickness. In other words, it shows the method of dividing a thick seam into slices parallel to the stratification, and working them off successively like so many distinct seams of ordinary thickness.

In figure 225 the slices are supposed to be worked by stripping them out successively without stowing; and, therefore, *of necessity*, in *descending* order.

This is called the Blanzy method.

In figure 226 they are worked with complete stowing, and consequently *generally* in the *ascending* order.

This is the Rive-de-Gier method.

In applying the Blanzy method the slices are taken of a greater thickness than the height of the galleries, in order to have a solid roof of coal during the first part of the working. This top-coal is ripped down during the final working, as shown in figure 221.

In the Rive-de-Gier method the slices are made of the same thickness as the height of the galleries, in order that the stalls may be the more easily filled up.

Figs. 227 and 228. — No. **316**. — Examples of working off pillars with complete stowing in the application of the Rive-de-Gier method.

The long pillar is supposed to be stripped by a series of contiguous crosscuts driven either from the dip towards the rise (fig. 227) or from the rise towards the dip (fig. 228). It should be observed that the same methods of stripping would be applicable to seams of moderate thickness were it considered advantageous to work them with stowing instead of allowing the roof to fall.

Fig. 229. — No. **320.** — Plan and sections of a method of working which is applicable when the seam is very thick and at the same time highly inclined. The bed is divided into slices as in the former case, but these are horizontal and not parallel to the stratification ; in other words, it is the method of *cross-working.*

Fig. 229 is, properly speaking, the application of the Blanzy method, with this peculiarity that the slices are carried across the bed and are consequently of limited width. This method may be designated *cross-work without stowing.*

Plate XL. — Figures 230-245.

Fig. 230. — No. **323.** — This figure and the two succeeding ones relate, like figure 229, to the working of thick and highly inclined seams.

The system consists in dividing the different blocks into a series of horizontal slices as before, then working these out in succession and filling up the space with stowing. It is a method of *cross-work with stowing* and is in every way analogous to that which is applied to wide lodes.

It may be further remarked that it bears the same analogy to the Rive-de-Gier method as the system of fig. 229 bears to the Blanzy method.

Figure 230 shows a particular arrangement which, though not essential to the method, may be extremely useful where the coal is easily ignited. Besides the level driven at the foot of the block, there is an auxiliary gallery driven outside the seam, and the latter is used as a haulage-way if the occurrence of a fire in the filling-up makes it necessary to dam up any part of the level (*see* No. **323**).

Figs. 231 and 232. — Nos. **325** and **326**. — These two figures show how, in applying the method of cross-work with stowing, we may help the breaking down of the coal, and, at the same time, materially increase the output from a given slice, by making it of greater thickness and so comparable to the slices taken in the method of cross-work without stowing.

It is then usually necessary to have two principal roadways: one at the level of the floor of the slice in course of being worked, by which the coal is taken away; the other at the level of the floor of the next higher slice, by which stowing materials are brought forward. The latter in its turn becomes the haulage gallery of the second slice, and then the stowing is brought forward by a roadway at the level of the floor of the third slice, etc., etc.

In figure 251 we suppose the working-places to be opened transversely.

In figure 252 we may suppose them to be driven in the direction of the stratification; so that a slice is removed by taking off the separate beds of which it is composed successively. This arrangement may render the working more easy. It may be recommended when the seam contains thick partings of sterile matter; for by this arrangement the partings may be left undisturbed, whereas they have to be taken down when the slice is worked off by a series of contiguous crosscuts.

Figs. 253-255. — No. **336.** — These three figures represent a manner of procuring stowing material in addition to that obtained in the stalls themselves, or at the surface.

. Figures 253 and 254 represent chambers for obtaining supplies of rubbish from the roof of the bed.

In figure 255 the bed is supposed to be crossed by a large fault filled with crushed stuff. In a case of this kind arrangements may be made whereby a supply of dead-stuff can be obtained at the point where one of the galleries intersects the fault. (*See* No. **336.**)

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