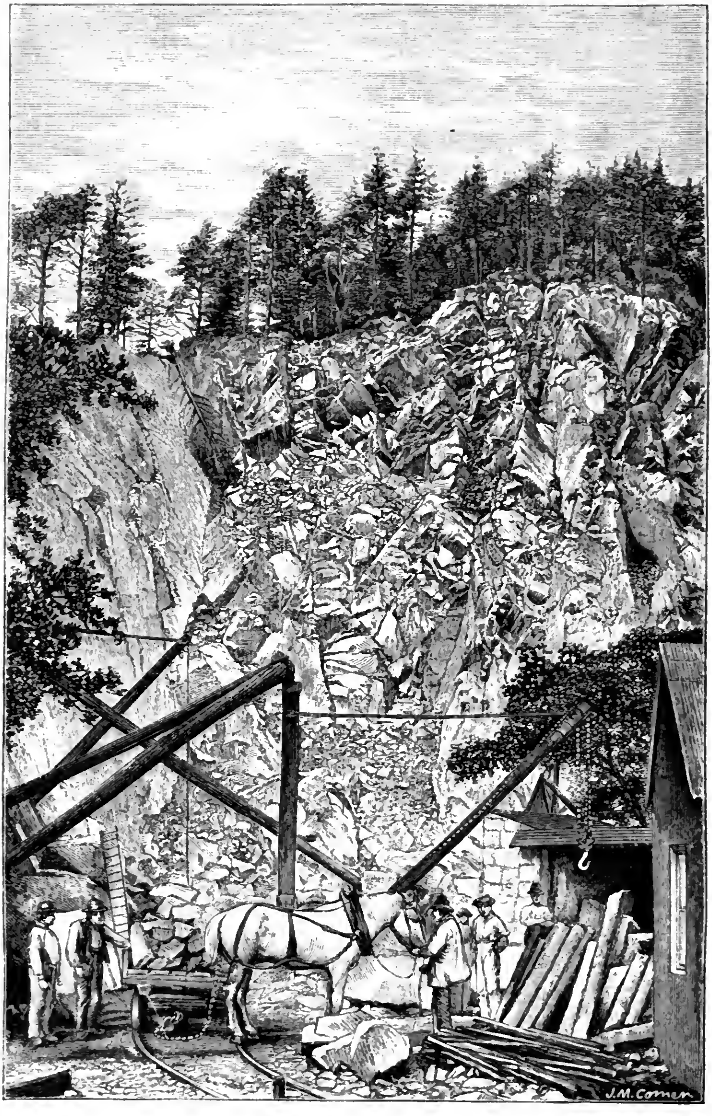
ECONOMIC GEOLOGY

"THE EARTH IS A GREAT STOREHOUSE OF WEALTH; BUT IT REQUIRES KNOWLEDGE WHERE TO SEARCH, AND SKILL HOW TO SECURE IT."

"THERE IS NOTHING SUPERFLUOUS IN NATURE; NOTHING USELESS, IF MAN ONLY KNEW HOW TO TURN IT TO HIS ADVANTAGE."



Granite Quarry, Dalbeattie (p. 134).

ECONOMIC GEOLOGY

OR

GEOLOGY

IN ITS RELATIONS TO THE

ARTS AND MANUFACTURES

BY

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PREFACE.

THERE are works on agricultural geology, on building and decorative stones, on mortars and cements, on coal-mining, on veins and lodes, and on ores and metallurgy; but as far as the author knows there is no general treatise on geology in its numerous relations to the Arts and Manufactures. As a teacher in a busy centre of miscellaneous industry, he has experienced the want of such a work, and especially of one sufficiently brief and methodical to be used as a Text-book; hence the origin of the present volume. While primarily intended for the student of Applied Geology, it may be useful to the agriculturist, builder, miner, civil engineer, manufacturing chemist, and others who have to deal with minerals and metals; and at the same time may not be devoid of interest to the general reader.

The field of industrial requirements is yearly extending, and there are few substances in the earth's crust which are now not turned to account in the multifarious industries of civilised life. A knowledge of these substances—their nature, geological position, and abundance—cannot fail to be of use to those who have to deal with them; and some acquaintance with them, in a general way, can as little fail to be of interest to the intelligent observer of that scientific invention and industrial skill which labour so assiduously to convert every p[illegible]f nature into objects of utility and ornament.

It is impossible, within the limits of a single volume, to notice every substance—and substances now lying waste and worthless may, in a few months, be utilised, and become of importance; but while not professing to notice every detail in Applied Geology, the author has endeavoured to present an intelligible outline of the subject, by grouping, under distinct heads, the various arts and manufactures in which mineral and metallic substances are employed. As it is chiefly with the raw materials—their characters and modes of occurrence—that the practical geologist has to deal, comparatively little notice has been taken of the processes by which these are converted into the useful and ornamental. Such processes belong to technology, and come within the domain of the chemist, the metallurgist, and fabricator, requiring other knowledge and other lines of research than those that fall within the scope of the geologist. Where necessary, however, for the elucidation of the subject, the nature of these processes and appliances has been briefly indicated. Manipulatory details must be sought for in technological treatises.

Covering such a wide field, and condensing within the limits of a convenient Text-book, the author is sensible of imperfections; and would therefore solicit corrections and suggestions from those interested in the cause of education, and the promotion of needful and accurate knowledge.

NEWCASTLE-ON-TYNE, *October* 1874.

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I.

INTRODUCTION.

The study of Geology presents itself in two great aspects—one purely scientific, and appealing to the intellect; another mainly practical, and appealing to the industrial necessities of life. In its scientific aim it examines, maps out, and arranges the rocks of the earth's crust into formations and life-systems according to their composition, relative positions, and fossil contents; endeavouring to deduce therefrom a connected history of our globe and its successive aspects from the earliest to the most recent times. In its practical effort it takes advantage of this chronological arrangement of rock-formations, and endeavours to discover in each those minerals and metals—their quality, quantity, and accessibility—which bear so directly on the arts and industries of civilised existence. Though thus apparently separate, the scientific and the practical cannot in reality be disjoined. The more exact our knowledge of the position and sequence of rock-formations, the more certain our economic explorations become; and the more successful our industrial adventures, the greater will be the impetus given to the extension and exactitude of scientific research. There can, indeed, be no antagonism between science and art, between theoretical knowledge and its economic applications. The practical expression of a truth can never be divorced from its theoretic conception.

Apart from its utilities, Geology will ever be a theme of intellectual interest and research, the problems of time, change, and progression it involves being amongst the most attractive that can engage the educated mind. It is equally true, however, that the science is pregnant with practical value, and will ever be so, so long as man has to draw from the earth the materials for the fabrication of his tools and machinery, for his heating and lighting, and for the construction of his dwellings and their adornment. Though appealing more directly to the agriculturist, the land valuator, the architect, the civil engineer, the mining engineer, and the manufacturing chemist, this practical aspect of Geology is of universal importance. Man cannot make progress in civilisation without drawing from the mineral and metallic stores of the earth's crust. He may lead a savage or a nomadic life, and subsist on roots and fruits, by hunting, by fishing, or on the produce of his herds and flocks; but he cannot settle down in civilised communities, or combat successfully with the forces of nature, till he has learned to arm himself with tools and implements. Personally he is weak—weaker than many of his fellow-creatures; and it is not till he has furnished himself with implements—and these, the best of them, drawn from the earth—that he can till the soil, reap his harvests, hew the wood, fashion the stone, or reduce the ore. And the more numerous his civilised wants become, the more he draws from the earth—rearing his cities, decorating his mansions, erecting bridges, piers, and harbours, creating new sources of heat and light, fabricating machinery, laying railways, building steam-ships, and stretching telegraphic cables, the raw materials of which he obtains, and obtains alone, from the rocky crust. In this way a knowledge of the composition and structure of the earth becomes more and more indispensable; hence an acquaintance with Geology, if he would learn where this or that mineral is to be found, the abundance in which it occurs, and the facilities with which it can be obtained. The minerals and metals are not scattered broadcast through the earth. Were coal, copper, and iron, for example, of universal dissemination, man would have only to dig and mine; but each has its own place and mode of occurrence, and to determine these, to map and describe them for the information of others, is the function of the geological surveyor. Whoever, therefore, has to deal with the products of the earth in their economic or commercial aspects, cannot fail to be benefited by some scantling of geological knowledge, were it only to enable him to read with appreciation the discoveries and descriptions of others. Let us endeavour to make this clearer by a few illustrative examples.

And first, the soils we cultivate depend for their fertility on their composition and texture. This composition and texture may be naturally unfertile, and yet may be capable of improvement by simple admixture of other soils, by drainage, or by mineral manuring. The agriculturist who knows the nature of his soils and subsoils, and of their underlying rocks, is surely, therefore, in a better position to correct their deficiencies by admixture, by draining, and by manuring, than one who cannot discriminate the nature of these soils or detect their deficiencies. The elements of fertile admixture may lie within the same farm; the defects in composition may be corrected by the application of appropriate mineral manures; but how can the farmer obtain this needed information save through a geological acquaintance with the nature of the materials he has to operate upon and apply? "Let him obtain it from the geologist," say some, "and apply it empirically." So far good; but infinitely better that the agriculturist knew something of the matter himself, and could separate the wheat from the chaff of his scientific advisers. There is no mystery in the relations of soils and subsoils, in their composition, or in their texture—nothing which a man of average intelligence may not readily master without going deeply either into the study of theoretical geology or into the manipulations of chemical analysis.

Secondly, as the worth of an estate depends not only on its agricultural, but also on its mineral value, the land valuator who is unable to determine the character of its soils and subsoils, and is ignorant of its mineral structure, can never do justice to his client. A knowledge of the geological structure of an estate is not less necessary to fixing its real value than a knowledge of its various soils and climate, and it is often for want of this knowledge that estates are either sold under their value or bought at unremunerative prices. At the present day, when farm produce meets so ready a market, and the minerals and metals bring such high prices, no estate should be bought or sold without a thorough survey alike of its surface capabilities and of its mineral stores, and this cannot be done with any degree of satisfaction without appealing to the mineral surveyor as well as to the mere agriculturist. No estate agent is worthy of the name who is incapable of appreciating this twofold aspect of the value of landed property.

Again, take the case of the architect who has to deal with beauty and durability of structure without, and with elegance of decoration within. The beauty and durability of a building-stone, and the facility with which it can be obtained and dressed, is of prime importance in architecture. The stone which will keep its colour in the open country may not do so in the smoky city; and the rock which will resist the action of the weather in its normal state may waste and crumble under the carbonated atmosphere of the manufacturing town. Nor is it structure and decoration alone that call for the assistance or suggestions of the geologist. The mortars, the cements, and concretes of the builder are yearly assuming a greater importance and receiving a wider application; and as the component materials of these are all drawn directly from the earth, geology comes in with important information to the manufacturer—indicating the nature and abundance of the limestones, and sands, and gravels with which he has to operate. It is ignorance on this point which often causes the builder to bring from a distance materials which could be obtained of equal quality and at a cheaper rate in his own immediate locality. It is also a want of knowledge on this head that permits the artificial manufacture of hydraulic cements and concretes, while limestones of natural hydraulic energy lie unknown and neglected.

In the next place, take the case of the civil engineer who has to plan and lay down roads and railways, to execute cuttings and tunnels, to excavate docks and harbours, to erect piers and breakwaters, to deepen and widen tidal rivers, and bring in water-supplies to towns. Not a step can be taken in any of these important operations without coming in contact with geological phenomena—not a plan can he lay down which does not depend more or less on a knowledge of rocks and rock-formations. It is true he may obtain information from geological maps and from professional geologists; but, even with this aid, his work will be executed with feebleness and uncertainty compared with that of one who can discriminate the geological structure of a country for himself. And it has simply been, and still is, for want of this geological knowledge that so many of our engineering works have been executed at so much cost and with so little pecuniary satisfaction to their proprietors.

Once more, and we come to the mining engineer—whether working among stratified rocks for such products as coal, ironstone, limestone, and fireclay, or following veins and lodes in search of the metals and metallic ores. In either case some knowledge of geology is indispensable; and though it is true that mining was largely followed ere geology had shaped itself into a science, yet the *practical skill* of the miner in dealing with successions of beds, with dykes and dislocations, and with kindred phenomena, is geology of a kind, requiring the noting of facts and the drawing of generalisations, not less real and serviceable than the deductions of the *theoretical* geologist.

The wider, however, the geological knowledge of the mining engineer, the better will he be able to cope with the difficulties that present themselves in his arduous calling. His services may not always be restricted to the same district. His advice may be sought in other districts, where there are other rocks, other successions, other dislocations and appearances, and he will be but poorly prepared to deal with these unless he is in some measure acquainted with the general principles of geology. Besides, new substances are yearly being utilised, and it is the duty of the mining engineer to keep pace with this progress, and to see that nothing in his workings be left unnoticed or unused. While every region of the globe is being ransacked to supply the mineral and metallic requirements of Europe and America, the mining engineer may safely calculate upon a wider field for his services—and these services can only be valuable and reliable in proportion to his scientific knowledge of the subjects with which he has to deal. Sinking shafts, driving drifts, pumping, and ventilation, are arts of prime importance; but where to sink, the nature of the minerals sought, their mode of occurrence, and the dislocations to which they may have been subjected, are of equal importance, and can only be known through some acquaintance with the science of geology.

But it is not alone to the farmer, the land agent, the builder, the civil engineer, or the mining engineer, that some acquaintance with geology is of importance. Its applications to the arts and manufactures are numerous and direct—to the fictile arts of the potter and glassmaker, to the manufacturer of mineral pigments and dyes, to the metallurgist and chemist, to the lapidary and jeweller, and even to the mechanical engineer and machinist. The potter and glassmaker derive all their clays and sands from the earth; all our mineral pigments are procured directly or indirectly from the same source; so likewise are all our metals, whether native or as ores; and so also our fossil fuels and lights; our millstones, grindstones, and whetstones; our salts and saline earths; our gems and precious stones. In fine, there are few of the arts and manufactures which do not less or more depend on the mineral and metallic treasures of the earth; and surely some acquaintance with the composition and structure of that earth, so that the place of those minerals and metals may be known, their abundance ascertained, and the facility of obtaining them be determined, cannot fail to be of advantage to those who have to fashion and fabricate them into objects whether of utility or ornament.

It is not required of practical men to go deeply into the theories of geology, for that is impossible, and useless even if it were possible; but surely an intelligent acquaintance with the nature and origin of the materials they are daily manipulating cannot be otherwise than a gain, and a source of satisfaction even where the thought of pecuniary gain is altogether out of the question. Civilisation depends in a prime degree upon our mastery over the opposing forces of nature, and we cannot conquer any force or power save by the application of a superior one. Physically, man is weak and helpless; armed with implements and machinery he becomes a Titan. Without tools and machinery, man has to succumb to the forces of nature; equipped with these, they become his willing servants —turning his wheels, raising his weights, wielding his hammers, lessening his labours, and carrying him over land and sea with unparalleled celerity. Our most important implements and machinery are derived from the mineral world; the heat that sets them in motion is derived from the same exuberant source. How direct, then, our civilised dependence upon the earth and a knowledge of its mineral and metallic treasures! How important to every art and manufacture to learn something of the nature and character of the source from which they are procured!

To obtain this information, in a general way, is by no means a difficult task. It is not required of the practical operator that he should be learned in geological theories, in mineral species, or in palæontological discriminations. Enough for his purpose to understand the chronological succession of the rock-formations, to know the general character of the strata of which they are respectively composed, the changes these strata may have undergone, the areas over which they are spread, and the facilities with which any of their products can be obtained. The study of any recent text-book, the power to read aright geological maps and sections, and a knowledge of the composition of the peculiar products he has to deal with, are about all he requires for the prosecution of his task. Armed with this amount of knowledge, he will be enabled to conduct his operations with greater certainty, and be less liable to be led into visionary speculations and experiments. Acquainted with the wide and varied field of geological products, he will cease to abide by local and restricted supplies, while cheaper and more easily manipulated substances can be obtained from other regions.

To put the facts of Economic or Applied Geology plainly and methodically before the reader is the aim of the present treatise; and though each department may be studied separately, a better knowledge of the subject will be gained by going over the whole, and especially by carefully reading the introductory chapters devoted to the general principles and classifications of the science. Understanding the chronological arrangement of the systems, and the general lithological character of the various formations, the practical operator will be in a much better position to understand the nature of the materials that come within the range of his own special department. Of course, it is only with the raw materials—their nature, position, and abundance—that the practical geologist has to deal. The moment they pass to the furnace, the retort, or the factory, they come under the domain of the metallurgist, the chemist, and fabricator, whose processes and appliances require other knowledge and other lines of research. It is true the geologist cannot be altogether indifferent to these processes and appliances; but, at the same time, it must be remembered that his special function is to discover the raw materials, to determine their positions and accompaniments, their abundance, and the facilities with which they may be procured; and generally, to arrange and classify them—be they mineral or metallic—so as to know their variety, their rarity, or their exuberance in the crust of the earth. Restricting himself to this function, the geologist can supply much valuable information, and this without at all infringing on the field of the technologist, whose methods are mainly of a chemical and mechanical nature.

II.

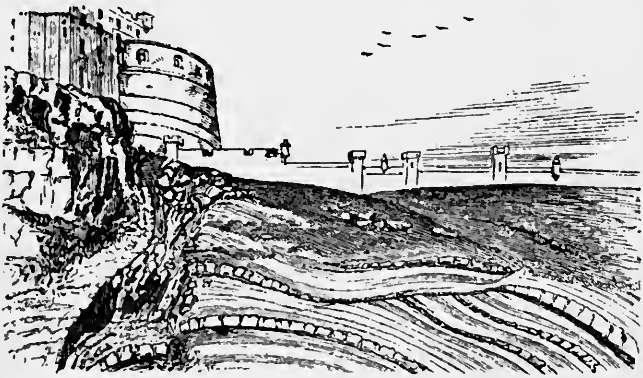
THE ROCKY CRUST.

I.—ITS STRUCTURE AND COMPOSITION.

ALL the minerals and metals with which the arts and manufactures have to deal being obtained from the earth's crust, some knowledge of its structure and composition is indispensable to the economic geologist. For this reason we devote the present chapter to a brief outline of Geology; more especially as regards the physical characters of rocks and minerals, their modes of occurrence, and their chronological arrangement. With due attention any intelligent reader may easily make himself acquainted with these peculiarities; and the more intimate his knowledge, the better will he be enabled to understand the nature of the industrial products and processes that may come under review.

Stratified and Unstratified Rocks.

The exterior crust, which forms the theme of the geologist, is composed of *rocks;* and under this term are included all its substances, whether hard or soft, superficial or deep-seated — sands, sandstones, clays, shales, peats, coals, limestones, ironstones, lavas, basalts, granites. Whatever their mineral character, these rocks are found to occur in two main positions —*stratified* or bedded, and *unstratified* or eruptive. Reasoning from the manner in which rock-matter is deposited at the present day in lakes, estuaries, and seas, the stratified are regarded as of sedimentary or aqueous origin—that is, as having been formed through and by the agency of water. And reasoning, in like manner, from the ejectments of volcanoes, the unstratified are regarded as of eruptive or igneous origin—that is, as having been formed through and by the agency of fire. In the accompanying illustration, the "Castle Rock" of Edinburgh is a truly eruptive or unstratified mass breaking through the sedimentary or stratified sandstones and shales which are tilted up, and slope away from the centre of eruption. Wind-blown materials, as sand-dunes—chemical deposits, as calcareous tufa—and organic growths, like peat-moss and shell-beds—are usually classed with the stratified; while showers of volcanic ashes, and other irregular ejectments, though arranged more or less in layers, are described merely as *stratiform.* Generally speaking, the sedimentary rocks are formed from the waste and debris of pre-existing rocks, are lam-



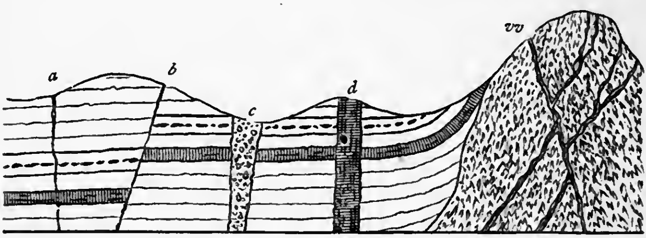
Edinburgh Castle Rock:—Basaltic Clinkstone passing through Lower Carboniferous Shales and Sandstones.

inated or bedded in structure, comparatively soft and fragmentary in texture, and frequently imbed the remains of plants and animals. The eruptive rocks, on the other hand, however originating, make their appearance from below, are amorphous, or occasionally columnar, in structure, uniform and crystalline in texture, and rarely imbed any traces of organic remains. While the preceding are the general characteristics of the stratified and unstratified rocks, it must be borne in mind that there are many anomalous masses of conglomerate and breccia on the one hand, and curious sheet-like overflows and stratiform ash-beds on the other.

At the present day, stratified rocks are being laid down in all lakes, estuaries, and seas, and unstratified ejected from all volcanic centres. And as the forces (meteoric, aqueous, organic, chemical, and igneous) by which old rocks are wasted and new ones reconstructed from their debris, are as enduring as the planetary system from which they take their rise, the geologist is entitled to ascribe the formation of the rocky crust to the operation of similar agencies in former periods. In this way, land and water are gradually but continually changing places — the rock-matter formed during each terraqueous change being not only the record of these mutations, but an indication of the physical aspects of our globe at the successive stages of its history.

Relative Positions of Rocks.

Laid down in water and assorted by water, the original position of the stratified rocks is that of horizontality; but having been subsequently acted upon by the vulcanic or eruptive forces, they usually occur, as may be seen in our sea-cliffs, ravines, and railway cuttings, in *inclined*, *bent*, and *contorted* positions, and more or less rent and *fissured*—some portions being thrown up and others thrown down, or, in technical language, *faulted* and *dislocated.* These rents and fissures are occasionally filled up with rubbly matter washed in from above, and sometimes with molten matter injected from below; and hence the occurrence of *dykes*, as they are termed—"soft" in



a Simple fissure; *b* Fault; *c* Soft dyke; *d* Hard dyke; *vv* Veins.

the former instance, and "hard" in the latter—intersecting and interrupting the continuity of the sedimentary strata. Again, when these rents and fissures have been filled up by slow infiltration of mineral and metallic matter, they constitute *veins* and *lodes*—the veinstone or matrix consisting of calc-spar, fluor-spar, quartz, baryta, or other sparry material, while the accompanying metallic ores are in the state of oxides, sulphides, carbonates, and other chemical combinations. The slope at which a stratum lies to the horizon constitutes, in geological language, its *dip* or angle of inclination; that portion of a stratum which comes to the surface its *outcrop* or basset-edge; and a line at right angles to the dip its *strike* or stretch across the country—this strike being always at right angles to the dip, and *vice versa.*

Melted and erupted by vulcanic heat from below, the igneous rocks, on the other hand, occur as unstratified or amorphous masses, and as regards their relations to the strata through which they pass are spoken of as *disrupting*, or breaking through; *overlying*, having flowed over; *interstratified*, having flowed over and been subsequently covered by other sediments; and *intrusive*, when thrusting themselves, as it were, with some degree of parallelism, among and between the sedimentary beds.

Structure and Texture of Rocks.

The manner in which rocks are arranged or piled up in the crust constitutes their *structure;* and this structure is described by such terms as stratified, bedded, jointed, tabular, columnar, massive, amorphous, &c. The internal arrangement of their particles constitutes their *texture*, and this, as the case may be, is spoken of as earthy, granular, crystalline, fibrous, porous, compact, vitreous, &c. The columnar aspect of the basalt of the Giant's Causeway is its structure; a chip from any of the columns exhibits its internal crystalline texture. The outward portion of a rock, exposed to and acted upon by the atmosphere, is spoken of as its *weathered surface;* and the internal texture, laid open by the hammer, as its *fresh-fracture*. The fresh-fracture of a rock may give no indication how it will be affected by exposure to the weather; the weathered surface, on the other hand, exhibits faithfully the effect of meteoric agency in discolouring and disintegrating, and is consequently of great use to the builder and architect. The fracture of rocks depends on their texture, and is described as even, flat, bladed, hackly or irregular, splintery, conchoidal and subconchoidal, according to the appearance it presents. Roofing-slate, for example, splits up with a flat or regular surface, calcareous spar cleaves with an even or smooth face, while a piece of flint or cannel-coal breaks up with a conchoidal or shell-like fracture. A knowledge of the manner in which a rock breaks and cleaves is often of great use, not only in facilitating the operations of the quarryman and mason, but in preventing unnecessary waste of the material. A workman—quarrier, paviour, or mason—acquainted with the structure and texture of rocks, will not only turn out a larger amount of material with the same labour, but will, by his skilful manipulation, effect a saving of the material itself.

Hardness and Specific Gravity of Rocks.

The *specific gravity* of rocks is determined by the standard of distilled water at 60°, which is regarded as 1; and their relative hardness is determined by the following scale, invented by the German mineralogist Mohs :—

Talc,	1	Felspar,	6
Gypsum,	2	Rock-crystal,	7
Calc-spar,	3	Topaz,	8
Fluor-spar,	4	Corundum,	9
Apatite,	5	Diamond,	10

Thus, common hæmatite, or red oxide of iron—$G = 4.5 - 5.5$; $H = 5.5 - 6.5$—means that its specific weight is from four and a half to five and a half times greater than that of water, and that in hardness it stands between five and a half and six and a half in the above scale. The determination of specific gravities is often a delicate and difficult operation; but the relative hardness of rocks and minerals is readily approximated. Thus, if a mineral scratches felspar, but is in turn scratched by rock-crystal, its hardness must be between 6 and 7, and may be indicated as 6.4 or 6.8, according as it seems to approach the felspar on the one hand, or the rock-crystal on the other. A knowledge of the relative hardness of rocks and minerals is often of essential importance in the arts and manufactures, and hence the value of their determination in practical Geology. The following table of Specific Gravities may also be of use for future reference :—

Agate,	2.590	Glass, green,	2.642
Alum,	1.714	,, flint,	2.760 to 3.000
Amber,	1.064 to 1.100	Granite,	2.660 to 2.800
Amethyst, Common,	2.750	Graphite,	1.987 ,, 2.400
,, Oriental,	3.391	Gypsum, Compact,	1.870 ,, 2.288
Amianthus,	0.315 to 1.000	,, Crystallised,	2.311 ,, 2.900
Arragonite,	2.900	Heliotrope,	2.629 ,, 3.000
Asphalt,	0.905 to 1.220	Honeystone, Mellite,	1.650
Azure-stone,	2.850	Hornblende,	3.250 to 3.830
Barytes, Sulphate of,	4.550	Hornstone,	2.555 ,, 2.810
,, Carbonate of,	4.600	Hyacinth,	4.000 ,, 4.780
Basalt,	2.421 to 3.000	Ironstone,	3.000 ,, 3.575
Beryl,	3.549	Jasper,	2.358 ,, 2.820
Borax,	1.714	Jet,	1.300
Calcedony,	2.600 to 2.650	Limestone,	2.386 to 3.000
Carnelian,	2.615	Magnesia, Carbonate,	2.240
Chalk,	2.000 to 2.255	Malachite,	3.572 to 3.994
Chrysolite,	3.400	Marble,	2.500 ,, 2.700
Coals,	1.025 to 1.350	Melanite,	3.600 ,, 3.800
Coral,	2.500 ,, 2.800	METALS—	
Corundum,	3.710	Antimony,	6.702
Diamond, Oriental,	3.521	Arsenic,	5.765
,, Coloured,	3.550	Bismuth,	9.880
,, Brazilian,	3.444	Brass,	7.809 to 8.400
Dolomite,	2.540 to 2.830	Cadmium,	8.600
Emerald,	2.600 ,, 2.770	Chromium,	5.900
Felspar,	2.450 ,, 2.700	Cobalt,	8.600
Galena,	6.565 ,, 7.786	Columbium,	5.600
Glass, crown,	2.520	Copper,	8.900

Gold, cast,	19.258	Nitre,	1.900
,, hammered,	19.361	Obsidian,	2.370
Iridium, ,,	23.000	Oolite,	2.100 to 2.600
Iron, cast,	7.248	Opal,	1.958 ,, 2.110
,, forged,	7.788	Pearlstone,	2.340
Lead,	11.352	Pitchstone,	2.000 to 2.700
Manganese,	8.000	Porphyry,	2.450 ,, 2.950
Mercury,	13.598	Pumice,	0.752 ,, 0.914
Molybdenum,	8.600	Quartz,	2.624 ,, 3.750
Nickel, cast,	8.279	Rock-crystal,	2.580 ,, 2.888
,, forged,	8.666	Ruby, Oriental,	4.285
Osmium-iridium,	19.500	Sandstone, Craigleith,	2.350
Palladium,	11.800	,, Fife,	2.100
Platina, forged,	20.336	,, Glasgow,	2.156
,, wire,	21.042	,, Derbyshire,	2.628
,, plate,	22.069	,, Newcastle,	2.229
Potassium,	0.865	Sapphire, Oriental,	4.200
Rhodium,	11.000	Schorl,	2.922 to 3.450
Selenium,	4.300	Serpentine,	2.264 ,, 3.000
Silver,	10.474	Slate,	2.000 ,, 2.000
,, hammered,	10.510	Spar, Fluor,	3.000 ,, 3.790
Sodium,	0.972	,, Calc,	2.510 ,, 2.800
Steel, soft,	7.833	Sulphur, native,	3.033
,, tempered,	7.825	,, fused,	1.990
Tellurium,	5.700 to 6.110	Talc,	2.000 to 3.000
Tin,	7.295	Topaz,	4.000 ,, 4.066
Tungstein,	17.400	Tourmaline,	3.000 ,, 3.680
Uranium,	9.000	Turquoise,	2.500 ,, 3.000
Zinc,	6.200 to 7.200	Ultramarine,	2.360
Mica,	2.650 ,, 2.934	Woodstone,	2.000 to 2.674
Mineral Tallow	0.780	Zeolite,	2.075 ,, 2.718
Naphtha,	0.700 to 0.840	Zircon,	4.385 ,, 4.700

Composition of Rocks.

But whether occurring as stratified or unstratified masses; whether horizontal, inclined, bent, or contorted; whether in dykes, veins, or lodes; whether bedded, tabular, or columnar in structure, or earthy, granular, or crystalline in texture, all rocks may be viewed as having a certain mineral and chemical composition. By this *mineral composition* is understood the mineral particles of which they are composed, as a quartzose sandstone chiefly of quartz grains, or as an ordinary granite of the minerals quartz, felspar, and mica. By their *chemical composition*, on the other hand, is meant the ultimate elements of which their various minerals are composed—quartz, consisting of oxygen and silicon, felspar of oxygen, silicon, aluminium, sodium, potassium, &c., and mica of oxygen, magnesium, potassium, &c. *Simple minerals*, which constitute the study of the mineralogist, have usually a definite crystalline form and chemical composition; but the great bulk of the earth's crust, which constitutes the theme of the geologist, consists of *mixed rocks*, having no definite form or composition, and made up of several mineral ingredients. The simple minerals are very numerous, as quartz, felspar, mica, hornblende, augite, calc-spar, &c.; the mixed rocks also occur in many kinds, as granites, porphyries, basalts, greenstones, sandstones, limestones, &c.; while the known chemical elements amount to sixty-five or sixty-six, some being metallic, as gold, silver, lead—some non-metallic solids and liquids, as sulphur, carbon, silicon, iodine—and others gaseous or aeriform, as oxygen, hydrogen, nitrogen.

The following Tabulations of Chemical Elements, Mineral Species, and Mixed Rocks, will be useful at this stage, as showing the nature and extent of the field with which the geologist has to deal; while they will be required for frequent reference when we come to treat of many of the products employed in the arts and manufactures.

CHEMICAL ELEMENTS.

The following list exhibits, in alphabetical order, the so-called "elementary substances," with the symbols by which they are known in mineral composition and analyses—thus, carbonate of lime, $Ca\,O + CO^2$ or $\dot{Ca}\,\ddot{C}$.

Elements.	*Symbols.*	*Elements.*	*Symbols.*
Aluminium,	Al	Nickel,	Ni
Antimony (*Stibium*),	Sb	Niobium,	Nb
Arsenic,	As	Nitrogen,	N
Barium,	Ba	Norium,	No
Bismuth,	Bi	Osmium,	Os
Boron,	B	Oxygen,	O
Bromine,	Br	Palladium,	Pd
Cadmium,	Cd	Pelopium,	Pe
Cæsium,	Cs	Phosphorus,	P
Calcium,	Ca	Platinum,	Pt
Carbon,	C	Potassium (*Kalium*),	K
Cerium,	Ce	Rhodium,	R
Chlorine,	Cl	Ruthenium,	Ru
Chromium,	Cr	Selenium,	Se
Cobalt,	Co	Silicium, Silicon,	Si
Copper (*Cuprum*),	Cu	Silver (*Argentum*),	Ag
Didymium,	—	Sodium (*Natrium*),	Na
Erbium,	—	Strontium,	Sr
Fluorine,	F	Sulphur,	S
Glucinium or Beryllium,	Gl	Tantalum or Columbium,	Ta
Gold (*Aurum*),	Au	Tellurium,	Te
Hydrogen,	H	Terbium,	—
Ilmenium,	Il	Thallium,	Ti
Iodine,	I	Thorium,	Th
Iridium,	Ir	Tin (*Stannum*),	Sn
Iron (*Ferrum*),	Fe	Titanium,	Ti
Lanthanum,	Ln	Tungsten or Wolfram,	W
Lead (*Plumbum*),	Pb	Uranium,	U
Lithium,	Li	Vanadium,	V
Magnesium,	Mg	Yttrium,	Y
Manganese,	Mn	Zinc,	Zn
Mercury (*Hydrargyrum*),	Hg	Zirconium,	Zr
Molybdenum,	Mo		

Of the preceding elementary substances only a few enter largely into the composition of the earth's crust; and of the others many are extremely rare, or only evolved from their natural unions by chemical analysis. In the following list the most important (geologically speaking) are printed in capitals, their characters being given as under the ordinary pressure and temperature of the atmosphere :—

Gases—HYDROGEN, OXYGEN, nitrogen, CHLORINE, and FLUORINE.
Non-Metallic Liquids and Solids—Bromine, iodine, SULPHUR, PHOSPHORUS, selenium, CARBON, boron, SILICON.
Metals being the basis of the Earths and Alkalies—POTASSIUM, SODIUM, lithium; BARIUM, strontium, CALCIUM; MAGNESIUM, ALUMINIUM, thorium, glucinium, zirconium, yttrium.
The Metals—MANGANESE, ZINC, IRON, TIN, cadmium, COBALT, NICKEL; ARSENIC, CHROMIUM, vanadium, molybdenum, tungsten, columbium, ANTIMONY, uranium, cerium, BISMUTH, titanium, tellurium, COPPER, LEAD; MERCURY, SILVER, GOLD, PLATINUM, palladium, rhodium, osmium, iridium, ruthenium; (and the following, of which little is yet determined) cæsium, erbium, terbium, didymium, lanthanum, niobium, norium, ilmenium, pelopium, thallium.

MINERAL GROUPS AND SPECIES.

The following list contains the more abundant minerals, arranged in chemical or characteristic groups and sections :—

Sub-Kingdom—Metals and Metallic Ores.

NATIVE METALS.

Metals occurring in the free or uncombined state.
SIMPLE GROUP—Gold, silver, platinum, palladium, mercury, copper, iron (?), lead, arsenic, antimony, bismuth, tellurium, zinc, tin (?)
DOUBLE GROUP—Gold-amalgam, silver-amalgam, platiniridium, iridosmine, arsenic-antimony, antimony-silver, arsenic-copper.
MIXED or TELLURID GROUP—Altaite, nagyagite, sylvanite, hessite, tetradymite.

SULPHURETTED ORES.

A. SIMPLE SULPHIDES :—
Metallic ores, as mono-, sesqui-, and di-sulphides.
PROTO or GALENITE GROUP—Galenite, argentite, naumannite, eukairite, berzelianite, clausthalite, bornite, pentlandite, sphalerite, chalcolite, stronmeyerite, pyrrhotite, cinnabar, Millerite, troilite, Greenockite, nickelite, Breithauptite, covellite, realgar.
SESQUI GROUP—Orpiment, stibnite, kermesite, bismuthite.
DEUTO or PYRITE GROUP—Pyrite, cubanite, chalcopyrite, barnhardite, stannite, linnæite, smaltite, cobaltite, ullmannite, marcasite, leucopyrite, arsenopyrite, molybdenite.

B. DOUBLE SULPHIDES :—
Metallic ores, as sulph.-arsenites, s. antimonates, s. bismuthites.
SULPHO-SALTS—Chalcostibite, zinkenite, Jamesonite, Bournonite, Stephanite, Dufrenoysite, Freislebenite, tetrahedrite, pyrargyrite, boulangerite, Tennantite.

OXIDISED ORES.

Metallic ores, as suboxides, monoxides, binoxides, and derived hydroxides; occasionally compound.
IRON GROUP—Hæmatite, magnetite, limonite, ilmenite, iserite, chromite, Franklinite.
MANGANESE GROUP—Hausmannite, braunite, pyrolusite, manganite, psilolmelane, wad.
TIN GROUP—Cassiterite, wood-tin.
COPPER GROUP—Cuprite, chalcotrichite, melaconite.
ZINC GROUP—Spartalite, zincite.
ANTIMONY GROUP—Valentinite, senarmontite, cervantite.
TITANIUM GROUP—Rutile, anatase, brookite.
OCHRE GROUP—Iron O., cobalt O., molybdena O. (molybdenite), bismuth O. (bismite, antimony O. stibiconite), uranium O. (pitchblende), lead O. (minium, massicot), chrome O., arsenic O. (arsenolite).

CARBONATED ORES.

Metallic ores, as carbonates of oxides.
ANHYDROUS GROUP—Siderite, rhodocroisite, Smithsonite, manganocalcite, cerrussite.—(Massive Clay-band and Black-band ironstones).
HYDROUS GROUP—Lanthanite, zaratite, hydrozincite, aurichalcite, malachite, azurite, bismutite.
SULPHATO-CARBONATES—Susannite, Leadhillite, Caledonite.

CHLORIDES, BROMIDES, AND IODIDES.

Metals in combination with chlorine, bromine, and iodine.
CHLORIDES—Calomel, cerargyrite, matlockite, mendipite, atacamite.
BROMIDES—Bromyrite.
IODIDES—Iodyrite, coccinite.

TUNGSTATES, MOLYDATES, CHROMATES.

Metallic ores with tungstic, molybdic, and chromic acids.
TUNGSTATES—Scheelite, stolzite, wolfram.
MOLYBDATES—Wulfenite, pateraite.
CHROMATES—Crocoisite, vauquelinite.

TITANATES, TANTALATES, COLUMBATES, &c.

Metallic ores with titanic, tantalic, and columbic acids.
TITANATES—Ilmenite, iserine, polymignite.
TANTALATES—Aeschynite, tantalite, yttra-tantalite.
COLUMBATES—Columbite, Fergussonite.
ANTIMONIATES—Monimolite, bleinerite.

VANADIATES, ARSENIATES, and PHOSPHATES.

Metallic ores with vanadic, arsenic, and phosphoric acids.
Occur generally as saline minerals—
LEAD SALTS—Vanadinite, minitesite, pyromorphite.
CALCIUM SALTS—Haidingerite, pharmacolite.
COPPER SALTS—Clinoclase, liroconite, erinite, olevinite, copper-mica.
IRON AND MANGANESE SALTS—Beudantite, vivianite, triplite, childrenite, scorodite, pharmacosiderite, dufrenite.

Cobalt and Nickel Salts—Cobalt bloom (erythrite), nickel green.
Aluminium Salts—Wavellite, turquoise, lazulite, amblygonite.
Zinc Salts—Adamite.

Silicated Ores.

Subsilicates, unisilicates, and bisilicates of the metals.
Anhydrous—Ilvaite, hisingerite, anthosiderite, chlorophæite, gadolinite, allanite.
Hydrous—Thorite, cerite, chloropal, calamine.

Sub-Kingdom—Non-Metallic Minerals.

Silicated Minerals.

Silicates of oxides of the earths and alkalies.
Quartz Group—(*crystalline*) rock-crystal, with its varieties; (*compact*) calcedony, with its varieties; (*compact hydrous*) opal, with its varieties.
Felspar Group—Anorthite, Labradorite, hyalophane albite, oligoclase, orthoclase.—Amorphous felstones, pitchstones, and obsidians.)
Clay Group—Kaolin, halloysite, smectite, bole, teratolite, saponite, sinopite, plinthite, bauxite.—(Massive and impure clays the results of decomposition.)
Scapolite Group—Scapolite, sarcolite, meionite, dipyre.
Leucite Group—Leucite, sodalite, haüynite, nephelite, lapiz-lazuli.
Epidote Group—Epidote, axinite, Piedmontite, Saussurite, fibrolite, Andalusite, staurolite.
Garnet Group—Garnet, grossularite, pyrope, almandite, ouvarovite, helvite, vesuvianite.
Hornblende Group—Hornblende, tremolite, nephrite, actinolite, asbestus, hypersthene, bronzite, diallage, pyroxene, augite, sahlite.—(Hornblendic and augitic rocks.)
Mica Group—Muscovite, margarodite, lepidolite, caryophyllite, phlogopite, biotite, lepidomelane.—(Micaceous slates and schists.)
Talc Group—Talc, steatite, agalmatolite, sepiolite, cimolite.—(Talcose rocks and schists.)
Chlorite Group—Chlorite, pyrosclerite, ripidolite, margarite, glauconite.—(Chloritic schists and earths.)
Serpentine Group—Serpentine, chrysolite, marmolite.—(Serpentinous rocks.)
Zeolite Group—(*hydrous*) Thomsonite, natrolite, scolezite, mesolite, analcite, prehnite, chabazite, harmatome, stilbite, Heulandite, Brewsterite.—(Occur in geodes and fissures; never form rock-masses.)
Chrysolite Group—Chrysolite, leucophanite, zircon, spinel, corundum, chrysoberyl, topaz, emerald, tourmaline.—(In crystals only.)

Haloid Minerals.

Non-metallic sparry minerals.
(Fluorides, chlorides, carbonates, nitrates, sulphates, &c.)
Calcite Group—(*carbonates*) calcite, dolomite, hydrodolomite, magnesite, hydromagnesite, arragonite.—(Massive and subcrystalline limestones and marbles.) (*Phosphates*) apatite (Phosphatic and coprolitic nodules).

Fluorite Group—(*fluorides*) fluorite, yttrocerite, fluocerite, cryolite.
Heavy-spar Group—(*carbonates*) witherite, barytocalcite, bromlite, strontianite; (*sulphates*) barite, celestite.
Gypsum Group—(*sulphates*) gypsum, selenite, satin-spar, alabaster, glauberite, anhydrite, polyhalite.
Halite Group—(*chlorides*) halite (rock-salt), sylvite, sal-ammoniac, carnallite; (*carbonates*) natron, trona, thermonatrite; (*nitrates*) nitre, nitratine, nitro-calcite, nitro-magnesite; (*sulphates*) epsomite, löwite, thenardite, mirabilite, kalinite (alum), alumite, apjohnite, halitrichite; (*borates*) borax, sassolite, boracite, hydro-boracite.
Organic Salts—(*oxalates*) Whewellite, Humboldtite; (*mellitates*) mellite.

The Inflammables.

Sulphur Group—Sulphur, selen-sulphur.
Carbon Group—Diamond.
Carbonaceous Group—Graphite, anthracite, common coal, jet, lignite, peat.—(Coal in its numerous varieties.)
Hydrocarbons—(*simple*)—naphtha, petroleum, maltha, elaterite, asphalt, albertite, ozocerite, hatchetine; (*oxygenated*) succinite (amber), ambrite, copalite.

MIXED ROCKS.

The "Mixed Rocks" constitute, as has been already stated, the main bulk of the earth's crust. They may consist of two or more mineral ingredients, and are often of very varied and irregular composition. Without rigid adherence to mineralogical exactitude, they may be arranged, according to their predominating or more obvious ingredients, into the following groups. We give such explanations as may enable the non-mineralogical reader to understand their distinctive characteristics.

(*Arenaceous or Fragmentary Group.*)

Sand is in general a loose aggregation of water-worn particles, arising from the disintegration of pre-existing rocks or other mineral matter. It occurs in many varieties, as quartz-sand, shell-sand, coral-sand, iron-sand. The finely comminuted particles of volcanic matter are spoken of as volcanic sand.

Gravel is the term applied to water-worn fragments of rocks when the particles or pebbles vary from the size of a pea to that of a hen's egg. There are many varieties, according to the nature of the rocks from which these may be derived, as flint-gravel, quartz-gravel, &c.

Shingle is the geological term for water-worn rock-fragments larger and less rounded than those of gravel. Shingle beaches are common on the more exposed portions of sea-coasts.

Rubble is a convenient and expressive term, applicable to accumulations of angular rock-fragments indiscriminately thrown together, and such as may arise from river-floods, ice-drift, or the action of frost on cliffs and precipices.

Boulder is a term applied to the larger water-worn blocks of stone found on the soil or amid the superficial material. They usually owe their origin to the ice-drifts of the glacial period, but occasionally also to wave-action, as the "Boulder Beach" of Appledore.

Block is the term applied to the more angular masses; hence such phrases as "blocks and boulders," "perched blocks," &c.

Sandstone is simply consolidated sand, the particles having been compacted by pressure, or cemented together by lime, clay, iron-oxide, or other material.

Grit is the term applied to a sand-rock, when the particles are hard and irregular—that is, "sharper" than in ordinary sandstones.

Conglomerates (sometimes termed *Pudding-stones*) are aggregates of gravel and pebbles of all sizes—in other words, consolidated gravel. According to the size of the fragments, geologists speak of "pebbly conglomerates" and "bouldery conglomerates."

Breccias (Ital. *breccia*, a crumb), are agglutinations of angular fragments, which have not suffered attrition, as in the pebbles of conglomerates.

(*Argillaceous or Clayey Group.*)

Clay is a fine impalpable sediment from water, and consists wholly, or almost so, of alumino-silicious particles. It is usually tough and plastic, and is of various colours, according to the presence or absence of organic matter and metallic oxides.

Fire-clay is a variety usually obtained from the coal formation, and is so called from its power of resisting the strongest action of heat—a property it acquires from its freedom from alkaline earths, such as soda, potash, and lime.

Fullers' Clay or Earth is a hydrous silicate of alumina, employed, from its absorbent nature, in the scouring or fulling of greasy woollens; hence the name.

Mud is the familiar as well as technical term for the fine impalpable matter worn and borne down by water, and deposited in seas, lakes, and estuaries. It is often a very miscellaneous admixture, partly of mineral and partly of vegetable and animal origin.

Silt is the general term for the miscellaneous matter deposited in lakes, estuaries, bays, river-reaches, and other still waters. It may consist of intermingled mud, clay, and sand, or of distinct layers of these.

Shale is merely consolidated mud, assuming a structure less or more laminated, and very variable, of course, in composition.

Mudstone is a convenient term employed by geologists to designate an earthy clayey rock, void of shaly lamination, and often of compact and homogeneous texture.

Slate is often applied indiscriminately to all hard, laminated, argillaceous rocks, that can be readily split up; hence slaty sandstone, mica-slate, clay-slate, &c. It would be better, however, to restrict the name to the clay-slates or roofing-slates.

Claystone, the name applied by the older mineralogists to the softer and earthy varieties of felstone or felsite, and now almost obsolete.

(*Calcareous or Lime Group.*)

Limestone is the general term for all rocks, the basis of which is carbonate of lime—that is, lime in union with carbonic acid. Calcareous rocks are all less or more acted upon by the ordinary acids, effervescing on the application of these liquids.

Marble is an architectural rather than a geological term, and is applied to the compact, crystalline, mottled, and veined varieties of limestone susceptible of a fine polish.

Chalk is a familiar as well as a technical term for the softer and earthier varieties of limestone. The chalks appear in various colours.

Calc-tuff and *Calc-sinter* are precipitates or deposits from calcareous waters, and appear as porous, incrusting, stalactitic, and stalagmitic masses.

Marl is a loose application for all friable compounds of lime and clay. The marls of fresh-water lakes are spoken of as "clay-marls," "marl-clays," and "shell-marls," as one or other ingredient predominates.

Gypsum is a sulphate of lime, which when calcined forms the well-known plaster of Paris or stucco. It occurs massive-crystalline, granular, or fibrous, and when crystallised is known as *selenite.*

Alabaster is the term applied to fine translucent varieties of carbonate of lime and of sulphate of lime, the former being known as *calcareous*, and the latter as *gypseous*, alabaster.

Magnesian limestone is a compound of carbonate of magnesia and carbonate of lime; but as many limestones contain a small portion of magnesia, the term is generally restricted to those containing from 18 or 20 per cent and upwards.

Dolomite (after the French geólogist Dolomieu) is a granular or crystalline variety of magnesian limestone.

(*Silicious or Flinty Group.*)

Quartz, properly speaking, is fine silica; *rock-crystal* is the name given to clear, transparent, crystallised varieties; and coloured varieties are known as *amethyst*, *cairngorm*, *topaz*, &c.

Quartz-rock is massive quartz of various colours, and occurs in veins or stratiform masses.

Quartzite is the term applied to granular varieties, and to sandstones apparently reconverted by heat or chemical change into quartz.

Jasper, *Agate*, *Carnelian*, *Hornstone*, *Lydian stone*, &c., are compact silicious rocks and minerals of various colours, exhibiting smooth or conchoidal fractures.

Flint is nodules of impure silica of various colours, and usually found in chalk and limestone strata.

Chert is the name given to highly silicious limestones or admixtures of flint and limestone, and occurs in concretions, nodules, and rock-masses.

Calcedony, *Opal*, *Silicious-sinter*, &c., are silicious minerals, generally produced by infiltration of water holding silica in solution, and appearing as incrustations of greater or less thickness.

(*Carbonaceous and Bituminous Group.*)

Coal is a well-known substance, and may be briefly described as mineralised vegetable matter, containing more or less of earthy impurities. It occurs in many varieties, as caking or coking coal, splint or slaty coal, cubic or rough coal, cannel-coal, &c., which are all bituminous, giving off smoke and flame in burning; and also as *anthracite* or stone-coal, which is non-bituminous, and burns without smoke or flame.

Lignite, also known as wood-coal, board-coal, and brown coal, is a variety of recent formation, and in which the woody structure is still apparent. Indeed, the transition from peat to lignite, from lignite to coal, and from coal to anthracite, is often so apparent, that there can be no doubt that they are all merely vegetable masses in different stages of mineralisation.

Jet is a compact, lustrous variety of coal, susceptible of a high polish, and on that account usually worked into personal ornaments.

Graphite (familiarly known as plumbago and black-lead, from its appearance, though entirely devoid of lead) is almost pure carbon, containing only slight traces of iron and earthy impurities.

Bitumen is an inflammable mineral substance (hydrocarbon), found either in a free or in a combined state. As free bitumen, it occurs limpid, as *naphtha;* liquid, as *petroleum* or rock-oil; slaggy, as *maltha* or *mineral* pitch; and solid, as *asphalt.* It can be discharged from coals, coaly shales, and other substances, by the application of heat; hence such substances are said to be "bituminous," or more properly "bituminiferous."

(*Saline or Salt-like Group.*)

Common Salt (chloride of sodium) is found in incrustations in desiccated sea-beaches, and in the sites of dried-up lakes. It occurs abundantly in the solid crust as *rock-salt*, and is held in solution by all sea-water and brine springs.

Nitrates of Soda and Potash (natron, trona, saltpetre, &c.) occur as incrustations and efflorescences in many plains, marshes, and lakes in hot countries. Such deposits or *salinas* are often of considerable thickness and extent.

Alum (sulphate of alumina and potash), though chiefly extracted for commercial purposes from certain shales and schists, is also found in nature in the saline or crystallised state.

Borax (borate of soda), another saline product, boracic acid being abundantly discharged by the thermal springs of some volcanic regions.

Borate of Lime, another saline substance occurring in radiated nodules, is a product of salinas, such as those of Bolivia and Peru.

Sulphur is found massive and in crystals in almost all volcanic districts. It is also found largely in combination with many of the earths and metals.

(*Simple Minerals and their Rock Compounds.*)

Felspar (a chemical admixture of silica, alumina, and potash or soda) is a softer mineral than quartz. The larger and softer crystals occurring in granite are of felspar; they can be scratched by the knife when quartz resists it, and can also be distinguished by the flat glassy aspect of their cleavage.

Compact Felspar, *Felstone*, or *Felsite*, is a massive, amorphous, felspathic rock, forming dykes and mountain-masses.

Porphyry and *Felspar Porphyry* are rocks mainly composed of compact felspar, with interspersed crystals of felspar.

Mica (Lat. *mico*, I glisten) is a soft, sectile mineral, readily splitting up into thin transparent plates, and is a chemical compound of silica, magnesia, and potash. The glistening scaly crystals in ordinary granites are mica.

Mica-schist and *Mica-slate* are schistose or slaty rocks, largely composed of micaceous particles—the former splitting irregularly, the latter with greater flatness and regularity.

Hornblende, *Hornblende-rock*, *Hornblende-schist.*—As a mineral, hornblende is of a dark or dark-green colour, with a horny glistening lustre (hence the name), and occurs largely as a constituent of certain greenstones and granites. When massive, it constitutes hornblende-rock; when fissile, hornblende-schist.

Hypersthene is a greenish-black or greenish-grey mineral, having somewhat of a metallic lustre, nearly allied to hornblende, and occurring largely in igneous rocks, or forming independent rock-masses.

Actynolite (Gr. *actin*, a thorn), another mineral closely allied to hornblende of a glassy lustre, and deriving its name from the thorn-like shape and disposition of its crystals. It occurs massive, as *Actynolite-rock*—and fissile, as *Actynolite-slate.*

Augite, a black and harder mineral than hornblende, forming the principal constituent of the basalts and clinkstones.

Asbestos or *Amianthus*, so well known from its fine fibrous texture, may be regarded as a variety of actynolite. It occurs in flexible fibres, in rigid masses, and in tough aggregates known as "mountain wood," "mountain cork," "mountain leather," &c., from its resemblances to these substances.

Chlorite (Gr. *chloros*, greenish-yellow) is a mineral of a greenish hue, and generally of a foliated texture, in which condition it forms the principal ingredient in the rocks known as *chlorite-slate* and *chlorite-schist*.

Talc, a whitish-green magnesian mineral, closely allied to and resembling mica. It is transparent in thin plates, but is generally massive, sectile, soft, and non-elastic. It enters largely into the earlier schists, known as *talc-schists* and *talcose-schists*.

Steatite, Stea-schist, Soapstone, Potstone.—All rocks containing steatite, which may be regarded as a variety of talc, have a greasy or soapy feel, hence the name, from *stear*, fat or grease. Some from this feel are termed *soapstone;* others, from their sectility and power of resisting heat, are known and used as *Potstones*.

Serpentine, so called from its variegated or mottled hues, like the skin of a serpent, is one of the magnesian rocks, occurring largely in primitive districts, and employed as an ornamental stone.

(*Igneous or Pyrogenous Rocks.*)

Granite and *Syenite.*—Ordinary granite is a granular-crystalline compound of quartz, felspar, and mica, and variously coloured from the presence of iron in the felspar, or from the hues of the mica. There are many varieties of granite, differing in size of grain, colour, and compactness. When hornblende takes the place of mica, or when present in addition, the rock is usually known as *Syenite*, from Syene in Upper Egypt, where it was early quarried.

Trap-Rocks (from Swedish *trappa*, a stair, owing to the step-like or terraciform aspect they give to the hills composed of them) include a great variety of igneous rocks all less crystalline than the granitic, and all more compact and less vesicular than volcanic products. These are the basalts, clinkstones, greenstones, felstones, pitchstones, amygdaloids, tuffs, and ashy agglomerates.

The *basalts*, *clinkstones*, and *greenstones* are generally hard, close-grained, subcrystalline rocks, often assuming columnar and subcolumnar structures. They consist of varying admixtures of felspar, augite, and hornblende. The *felstones*, *amygdaloids*, and *trap-tuffs* are softer and less crystalline rocks—the felstones compact or earthy ; the amygdaloids having their vesicular cavities filled with agate, carnelian, calc-spar, &c ; and the tufas evidently consolidated ejections of dust and ashes.

The *Volcanic Rocks* consist of lavas, obsidians, pumice, scoriæ, ashes, lapilli, sulphurous muds, &c., and occur, according to their age, from rocks differing little from greenstones and basalts to loose accumulations of dust and cinders.

The *Trachytes* are rough-grained (Gr. *trachys*, rough) subcrystalline varieties of felspathic lava.

The *Lavas proper* occur in many varieties—porous, vesicular, compact, basaltic, subcrystalline ; glassy, as *obsidian*—and light and cellular, with silky-fibrous texture, as *pumice*.

Scoriæ, lapilli, bombs, dust, sand, &c., are the familiar names for the loose and fragmentary ejections.

(*The Metallic Group.*)

The *metals* are found either *native*—that is, in a pure state—or combined with mineral matter in the state of ores. Gold, silver, platinum, copper, and one or two others, are found native in nuggets, pellets, plates, and thread-like branches; the majority of the metals occur as ores—that is, as oxides, sulphides, carbonates, &c., as shown in the tabulation of mineral groups, p. 15, 16. Most of these ores are found in veins associated with sparry matter, as calc-spar, fluor-spar, quartz, baryta, &c., which form the veinstone, gangue, or matrix; a few only occur as stratified deposits.

II.—CHRONOLOGICAL ARRANGEMENT OF ROCK-FORMATIONS.

It is not enough, however, to determine merely the positions, structure, texture, and composition of rocks; the geologist must endeavour to ascertain their relative ages—that is, their succession in time and sequential place in the earth's crust, so as to be able to map out their respective areas, their extent, thickness, and abundance. In this task he is mainly aided by three considerations — superposition, mineral composition, and fossil remains. In any succession of deposits it is obvious that the lowest must be the oldest, and that those above will take their places in chronological order. It is also for the most part true that the older and deeper strata will have undergone a higher degree of internal or mineral change through pressure, chemical replacement, and other metamorphosing agents. And it has been further ascertained that the older or deeper any rock-formation is, the more widely do its organic remains differ from existing genera and species. Guided in his determination by these and similar truths, the geologist has been enabled to arrange the stratified rocks in chronological sequence—that is, into formations, groups, and systems or life-periods, from the deposits now taking place in existing waters to the deepest or most ancient in the earth's crust, and about whose nature and origin he can reason with something like certainty. Having determined the relative ages of the stratified rocks, he also attempts a similar arrangement of the unstratified or igneous, being guided in this attempt by the strata through which they pass, by the fragments of other rocks they may enclose, and lastly, by the manner in which they intersect and overlie each other.

Classification of Stratified Deposits.

In this classification of stratified deposits, the geologist understands by a *formation* any series of strata that has been deposited continuously in the same area, be that lake, estuary, or sea; and hence he speaks of *lacustrine*, *estuarine*, and *marine* formations. By a *group* he embraces such strata as have several lithological and palæontological features in common, though they may be partly of fresh-water and partly of marine origin. And under a *system* or *life-period*, he includes such formations and groups as present the same general facies of fossil remains—that is, such groups as are characterised by the presence of the majority of the same plants and animals. Abiding by these principles, modern geologists have arranged the stratified rocks of the crust, and especially those of Europe, as in the annexed tabulation—the terms Primary or Palæozoic (ancient life), Secondary or Mesozoic (middle life), and Tertiary or Cainozoic (recent life), being analogous to the subdivisions of human history into ancient, medieval, and modern :—

TABULAR SYNOPSIS OF EUROPEAN STRATA.

Group.	*Systems.*	*Cycles.*	
Recent.	POST-TERTIARY.		
Post-Pliocene.			
Newer Pliocene.	PLIOCENE.		
Older Pliocene.			
Miocene.	MIOCENE.	TERTIARY OR CAINOZOIC.	
Upper Eocene.	EOCENE.		
Middle Eocene.			
Lower Eocene.			
Maestricht Beds.	CRETACEOUS.		NEOZOIC.
Upper White Chalk.			
Lower White Chalk.			
Upper Greensand.			
Gault.			
Lower Greensand.			
Wealden Clays and Sands.	OOLITIC OR JURASSIC.	SECONDARY OR MESOZOIC.	
Purbeck Beds.			
Portland Stone.			
Kimmeridge Clay.			
Coral Rag.			
Oxford Clay.			
Great or Bath Oolite.			
Inferior Oolite.			
Lias Marls and Shales.			
Lias Limestones.			
Upper Trias.	TRIASSIC.		
Middle, or Muschelkalk.			
Lower Trias or Bunter.			
Magnesian Limestone.	PERMIAN.	PRIMARY OR PALÆOZOIC.	PALÆOZOIC.
Variegated Sandstones.			
Upper Coal-Measures.	CARBONIFEROUS.		
Millstone Grit.			
Carboniferous Limestone.			
Lower Coal-Measures.			
Sandstones and Limestones.	DEVONIAN.		
Sandstones and Conglomerates.			
Upper Limestone and Shales.	SILURIAN.		
Lower Slates and Grits.			
Slates, Grits, and Schists.	CAMBRIAN.		
Schists, Quartzites, Serpentines.	LAURENTIAN.		
Crystalline Schists.	METAMORPHIC.	AZOIC.	

In further explanation of the preceding synopsis, it may be stated that the *Post-Tertiary System* consists in the main of clays, gravels, sands, peat-mosses, marls, coral-reefs, foraminiferal muds, and other accumulations, which are still forming, or which have been formed within a comparatively recent period, in lake-basins, river-valleys, estuaries, and along the shores as well as in the depths of the ocean. They imbed, in a sub-fossil state, the remains of plants and animals still living, though often removed from, or extinct in, certain localities which they once inhabited. In volcanic districts they are associated with lava, scoriæ, and other igneous ejections; and, generally speaking, they occupy low-lying tracts, and constitute the surfaces of valleys, plains, and other alluvial expanses.

Immediately underlying these recent deposits, there occur over the northern hemisphere (down to the 40th parallel of latitude or thereby) thick accumulations of clay and gravel, imbedding huge water-worn blocks or boulders; and as these seem to point to a time when large areas of the northern hemisphere were under ice, or subjected to the drift of icebergs that dropped their burdens of clay, gravel, and boulders on the then submerged surface, this period is generally known as the *Boulder*, *Northern Drift*, or *Glacial Epoch*, and holds a place intermediate between the Post-Tertiary and Tertiary Systems. For the most part, these glacial accumulations are destitute of organic remains, but in some of the upper and laminated clays, shells, star-fishes, bones of birds, seals, and whales make their appearance, and these are all strictly of boreal species.

The *Tertiary System* consists, in general terms, of clays, sands, gravels, limestones, marls, and lignites, or beds of wood-coal, and occupies well-defined areas (*Basins*), as if these at one time had been extensive fresh-water lakes, estuaries, and inland seas. The fossils imbedded in tertiary strata, though closely allied to existing genera and species, are in most instances extinct, and point to conditions of climate and distributions of life very different from that at present prevailing. The igneous rocks associated with them are lavas and basalts, the products of volcanoes long since extinct, or now but partially active. Undulating lowlands may be said to constitute the physical features of tertiary tracts—the basins of London, Paris, and Vienna, and the upper pampas of the La Plata, being typical examples.

The *Cretaceous* or *Chalk System* consists, as its name implies, of thick beds of chalk or soft marine limestones, associated with sand, sandstones, clays, and in some localities with beds of coal and lignite. The fossils belong almost wholly to extinct species; and even where the chalk beds are wanting, the other strata are so replete with the characteristic remains of the system (sponges, foraminifera, sea-urchins, shell-fish) that there is generally little difficulty in recognising it. The associated igneous rocks are chiefly basalts and greenstones; and the physical features of the system may be said to be low rounded hills (like the "Downs" of Kent, Surrey, and Sussex), with dry intermediate depressions (coombs) where the chalks and sand prevail, and flat fertile vales, where the rich fossiliferous clays come to the surface.

The *Oolitic* or *Jurassic System* consists largely of limestones, alternating with calcareous clays, sandstones, bituminous shales, and, in some districts, of beds of ironstone and workable coals. It derives its former name from its peculiar limestones or roestones (Gr. *oon*, egg; *lithos*, stone), which have a minutely concretionary texture; and its latter from its extensive development in the Jura Mountains. Palæontologically, it is characterised by its cycadaceous plants and tree-ferns, by its abundant marine fauna (corals, bivalves, and nautilus-like ammonites), and by its huge aquatic and terrestrial reptiles. The unequal weathering of its harder limestones, soft clays, and shales, confers on the oolitic landscape that succession of long undulations so noticeable in that broad belt of country which stretches from Yorkshire on the north-east, to Dorset on the south-west of England.

The *Triassic* and *Permian Systems*, which were formerly considered as a single system under the name of the *New Red Sandstone*, consist in the main of soft reddish (sometimes pebbly) sandstones, yellowish magnesian limestones, and variegated clays and marls, with occasional deposits of rock-salt and gypsum. The lower portion, being largely developed in Perm in Eastern Russia, has given rise to the term Permian; and the upper, consisting in Germany of three well-marked members (sandstones, limestones, and marls), has received the name of Trias, or triple group. The fossil remains of these systems differ widely—those of the Permian being closely allied to the Carboniferous flora and fauna, and therefore Palæozoic; while those of the Trias are Mesozoic, and consist of marine organisms, with footprints of birds and amphibian reptiles. The physical features of the New Red Sandstone are by no means decided—the limestones and harder sandstones forming inconspicuous hills and ridges, the softer clays and marls being worn into vales and expanses, of a flat, moist, and retentive character, better fitted for pasture than for corn-culture, and of which Cheshire, in our own country, may be taken as a typical example.

The *Carboniferous System*, so called from its yielding the main supply of coal (Lat. *carbo*, coal) in Europe and America, consists of sandstones, shales, clays, limestones, ironstones, and coals in frequent alternations, as if they had been deposited for ages in seas and estuaries, subjected to repeated subsidences and elevations. The fossils of the system are abundantly marine, estuarine, and terrestrial, and all of palæozoic forms—the most notable being that excess of vegetable growth that went to the formation of numerous seams of coals. With the exception of the trap hills (greenstones, basalts, amygdaloids, &c.) that intersect the system in some localities, and those bold cliffs and scars of limestone (mountain limestone) so characteristic of Yorkshire and Derbyshire scenery, there is little attractive in the physical features of the coal-formation, monotonous moorlands of cold retentive soil (Northumberland, Lanark, Linlithgow) being a common occurrence in the geography of the system. Though superficially unattractive, it is rich in mineral and metallic products—coals, limestones, fire-clays, building-stones, ironstones, and ores of lead, zinc, silver, and antimony, being among its most important contributions to modern industry and civilisation.

The *Old Red Sandstone* or *Devonian System* (from Devonshire, where a portion of it is typically developed) consists in the main of reddish sandstones, conglomerates, flagstones, and shales, with subordinate beds of limestone. In Devon the fossils are chiefly corals, shells, and other marine exuviæ; in Hereford and Scotland, crustacea and fishes prevail. Thrown into many irregularities by trap (often felstone) eruptions, the physical features of the Old Red Sandstone are usually varied and picturesque, and in general its slopes are dry and of moderate fertility. The larger portions of Devonshire, Hereford, Perthshire, and Forfar, as well as of the south of Ireland, may be taken as typical areas of Old Red Sandstone.

The *Silurian System* (so called from its typical development in that district of Wales anciently inhabited by the Silures) consists of numerous slaty or hard shaly beds, with sandstones, grits, and intercalated limestones. As in all the older and deeper-seated formations, there is a tendency to crystalline texture, and these are not unfrequently traversed by metalliferous veins—tin, copper, silver, and gold. Its fossils are eminently marine, and consist almost wholly of the invertebrate orders (corals, shell-fish, and crustacea), few fishes being found in its strata, and these only in the upper portions of the system. Flanking and often borne up by the older granitic hills, the physical features of the system are frequently irregular and mountainous; but, from the softer nature of the rocks, are more rounded and massive, and less abrupt and precipitous, than those of the crystalline or metamorphic strata. Western Wales and the southern uplands of Scotland, from St Abb's Head on the east to Portpatrick on the west, with all their variety of hill, glen, and valley, may be taken as typical areas of Silurian soil and scenery.

The *Cambrian and Laurentian Systems* (so called, the former from being typically developed in Wales; and the latter, from its vast development in the Laurentide mountains in Canada) consist, for the most part, of slates, grits, quartzites, schists, serpentines, and other crystalline strata. Being chiefly altered rocks, they contain few fossils, and present in their geographical features peaks and splintery pinnacles, with steep precipices and ravines—thus conferring on their areas picturesque and romantic scenery, like that of Wales and the lake district of Cumberland; or still more irregular and mountainous regions, like those of the Laurentian and Norway Highlands.

The *Metamorphic System* (so called because its strata have undergone a metamorphism or change by heat, pressure, and chemical action, from ordinary sandstones, shales, and limestones into hard crystalline schists) consists of such rocks as gneiss, quartzite, mica-schist, slates, serpentines, and primitive marbles. They yield no fossils; but whether all traces of life may have been obliterated by the mineral change these rocks have undergone, or whether they were deposited before life existed on the globe, Geology cannot determine. These crystalline schists are generally found at high angles, flanking or composing the main mass of the older mountains; and from their hard splintery nature, present those peaks and ridges that confer on primitive districts their abrupt, wild, and Alpine character.

Classification of Unstratified Rocks.

As with the stratified so with the unstratified rocks; each great group has its own physical features, and though perhaps less sharply defined, they are still sufficiently distinct to be recognised in hill and mountain ranges as Volcanic, Trappean, and Granitic.

The *Volcanic* are generally associated with the more recent stratified formations, and consist of trachytes, basaltic lavas, vesicular lavas, scoriæ, and other similar products—loose and less consolidated in the more recent and active, and harder and more compact in the older and extinct volcanoes. They rise up in dry rocky hills, more or less conical and crateriform; and these are, perhaps, more frequently grouped round some common centre than arranged in linear or axial directions. The cones of Vesuvius and Etna, and the crateriform hills of Auvergne, are familiar and well-known examples — the slopes varying in abruptness from peaks of scoriæ, and less abrupt mixtures of scoriæ and lava, to the flatter hills composed mainly of lava or liquid ejections; hence the familiar designations of cinder-cones, mixed-cones, and lava-cones.

The *Trappean* (so called from the terraciform aspect of many of the hills they compose—Swedish, *trappa*, a stair) consist of greenstones or whinstones, basalts, felstones, porphyries, amygdaloids, tufas, and other kindred rocks, and are generally associated with the secondary and upper primary strata. They are usually elevated into hill-ranges more or less persistent, and from their higher antiquity and longer subjection to wasting influences, are now worn into rounded heights, exposed crags, slopes, and terraces, which confer on the landscape a beauty and diversity peculiarly their own—the harder basalts and greenstones standing out as the crags and terraces, while the softer tufas and ashes have been worn down into gentle slopes and declivities. Their soils being dry and genial, the "trap-soils" of a country are generally possessed of great amenity and fertility, and constitute, perhaps, the most valuable agricultural portions of the districts in which they occur.

The *Granitic*, or oldest series of igneous rocks, consists of granites, syenites, porphyries, and the like, which, from their more ancient and deeper-seated relations, are generally hard and crystalline in texture, and massive in structure. They constitute the nucleus or backbone, as it were, of all the higher and older mountain-chains—elevating the metamorphic schists into splintery peaks and abrupt ridges, or presenting of themselves broad massive shoulders of cold sterile moorland and unprofitable heath.

Geological Maps and Sections.

To map out the areas occupied by these respective systems, and to exhibit the thickness, alternations, and relations of their strata by sections and sketches, is the task of the field geologist. The areas occupied by the respective formations are generally marked by distinctive colours, as in the map of the British Isles which accompanies this volume; and the alternations, dips, faults, &c., of the strata are exhibited by sketch-sections. These sections are constructed from observations of outcrops, exposures in sea-cliffs, ravines, railway and road cuttings, borings and sinkings of wells, coal-pits, and the like. Wherever a rock comes to the surface, or can be seen, its place and dip are noted down; and by a careful succession of such jottings wonderful approximations to the actual structure of any locality can be arrived at. By certain conventional signs—arrows for dips, bold lines for outcrops, white lines for faults, coloured lines and masses for igneous dykes and eruptions, bronzed lines for veins, and the like—a vast amount of geological information can be at once conveyed to the eye, while descriptive notes supply the details of mineral and other peculiarities. It must not be supposed, however, that the space coloured on a map exhibits the absolute extent of any formation, for a large amount of that formation may be covered or overlaid by more recent formations—a circumstance which can often be inferred with great accuracy, but which can only be proved by direct exploration.

Such maps as are here spoken of exhibit the extent, thickness, dip, and other relations of the solid rock-formations only. But as these formations are, for the most part, overlaid by clays, sands, gravels, peat-mosses, alluvial silts, and other superficial accumulations, and as these accumulations are often of agricultural and commercial importance, they require a separate survey and mapping. In fact, every well-conducted geological survey should have two sets of maps—one exhibiting the superficial accumulations, and another the subjacent rock-formations. Provided with two such maps, the farmer, builder, engineer, miner, or technologist, should have no difficulty in arriving at some estimate of the amount, quality, and facilities of obtaining the industrial products of any locality—the value of the maps depending, of course, upon the minuteness and accuracy of the survey. The value of the maps is greatly enhanced by well-constructed sections, showing the successive alternations and thicknesses of the respective strata, though for special purposes a section is generally obtained by boring or pitting the locality in question.

In the preceding chapter we have drawn attention to the structure and composition of the Rocky Crust from which all our industrial products—mineral and metallic—are derived. Some acquaintance with its rocks—their origin, relative positions, structure and texture, mineral composition, and chronological succession—is indispensable to the thorough utilisation of its products. The crust of the earth has a masonry of its own; every course or system in that masonry has its own peculiarities, and without some knowledge of these peculiarities the practical man is working at hazard and in uncertainty. This information we have attempted to supply in the preceding sketch: those who would enter into details must apply to the pages of some work on General Geology. In the mean time, what we have given will render more intelligible the following chapters, whether devoted to farming, building, engineering, mining, heating, lighting, or other technological purposes.

Works which may be consulted.

Lyell's 'Student's Elements of Geology;' Dana's 'Manual of Geology;' Juke's 'Manual of Geology'—Geikie's Edition; Page's 'Advanced Text-Book of Geology;' Tate's 'Rudimentary Treatise on Geology.'

III.

GEOLOGY AND AGRICULTURE.

THE relations between Geology and Agriculture are direct and immediate: the nature and composition of soils, their improvement by admixture and drainage, and their enrichment by manures, being subjects on which landowner and farmer can frequently obtain important information from the practical geologist. A soil may be deficient in composition and texture, and yet the elements of improvement may lie in another soil on the same farm: the question of drainage depends much on the nature of subsoils and subjacent rocks; and substances having a manurial value may be close at hand, and yet be unsuspected by the working farmer. On all such points the geological surveyor can render valuable assistance; and it is often more through the indolence of routine than through prejudice that the agriculturist fails to avail himself of the suggestions of science. It is true that by some the bearings of geology on agriculture have been overstated, and their value exaggerated; but it is equally true that the chances of success are on the side of the farmer whose practice is directed by a knowledge of the facts and principles which lie at the foundation of his art. Nor for the farmer alone, but for the country at large, is it desirable that scientific principles should rule more thoroughly in practical agriculture. The area of our country is limited, and of that limited area a large portion, partly from structure and partly from climate, is totally unfit for general husbandry; hence the necessity (with an ever-increasing population) that the available portion should be rendered as fertile as it is possible for skill and industry to accomplish. In the present chapter we intend to direct attention, *first*, to the geological character of soils and subsoils, and the possibility of their permanent improvement by intermixture and by drainage; and *secondly*, to those mineral manures which modern agriculture has applied with such success alike to the increase and to the earlier ripening of our white and green crops.

I.—SOILS AND SUBSOILS.

The soils upon which the agriculturist has to operate are usually classified as sandy, sandy or light loams, loams, clayey loams, heavy or retentive clays, marls, calcareous loams, peaty soils, or bog-earths. This classification has reference chiefly to composition and texture, a special chemical composition (silicious, calcareous, &c.) being necessary for the profitable growth of particular crops, and a certain mechanical texture (friable, porous, &c.) suiting best for the permeation of rain and air, and the descent or spreading of special roots and rootlets. Loams, consisting of fertile admixtures of sand, clay, and *humus* or decayed vegetable matter, may be regarded as typical soils, which become, on the one hand, *light*, by a preponderance of sand, and on the other, *heavy*, by a preponderance of clay. But whatever their composition and texture, these soils, geologically speaking, are mainly of two sorts,—*soils of disintegration*, arising from the waste and decay of the immediately underlying rocks, together with a certain admixture of vegetable and animal debris; and *soils of transport*, whose ingredients have been brought from a distance, and have no geological connection with the rocks on which they rest. Under the former are comprehended such as arise from the disintegration of limestones, chalks, traps, granites, and the like, and which are directly influenced in their composition, texture, and drainage, by the nature of the subjacent rocks from which they are derived. Under the latter are embraced all drift and alluvial materials, such as sand, shingly debris, miscellaneous silt and clay, which have been worn from other rocks by meteoric agencies, and transported to their existing positions by winds, waters, or ancient glacial agencies. Besides these there are also soils of organic origin, such as peat-earths, and vegetable mould or *humus*, which is to a great extent also of animal origin or elaboration. Indeed, in all superficial soils there is a certain amount of vegetable and animal matter—the decay of plants, the droppings of animals, the exuviæ of insects, the casts of the earth-worm, and the like, conferring upon them that dark, friable, and loamy character so indicative of richness and fertility.

Beyond the *soils* proper, which come immediately under the plough, there are in most situations a set of *subsoils*, differing from the true soils, and which cannot be ignored by the farmer. Thus peat may lie upon clay, sand upon clay, common *humus* on sandy clay, and clay may rest upon shingly debris; while in many of our alluvial flats (old lake-sites and estuaries) there may be several alternations of peaty matter, clay, sand, silt, and marl, before the underlying rock-formation is arrived at. In general, the subsoils differ notably in colour and consistence from the soils above them. The true soils are usually of a darker colour, from the larger admixture of humus, while the subsoils are lighter in hue—yellow, red, or bluish, from the greater preponderance of iron oxides. The soils are also more or less friable in their texture, while the subsoils are tougher, more compact, and more largely commingled with rubbly and stony debris. The soils are usually little more than a mere surface covering, while the subsoils may be many feet, or even yards, in thickness.

All these soils and subsoils repose on the rocks below, but it is only where they are immediately derived from these rocks by disintegration that they are materially influenced by this relation. Hence, for agricultural purposes, it is necessary to have two sets of geological maps—one showing the range and disposition of the older rocks, and another exhibiting the disposition of the superficial accumulations by which these are masked. On examining two such maps of any district in Britain, it will be seen that the soils of disintegration occupy limited areas in comparison with those of transport. In all our river-valleys, dales, levels, fens, straths, and carses, the soils are those of transport, and consist of miscellaneous river-drifts, the alluvia of former lakes and sea-beds, or of the sands, shingles, and bouldery clays of the glacial epoch. Over the higher uplands—largely over carboniferous districts, and on many of the other formations—the drifts of the glacial period are thickly spread; so that it is chiefly on the hilly portions of the Chalk, the Oolite, the Mountain-limestone, the old Slates and Schists, the Traps and Granites, that we find soils of disintegration. And even there, there are many patches of bouldery clay, sand, and shingly drift, whose materials have been brought from other and distant localities.

Soils of Disintegration.

All rock-surfaces, however hard and refractory, break up, in course of time, under the influence of meteoric agencies. Those containing lime are acted upon by the carbonic acid of the atmosphere; those containing iron by the oxygen; and all suffer more or less through frosts, rains, winds, and other kindred forces. These disintegrating agencies are further aided by the root-growth of plants, by the burrowing of worms and other earth-dwelling creatures, and in no small degree by the acids (*humic*, *geic*, and *crenic*) generated by organic decay. From the hardest granites, basalts, and lavas, to the softest chalks and marls, all are undergoing this disintegration; and the soils thereby produced will vary in depth, composition, and texture, according to the softness and mineral character of the rocks, and the length of time during which they have been subjected to the comminuting forces.

If we take a geological map of the British Islands and turn to the districts coloured as *granitic*, we shall find them largely covered with a thin cold clayey soil derived from the decomposition of the subjacent granite. Ordinary granite is composed of quartz, some variety of felspar, and mica; and it is the felspar (silicates of alumina, with minor proportions of soda, potash, lime, and iron) which mainly yield this poor moorland covering, the sterility of which is aggravated by its general high elevation, whitish colour, and the impervious nature of the rock on which it rests. We say whitish colour, for, area for area, white soils take in less heat than dark-coloured ones—the former reflecting and the latter absorbing the solar rays. If we turn, on the other hand, to the tracts coloured *Trappean*, we will find them covered, for the most part, with a dark-coloured, dry, crumbling soil, noted for its fertility and certainty of cropping. This arises from the disintegration of the softer trap-tuffs, amygdaloids, and wackès, and consists, according to the analyses of the late Professor Johnston, of silica, alumina, and lime, with varying proportions of soda, potash, and iron; its fertility and mellowness being augmented by its colour, which absorbs the sun's heat, and by the fissured structure of the rocks beneath, which carries off all superfluous moisture.

In slaty and schistose tracts—that is, those coloured *Metamorphic*, *Cambrian*, and *Silurian*, we find that where these rocks are not masked by diluvial drifts, they have weathered into thin clayey soils of indifferent fertility, partly owing to their elevation, and partly to their retentive texture—green nutritive pastures occurring, as in the southern uplands of Scotland, only where the high inclination of the beds, with their slaty structure, affords a ready and efficient natural drainage. The soft, sandy, and marly strata of the *New Red Sandstone* break up into a dry fertile soil, especially suited for barley and green crops; while the clayey and marly beds weather down to a stiff retentive clay, like that of Cheshire, much better adapted for permanent pasture than for the varied requirements of corn culture. Over the *Lias* and *Oolite*, consisting of alternations of calcareous and argillaceous strata, we have those noticeable belts of dry, rubbly, and stiff clayey soils, which characterise a large portion of England, from Yorkshire on the north-east to Dorset and Somerset on the south-west—the calcareous freestones forming the drier ridges, and the clays the moister valleys.

In the south-east of England, the tracts coloured as *Hastings sands*, *Weald Clay*, *Greensand*, *Gault*, *Chalk*, and *London Clay*, are respectively characterised by thin, light sandy, stiff clayey, or dry calcareous soils—the direct results of the disintegration of their immediately underlying rocks. Indeed, this connection between the soils and subjacent rock-formations is best seen along the Secondary and Tertiary tracts of England—that is, from the New Red Sandstone upwards through the Lias, Oolite, Wealden, Chalk, and Eocene deposits of the London and Hampshire basins. No doubt sporadic patches of diluvial drifts occur here and there to break the connection, but, generally speaking, the soils, modes of culture, crops (wheat, barley, beans, hops), coincide with and are favoured by the lithological belts, as depicted on the geological maps of the country.

Nor do these lithological areas influence alone the white and green crops of the husbandman; they are equally, if not still more, operative in the growth and value of the timber trees of the forester. The firs and larches which thrive so magnificently on the decomposed mica-schists of the Scottish Highlands would be but poor stunted sticks on the thin cold clays of the granite; while the oaks, and elms, and orchard-growths which flourish on the marly clays of the New Red Sandstone, would become stunted and gnarled if transferred to the drier and scantier soils of the Chalk and Carboniferous limestone.

Soils of Transport.

When we turn to the soils of transport we find them of a much more miscellaneous character, and occupying much more extensive and unbroken areas. Some consist of river-drifts—shingly gravel, sand, or alluvium; others of old lake-sites—peaty earth, clays, sands; some of old estuary beds—tenacious clays and silts; others, again, of wind-blown sands and sand-dunes; and many of glacial drifts—sand, shingly gravels, and stiff bouldery clays. These may of themselves form the arable soils, or they may constitute the subsoils, and be overlaid by a coating of less or greater thickness, partly derived from their own disintegration, augmented by the growth and decay of plants, and partly formed by the plough and repeated cultivation. But whatever be their nature and origin, they are little, if at all, influenced by the subjacent rock-formations, and have to be studied and treated by themselves. Over the *Old Red Sandstone, the Carboniferous and Permian systems*, which consist mainly of sandstones, shales, and clays, there is in most parts of the British Islands a thick coating of diluvial or bouldery clay, very stiff, retentive, and sterile. Much of this boulder-clay has been brought from a distance by ice-action; but the major portion, perhaps, is but the ground-up material of the formations on which it rests, hence its reddish tints on Old Red tracts, and its dark-blue colour over the Coal-formation. In many of our larger plains —Strathmore and Strathearn, for example—there is a very miscellaneous assortment of drifts — sands, gravels, shingly debris, and boulder-clays; and in the lower and wetter portions, peat-earths and alluvia, the remains of silted-up lakes, or of lakes still in process of obliteration. In our lower carses and valleys—Carses of Gowrie, Falkirk, and along the Humber —there are large expanses of soft plastic clays (old estuary bottoms) of great fertility, but of difficult and uncertain cultivation; while such tracts as the Fens of Lincoln, Romney Marsh, and the like, are chiefly marine silts and marsh growths. Sand-dunes, or link-lands along the sea-shores, and inland marshes, also occupy extensive tracts; and, indeed, by far the larger area of these islands consists of subsoils and surface soils, having no connection with the rocks on which they rest, and little, if at all, influenced by their proximity. These soils of transport must therefore be studied and treated by themselves, whether as regards fertile and permanent admixture, draining, or manuring.

Along with these soils of transport may be classed some of organic accumulations, such as peat-moss and bog-earths, which have no geological connection with the subsoils or rocks on which they repose. Such accumulations are often of great thickness, and rest on old estuary and lake silts, on sands, and on clays of totally different origin, and indeed, as in the case of Blair-Drummond, the peaty stratum may be altogether removed in order to expose the finer and more fertile clay that lies below.

Fertile Admixture of Soils.

It must be obvious that soils varying so much in their origin, composition, and texture cannot be all alike culturable and fertile; and hence to correct the one by admixture with the other, to render this one more friable and that more compact, to improve this one by drainage and that by manuring, is the sum and substance of judicious and successful farming.

Taking a good *loam* (an admixture of clay, sand, and organic matter) as the type of productiveness, we find some soils too sandy and light, and others too clayey and heavy. Sandy soils, though active, soon become exhausted, and are apt to be parched in dry seasons; and clayey soils, though often rich and absorbent of ammonia from the atmosphere, are apt, in wet seasons, to become water-logged and unworkable. It is thus that some soils are too cohesive, others not cohesive enough; some deficient in one element, and others having that element in excess. It is the duty of the skilful agriculturist, therefore, to correct these deficiencies by admixture, and to bring his soils as near as he can to the normal condition of easy cultivation and fertility.

If we take an estate of some extent, for example, and after careful pitting and examination map out its soils and subsoils, and find that some of its fields consist of stiff retentive clay resting on the rubbly outcrops of the strata below, others of thinnish loam resting on a subsoil of sandy clay, some in the hollows and along the streams of soft peaty earth, and the remainder skirting the sea-shore of dry shelly sand, the question arises—How are we to effect a permanent improvement of these various soils by drainage and admixture? The cold retentive clays, on which insolation is spent in evaporating moisture before it can impart any warmth, may be dried by draining, and subsequently cut up and rendered friable by admixture with the shelly sand; and such clayey soils may also be improved by burning, which not only renders them freer, but converts their potash from an insoluble to a soluble state. The thinnish loam might be deepened by subsoiling, provided there was nothing deleterious in the clayey subsoil; the soft spongy peat-earths which throw out their seeds and roots after frosts might be improved, as every one knows, by an admixture of the clays; and the loose dry sands can be readily compacted and rendered fertile by a good addition of clay, as we have seen near the estuary of the Eden in Fife, where sands, almost useless as sheep-runs, have been converted into profitable grain-fields by admixture with the soft red brick-clays which abound in that locality. We have taken an imaginary instance; but, whatever the example, there are few estates which have not their fertile and unfertile portions, and all of which might be permanently improved by such admixture of soils, and these admixtures often lying within their own boundaries. We refer to lands at moderate elevation, and naturally fitted for the plough; for there are wide expanses in Britain which should never be broken up from their natural pasture, unless they could be put under glass—a provision which fluent expatiators on the conversion of waste lands forget to make allowance for in their Utopian speculations. For such admixtures as those to which we have referred, a geological knowledge of the district is indispensable; and be it observed that fertile admixture of soils is a *permanent improvement*—a creation, as it were, of new soils—and not like manuring, which is a mere temporary expedient, soon losing its effect and requiring to be repeated at every rotation.

Draining.

The same may be said of draining, and there is much in draining that depends on the geology—superficial and lithological—of the district in which it is to be effected. The main object of draining is to get rid of superfluous water, thereby rendering the soil drier and more absorbent of the sun's heat, more friable and opener in texture for the admission of air and rain, which prevent the generation of deleterious acids, more accessible to the tender permeating rootlets of the crop, and likewise more easy and certain of cultivation. Before excavating the drains, it is always worth inquiring whether the wet is retained in the surface soil by an impermeable underlying "pan," which, if broken up by the subsoil plough, would be sufficient to let off the superfluous moisture through the underlying beds; or whether the thin clayey soil would not require all the moisture if it were cut up and deepened by sandy admixture? Again, in some very level tracts where sufficient fall is difficult to be obtained, it is also worth trying the nature of the subjacent beds to see whether they might be porous enough to receive and carry off the discharge of the drains. Under some morasses there have been found beds of open quartzose sand, which when dug down to were sufficient to carry off all the drainage water; and in the Wealden and Chalk districts it is not unusual to find in the porous Kentish Rag and Chalk, which lie below, a sufficient outlet for the drainage of the superincumbent heavy clays and loams.* This property

* "Owing to the greater part of the farm (Hall Farm, near Sevenoaks, Kent) being naturally dry, very little draining has been required, but that little has been effected by the following rather ingenious method: Wells have been sunk to the depth of from twenty to thirty feet, at which distance from the surface the Kentish Rag or stone is usually found. These wells receive the water from the different drains which empty into them, and as the Kentish Rag is of great extent and thickness, and very porous, the wells are capable of receiving any quantity of water which may issue from the drains. Part of Knole Park has been drained upon the same principle, and could have been drained in no other way without a very great expense, as from the formation of the surface much difficulty would have been found in obtaining a fall."—Jour. of Roy. Agric. Soc., vol. viii.

of taking away surface water is possessed by all rocks having sufficient porosity, and especially by sands and gravels, chalks and limestones, absorbent sandstones and fissured trap-rocks. As draining, when thoroughly executed, should be viewed as a permanent improvement, every precaution should be taken to ascertain the nature of the soil and subsoil to be operated upon, to fix upon proper depths so as at once to deepen the soil, and not to carry off the dissolved manures, to see whether there be surface stones on the estate for the filling of the drains, or whether these might be rendered more efficient by covering the tile-pipes by stones which have otherwise to be got rid of.

The sole object of admixture and drainage is to render soils at once more easy of cultivation, and more certain and abundant in their productiveness. The qualifications of a productive soil are thus succinctly epitomised by Professor Ansted: "It should be composed of nearly equal parts of three earths—sand, clay, and lime; it should contain a certain quantity of decomposing vegetable and animal matter; it should imbibe moisture, and give it back to the air without much difficulty; it should have depth sufficient to permit the roots of plants to sink and extend without coming to rock, to water, or to some injurious earth; the subsoil should be moderately porous, but not too much so: and, in case of need, the subsoil should be able to improve the soil by admixture with it. The proper proportion of the various earths may vary from 50 to 70 per cent of silicious matter, 20 to 40 per cent of clay, and 10 to 20 per cent of calcareous matter. According as the climate is wet or dry, the soil should be friable or porous, or adhesive and retentive, and the best soil is that which, in long drought, is never very dry, and in the wettest seasons does not become choked and soured with water." To these remarks may be added those of M. Schübler (Jour. Roy. Agric. Soc.): "The more an earth weighs, the greater also is its power of retaining heat; the darker its colour, and the smaller its power of containing water, the more quickly and strongly will it be heated by the sun's rays; the greater its power of containing water, the more has it in general the power also of absorbing moisture when in a dry, and oxygen when in a damp state, from the atmosphere—and the slower it usually is to become dry, especially when endued with a high degree of consistency; lastly, the greater the power of containing water, and the greater the consistency of a soil, the colder and wetter, of course, will that soil be, as well as the stiffer to work either in a wet or dry state."

II.—MINERAL MANURES.

Under this head we advert to those manurial substances which are obtained from the crust of the earth, and which are spoken of as *mineral*, in contradistinction to farmyard manure, nightsoil, shambles-offal, and the like, which are of *organic* origin, and result from the decay, secretions, and exuviæ of plants and animals. These mineral manures play an important part in modern agriculture, both in top-dressing for pastures, and as feeders and stimulants to grain and green crops. Though generally spoken of as "mineral," most of them (peat, marl, chalk, coprolites, osite, guano, &c.) owe their origin to organic agency, but are now separated from the "organic" because they are more or less mineralised, and form component portions of the rocky crust.

However much the soils of a farm may be benefited by admixture and drainage, they cannot continue to be cropped without the application of manures. Every crop, as may be seen by an analysis of its ashes, takes so much mineral matter from the soil on which it grew. In course of time this mineral matter will become exhausted, and the plant, deprived of its appropriate nourishment, will cease to flourish. To maintain the standard of fertility is the great object of manuring; and whatever will restore to the soil in a state of solubility what the plant has withdrawn — for plants can take no food in by their roots and spongeoles, save in solution—becomes a manure. The manures obtained from the mineral kingdom are very numerous, but the most important and abundant are those of a carbonaceous, calcareous, and saline nature, yielding to the growing plant carbon, silica, lime, soda, potash, and other essential ingredients.

Different crops require, of course, different manures, and what may start turnips into luxuriant growth may have comparatively little effect upon a field of clover. The mode and amount of application belong to the art of husbandry; geology deals only with the nature, occurrence, and abundance of the manurial substance. Numerous experiments, however, have been made with the mineral manures, and the special results recorded in the Journal of the Royal Agricultural Society of England, and in the Transactions of the Highland and Agricultural Society of Scotland, to both of which the farming reader may refer with advantage.

Carbonaceous Manures.

First among these mineral manures we may notice *peat*, which occurs largely as a surface accumulation in most situations in all temperate and coldly-temperate countries. In our own country, especially in Scotland, Ireland, and the northern counties of England, it can be obtained in inexhaustible supplies. It is strictly of vegetable origin, contains little earthy matter, is found from the "turf" now growing to the old compact "peat," 20 or 30 feet in depth, and often covering areas thousands of acres in extent. When dug up and exposed to the weather, it crumbles into a dark pulverulent mass, and in this state, either alone or in admixture with quicklime, has been applied with beneficial results to stiff loams and clays. It has been also fermented in admixture with farmyard manure, thereby not only increasing the mass, but absorbing and fixing the ammonia which escapes during fermentation. And in many cases it has been charred by combustion in smothered heaps, and the dry ashes applied with excellent effect to soils deficient in vegetable or carbonaceous matter. According to Professor Johnston, "charred peat forms, likewise, an excellent absorbent for the liquids of the farmyard and the stable, and for drying up dissolved bones."

Coal-dust or "slack" is sometimes spread on cold stiff clays, but with little effect, we presume, beyond that of cutting them up and rendering them more friable. *Coal-ashes* and the light porous *coke* from shale retorts, tell with better effect; and *soot*, which is merely charcoal in a very fine state of subdivision, is often employed with wonderful results as a top-dressing to pastures, as well as to grain crops. Its fertilising properties are mainly due to the ammonia, sulphate of lime, nitric acid, and certain other ingredients which it contains.

Calcareous Manures.

Marl, which occurs in lakes, or is found at or near the surface, in bogs and morasses, the sites of obliterated lakes, is a soft earthy carbonate of lime, resulting from the shells of freshwater molluscs (paludina, limnea, &c.) and other minute animal organisms. It generally occurs in layers and patches, from one to several feet in thickness: and when the shelly matter predominates, it is spoken of as *shell-marl;* where the silty matter prevails, as *clay-marl*. It is now seldom used; but about the beginning of the present century was largely dug or dredged up, and applied in a raw state as a top-dressing to pastures, or as a corrective to clayey and peaty soils.

Another calcareous substance often applied with beneficial results to stiff clayey soils is the *shell-sand* (shelly, coralline, and other limey debris) which occurs largely along certain portions of our sea-coast. Consisting, for the most part, of carbonate of lime, with a certain amount of the phosphate, it not only acts as a breaker-up of the stiff-textured clays, but from its gradual solution by the carbonated rain-water supplies to the soil an important element of fertility. Considering the vast amount of this material which lies scattered along our shores, and which is easily manipulated, it looks like ignorant neglect on the part of our farmers that so little of it should be employed. In the Report on the Geology of Devon, Cornwall, and Somerset (1839), it is stated that, in 1811, Mr Worgan estimated the cost of the land carriage of this sand in Cornwall at more than £30,000 per annum. Large quantities are obtained at the Durbar Sands, in Padstow Harbour, the annual amount estimated at 100,000 tons. It has been calculated that 5,600,000 cubic feet of sand, chiefly composed of comminuted sea-shells, are annually taken from the coasts of Cornwall and Devon, and spread over the land in the interior as a mineral manure. It is also applied in some of the Western Islands, where the shores are thickly fringed with it, with beneficial effect to hill pastures and peaty soils; but notwithstanding these facts and figures, the substance, considering its abundance and obvious utility, is strangely neglected. It abounds on the shores of France, and, according to M. Burat, is highly valued as a cheap and efficient manure, as well as an improver of stiff clayey soils.

Like marl and shell-sand, the upper *Chalk* of the south of England (a soft earthy carbonate of lime) is sometimes broken down and applied to clayey soils and pastures. Applied in this way, at the rate of 30 and 40 loads an acre, it acts chemically as a manure, in rendering the soil richer, and mechanically, in rendering it lighter and more friable. Though now a lime-rock of great extent and several hundred feet in thickness, chalk is mainly of organic origin—about 80 per cent of its mass being composed of the minute shields of foraminifera, similar to those now forming the calcareous ooze of the mid-Atlantic.

Gypsum, or sulphate of lime, is applied in a similar way to grass-lands in this country, at the rate of 2 or 3 cwt. per acre; but in Germany and the United States of America it is largely used in general husbandry, and with marked effect on crops of maize, pea, bean, and clover. Gypsum occurs crystallised and massive, in various formations; but the most extensive beds are found in connection with rock-salt in the New Red Sandstone, and alternating with the clays and marls of Tertiary basins. In Britain abundant supplies can be obtained in Chester, Nottinghamshire, Derbyshire, Westmoreland, and other localities; and not a little of that which is raised finds its way to the artificial manure factories.

But while the carbonates of lime (marl, shells, and chalk) are applied in the raw, mild, or uncaustic condition, limestone in general is much more extensively used in the caustic or *quicklime* state. In this condition it is extensively used, not only as a top-dressing, but incorporated in the soil as a feeder, dissolver, and stimulant—its effects being partly mechanical and partly chemical. "They are mechanical," according to Professor Johnston—"as by slaking, the burned lime can be reduced to a much finer and more bulky powder than the limestone could be by any mechanical means; and they are chemical, inasmuch as by burning the lime is brought into a more active and caustic state, and is, at the same time, mixed with variable proportions of sulphate and silicate of lime (evolved in the kiln) which may render it more useful to the growing crops." The limestones are largely developed in the British Islands, and occur in all the geological systems—Metamorphic, Silurian, Devonian, Carboniferous, Permian (Magnesian Limestone), Oolitic, and Cretaceous. There are few districts that cannot command a supply within their own area, or, at all events, at comparatively little expense from some contiguous area. (See Chapters V. and VI.)

Besides the carbonates and sulphates of lime, the phosphates are also extensively used and highly valued as mineral manures. A crystallised variety under the name of *apatite* (56 lime, 44 phosphoric acid) is obtained from veins in the older rocks; is of various shades of colour, white, yellowish white, and greenish white; stands 5 in the scale of hardness, and has a specific gravity of 3 or 3.25. It occurs in various countries, Norway, Spain, Bohemia, Switzerland, France, &c., and is often accompanied by a massive variety, which is known as *phosphorite*. This phosphorite is the more abundant product, and consists of phosphate of lime 81, fluate of lime 14, with iron oxide and silica. These hard phosphates, of which there are several varieties, require expensive mining and reduction, and hence they have given way, in a great degree, to the phosphatic nodules and concretions of the Greensands and Tertiary formations.

Phosphatic nodules, *coprolites*, or "*cops*," as they are familiarly termed, are occasionally concretions round bones and true coprolites or fossil excrement; but, generally speaking, they are mere nodular or concretionary masses of a soft and earthy texture. They are found in the Greensand and Crag formations of England, and also in the Greensands of France, in layers and in sporadic deposits, from a few inches to several feet in thickness, and when moderately pure contain about 50 per cent of phosphate of lime. Well-cleaned examples from Cambridgeshire have been found to yield—phosphates 61, carbonates 28, insoluble silicious matter 7, and water, with traces of organic matters, 4. Their dissemination in the Crag and Greensand is rather uncertain; but £80, £100, and even it is said as much as £400 per acre has been paid for the right to dig and remove them from the estate. According to Hunt's 'Mineral Statistics,' the amount raised in 1872 was estimated at 35,000 tons, value £50,000. Similar deposits of a much more extensive nature occur in the Tertiary formations of the Carolinas, New Jersey, and Georgia, and are largely used in the United States of America, as well as imported into Britain for the manufacture of artificial manures. Picked, crushed, and treated with sulphuric acid (and variously mixed with other substances), they form the "superphosphates" of commerce —every manufacturer adopting his own treatment and proportions of admixture. Whatever the admixture, the great object of the sulphuric acid is to convert a considerable part of the insoluble earthy phosphate of lime into sulphate and soluble superphosphate. Plants take in no food save in a state of solution, and the main value of a manure (other things being equal) is its capability of being dissolved by the moisture of the soil according to the requirements of the crop to which it is applied.

What is termed *osite*, *Sombrero guano*, or *Sombrerite*, is another phosphate of lime used also in the manufacture of artificial manures. It is obtained from Sombrero, one of the West India Islands—an islet about two and a half miles long, from a half to three-fourths of a mile wide, and not more than 20 or 30 feet above the level of the sea. The islet is entirely composed of this substance, which consists of a breccia of bones of turtles and other marine vertebrata, coral debris, &c., collected when the area was a shallow shoal, and before its elevation above the water. Since its elevation the rains have carried down through the mass the dissolved droppings of birds (guano), and cemented the whole into a compact mass of valuable phosphate.

The true *guano* (*huanu* of the Peruvians), though of animal origin, has undergone so much alteration by internal chemical change, and occurs in such masses, that it may, without much error, be treated as a mineral manure. It consists mainly of the droppings of countless sea-fowl, intermingled with their skeletons and eggs, the decomposed bodies and bones of fishes, seals, and other marine creatures frequenting the islands on which it is deposited. Though obtained principally from the rocks and islets that stud the Bolivian and Peruvian coasts, it accumulates in all rainless regions—the drier the latitude the thicker and richer the deposit. On some of these islets it is found in great thickness (40, 60, 80, and in some places, according, to Dr Scherzer, 120 feet, and, considering its necessarily slow accumulation, must be of vast antiquity. The digging of the deposits and the frequency of modern shipping has greatly disturbed the birds, and much less is now deposited than in former times. About five-and-twenty years ago considerable quantities were obtained from Ichaboe, and other places on the west coast of Africa; but as absolute dryness is necessary to the preservation of the ammoniacal salts, which constitute the chief value of guano, these supplies brought little more than half the price of the Peruvian, and we believe are now entirely exhausted. The amount imported into Britain from Peru, since 1844, is estimated at five and a half million tons, valued at sixty-four millions sterling; but this rate of importation cannot long continue—for, according to the estimate of the British Consul at Callao in 1873, the whole of the exportable guano which Peru then possessed did not much exceed three million tons.

The following analyses, from Johnston's 'Agricultural Chemistry,' show the relative composition of American and African guanos:—

	Peruvian.	Bolivian.	Ichaboe.	Saldanha.
Water,	13.09	6.91	16.71	18.35
Organic matter containing ammonia,	53.17	55.52	46.61	22.14
Common salt and sulphate of soda,	4.63	6.31	12.92	5.78
Carbonate of lime,	4.18	3.87	0.27	1.49
Phosphate of lime and magnesia,	23.54	25.68	22.40	50.22
Sand,	1.39	1.71	0.52	2.02

Saline Manures.

Besides these calcareous minerals and guanos, a considerable number of saline substances have recently been employed with wonderful effect, both as top-dressings and as incorporated manures. The chief of these are sulphate of ammonia, carbonates of potash and soda, nitrates of potash and soda, sulphate of potash, common salt, sulphate of soda, silicates of soda and potash, and sulphate of magnesia. Most of these are manufactured artificially, as sulphate of ammonia, for example, from the ammoniacal liquor of gas and paraffin oil works; but many also occur in a crude or impure state in deposits often of considerable magnitude. In and around salt-lakes like those of Central Asia, along dried-up lakes and deserts like those of Asia and Africa, and over extensive reaches like the salinas of South America, these salts occur in abundance, and constitute important articles of commerce.

The *desiccated lakes* of Central Asia have been described by various travellers as flat expanses, covered during the dry season with white efflorescences of various salts, from a few inches to 2 or 3 feet in thickness, and over which their horses had to pass, treading up to the knees among crackling crystals of great beauty and purity. Mr Shaw, in his recent travels in Tartary, rode through desiccated lake-sites, covered with a thin crust of sandy soil, but consisting beneath of beds of common salt, and salts of soda and potash, varying from 1 to 3 feet in depth, and often of almost transparent purity.

The *salinas* of South America, which at present yield our main supplies, are described as superficial deposits, occupying extensive plains on the Pacific, or rainless side of the Andes, and usually covered with a white saline efflorescence or crystalline incrustation. They occur at all elevations, from a few feet to several thousand feet above the sea-level, and are evidently the remains of old sea-reaches and lagoons that have been desiccated by the upheaval of the land. They extend for about 600 miles north and south, but find their greatest development between latitudes 19° and 25° south, and at distances varying from 10 to 40 miles inland. The usual salts occurring in these salinas, as in those near Iquiqué and the desert of Atacama, are common salt or muriate of soda, sulphate of magnesia, sulphate of soda, sulphate of soda and lime, soda-alum, magnesia-alum, gypsum, anhydrite, along with chloride of calcium, iodide and bromide of sodium, carbonate and nitrate of soda, and in some places borate of lime and borax. The saline plain of Taramugal, for example, which is 3000 feet above the sea-level, consists, in some places of many feet in thickness, of sand indurated with salt, in others of soft sand with crystals of nitrate, and occasionally of true *caleches* of concreted soda and stony debris. These saline sands and gravels are dug and lixiviated on the spot, the liquor evaporated, and the crude salts exported at the rate of many thousand tons per annum.

We have said nothing of *artificial manures*, whose name is legion, but restricted our notice chiefly to manurial substances which occur native in the crust of the earth. No doubt these substances enter largely into the artificial manures of commerce; but other substances of an organic nature are also employed, taking the manufacture more under the head of Chemical Technology than of Applied Geology. Indeed it is often difficult to say what enters into the composition of many of these artificial manures—ashes, peat-mould, sawdust, gypsum, chalk, salt, sand, loam, and other substances still more worthless and objectionable than the worst of these.

In the preceding paragraphs we have endeavoured to explain, as fully as our limits will permit, the relations that subsist between Geology and Agriculture. Those refer to the *soils* upon which the farmer has to operate, whether they be soils of disintegration, resulting from and directly affected by the rocks on which they rest—or soils of transport, which have been weathered and wasted from distant rocks and laid down by various agencies in the situations they now occupy. They refer also to the *subsoils* on which the arable soils rest, and the influence these may exert on their drainage, texture, and fertility. Much of the agricultural surface of Britain consists of what the farmer terms "made soils"—soils reclaimed from stony bouldery wastes, heathy, peaty moorlands, and plashy swamps and morasses, by blasting and removal of boulders, by turfing and burning, and by draining. But whether reclaimed or natural, soils are not all alike fertile, some being too sandy, too clayey, too peaty, or too calcareous; and the question arises, How far their defects may be remedied by *admixture with other soils*, so as at once to impart to them the necessary composition and texture? Besides fertile admixture, there also arises the question of *drainage*, by which the superfluous moisture may be got rid of most effectually, and at the cheapest rate, so as to render the soil drier and mellower, and more easy of cultivation, more friable, and thereby more permeable by air and moisture, and deeper and softer, that the crops may readily extend their rootlets in search of the nourishment they require. As this nourishment or manure is largely obtained from the mineral kingdom, it becomes necessary, in the next place, to advert to the more important of the *mineral manures*—treating of their geological nature, their abundance, and the facilities with which they can be obtained. Whether carbonaceous, calcareous, or saline, these mineral manures are yearly assuming a greater importance; hence the value of an intelligent acquaintance with them to the practical agriculturist. Considering, therefore, the nature of soils and subsoils, their composition, texture, and relations to the subjacent rocks; and considering also the importance of drainage, and the application of mineral manures—all of which involve some acquaintance with the materials and structure of the earth—the relations of Geology to Agriculture must be sufficiently obvious and deserving of study alike by the landlord and farmer.

Works which may be consulted.

Johnston's 'Elements of Agricultural Chemistry and Geology;' Stephens's 'Book of the Farm;' Burn's 'Soils, Manures, and Crops'—Weale's Series; Liebig's 'Agricultural Chemistry;' 'Burat's Géologie Appliquée;' 'Journal of the Royal Agricultural Society;' 'Transactions of the Highland and Agricultural Society.'

IV.

GEOLOGY AND LAND VALUATION.

Every landed estate has a twofold value—one superficial or agricultural, and depending on the nature of the soil and climate above, another underlying or mineral, and depending on the nature and abundance of the rocks and minerals below. The surface value will vary according as the soil and situation are fitted for general husbandry, for pasture, for forestry, or for sporting purposes. Land valueless for grain-growing may be valuable for pasture, and wide expanses unsuited for either, may bring large prices as game moors and deer forests. Fancy prices may also be given for certain estates, the adjuncts of scenery—wood and water, dell and dingle, cliff and crag—conferring on them an adventitious value; but, generally speaking, the richness of the soil, the geniality of the climate, good roads, and access to markets, are the conditions which determine the price to be paid for the mere land-surface. We here refer to country estates in general, and not to those in the proximity of towns, or contiguous to navigable rivers and harbours, which often bring fabulous prices for building-sites, ship-yards, factories, and other similar purposes.

But beyond this superficial value there is a mineral one, and this will be regulated by the nature of the rocks and ores below, their abundance, the facility with which they can be obtained, and the prospect of continuous or increasing demand. In selling or in purchasing estates, this twofold value should always be held in view; and no factor or estate agent can do justice to his client who is incapable of estimating, or of procuring reliable estimates, at once of the capabilities above, and the resources that lie below. We have known estates sold for the mere agricultural value of their cold, clayey, and retentive soils, without taking into account the bands of ironstone and fire-clay which lay below, and which could have been readily estimated by a competent mineral surveyor, or by a little judicious outlay in trial by boring. We have known others sold much beyond their value, from the impression that they contained ores of copper and lead, because at certain spots there were traces of old trials for these metals. In either case thousands might have been gained and saved by proper precautions to arrive at some definite estimate of the nature and abundance of the minerals that lay below.

I.—SURFACE OR AGRICULTURAL VALUE.

And *first*, of the surface value, and the mode of estimating it as far as geology is concerned. Having ascertained the nature of the climate, water-supply, condition of roads, access to markets, public burdens, and other accessories, a minute inspection of the soils should be made, their capability of improvement by draining, and their correction by admixture. As stated in the preceding chapter, a map of the superficial accumulations of the district may be consulted with advantage, but this cannot supersede a detailed survey of the soils and subsoils of the estate. One portion may consist of sands, another of peaty earth resting on clay, a third of stiff heavy loam, and a fourth of dry shingly soil resting on the subjacent rock. Are the sands calcareous or simply silicious? Can the heavy loam be rendered drier and lighter by draining and by admixture with the sands? Can the peaty earth be improved in quality and texture by admixture with the clay, or can the peaty surface be conveniently removed, as in the case of Blair-Drummond moss, and the clay be exposed as the agricultural surface? Again, as some soils are better suited for certain crops,—some for grain, others for green crops—some for pasture, and others for forest growth,—a knowledge of these facts may enable one purchaser to offer a price with safety, which would simply stagger another who was incapable of such discernment. These and similar considerations must be weighed and balanced before the value of any estate can be fairly determined; and for this purpose frequent pittings in the soils and subsoils should be made, and the nature of the material methodically ascertained. A few spadefuls to reach the subsoil is all that is required in such pittings; and considering the certainty they confer on the estimates of the valuator, it is astonishing that this mode of determination is not more extensively and systematically adopted.

As the estate stands, it has a certain value which depends upon the rental received; and to one purchaser ignorant of its capabilities, this may determine the price — while to another acquainted with all its facilities for improvement, a much larger sum may be given, and yet in the long-run it may be a cheap and profitable purchase. The farmer in offering for a new farm is never altogether guided by its existing condition, but looks forward to how much it may be improved during the currency of his lease, by judicious outlay in draining, subsoiling, removal of surface stones, and the like; knowing well that by these means he will not only increase the quantity and quality of its produce, but greatly diminish the cost of cultivation. And so it should be with the purchaser of an estate; he must not be altogether guided by existing appearances, but should consider well how far the property contains within itself, or lies adjacent to, the ready means of permanent improvement. The grazier who gives ten pounds for a growing beast, and pays five for its pasture, may at the end of the season sell it for twenty; and so the purchaser of landed property who gives twenty thousand, and judiciously expends five on its improvement, may in a few years raise its value to thirty thousand.

The Landscape.—Surface Amenity.

Closely connected with the value of the land-surface, is the art of laying it out into fields, parks, and plantations, so as to enhance at once its value and amenity. Few arts require more skill, and observation of nature's aspects, than that of landscape-gardening, not only in improving features which an estate may already possess, but in bringing out new features by judicious planting and enclosing. A domain naturally regular and tame in surface, may be rendered more attractive by the disposition of its woods and the winding lines of its enclosures. Another, naturally more diversified by hill and vale, crag and dell, may have its charms doubly increased by the skilful introduction of wood and water. It is astonishing how much can be done by a little judicious planting and enclosure. A few clumps to break the monotony of a moor, a trail of ivy over a bald brow of rock, a few climbers to mask the face of an old stone quarry, or a sprinkling of shrubs to enliven the slopes of an ordinary road-cutting, will often produce an effect worth ten times the outlay. And as with the minor, so with the major features of a domain,—the tamest may be improved by intelligent treatment. No doubt such dispositions depend very much upon the artistic tastes of the disposer; but there are certain geological connections between trees and soils, woods and crags, rocks and waterfalls, a knowledge of which cannot fail to be of use to the landscape-gardener. Nature does not lay down clumps and belts of wood at random, nor erect crags and cliffs where there can have been no producing cause; and it is the study of these causes and associations which lies at the foundation of all successful imitation by art. Every rock—granite, slate, limestone, trap, sandstone, chalk—weathers after its own fashion, and presents its own distinctive aspects (Chap. II.); every soil has its own peculiar vegetation; and the whole success of landscape disposition depends upon an acquaintance with these peculiarities. But beyond the mere beautifying of the surface, in a cold and fickle climate like Britain, shelter is indispensable, and wherever woods can be disposed so as to secure both warmth and amenity, the value of an estate is substantially increased.

II.—MINERAL OR GEOLOGICAL VALUE.

In addition to its surface or agricultural value, every estate has a mineral worth depending on the nature of the rocky substances that lie below. In some instances this value may arise from the superficial clays, sands, peats, marls, coprolitic deposits, and the like; in others, from the sandstones, limestones, coals, ironstones, granites, and greenstones; and in others, again, from the occurrence of metalliferous veins. From whatever source it may arise, it is evident that no approximate estimate can be formed without a competent mineral survey. It is true the maps of the Geological Survey, when completed, will be of vast service in Britain; but even with these a more minute examination and report should be obtained. The sheets of the Government Survey contain the broad and general features of the geology of the country; but the details of any single estate, the thickening or thinning of its strata, their dips and dislocations, their quantity and quality, and the like, can only be approximated by a special investigation. Such a survey—even when corroborated by trial-borings—can generally be obtained at no great cost compared with the interests at issue; and yet for want of this precaution, every year witnesses blunders in purchase as well as in sale. And if such a precaution be needed in an old and well-known country, much more is it needed in colonies and countries that have not been systematically explored.

The mineral wealth of an estate, we have said, may arise from various sources. Its superficial sands may be fitted for mortar, for moulding purposes, or for glass-making: its surface clays may be adapted for brick and tile making, or even for finer pottery uses; while its peat-earths and bog-marls may all be of value, if not for sale, at least in the improvement of its other field-soils. These superficial accumulations are too much neglected. A good field of brick-clay in the neighbourhood of a rising town may be worth thousands; a small estate full of sand-hummocks in the suburbs of Edinburgh brought nearly as much to its proprietor for builders' sand as he paid for it; while the excavations were filled up with shot-rubbish, and the original surface-soil restored. Again, there may be dykes and bosses of greenstone and basalt valuable as road-metal; granites and sandstones suitable for building; limestones for mortar or for furnace flux; and limestones unfitted for these purposes on account of their argillaceous nature, may be eminently useful for their hydraulicity. If an estate lies on the coal-formation, there is generally an effort made to estimate its mineral value; and yet in this respect how much caution is necessary may be seen from the high prices that the cannels have recently brought, relatively to the price of other coals, from the yearly increasing demand for fire-clays, and also from the rapid utilisation of the bituminous shales, which in 1855 were of no account whatever, and are now, for the distillation of paraffine oil and other products, worth hundreds of thousands. Lastly, an estate may derive its value from the occurrence of metalliferous veins and stream-drifts, and though these may have been worked and known, yet new values are constantly being attached to certain ores from their wider application in the arts, and their consequently increasing demand.

It must be obvious, from what has been stated, that a careful estimate of the mineral value of an estate is a thing of prime importance alike to the seller and purchaser. Of course, one cannot always anticipate the utilisation of products which may now be lying waste and worthless, nor the increasing demand and price of substances which may now be of little value; but seeing within the last quarter of a century the increase of fire-clay manufactures, the demand for mineral manures, for oil-shales, for gas or cannel coals, for iron ores, and, above all, the recent advances in the prices of ordinary coal, it were folly to part with estates without due consideration of their mineral resources. In a country like Britain, where the geological formations are so varied, and where the progress of invention is so rapid, one can never tell when disregarded products are to be utilised, or known ones increased in value; hence the necessity, in dealing with landed property, of stricter attention to their mineral resources—whether these belong to the older rock-systems below, or to the superficial accumulations above. Compare the price of an estate in the Cleveland district of Yorkshire in 1853 with its value in 1874; estimate the worth of a poor moorland tract in Linlithgowshire in 1856 with its value (for oil-shales) at the present moment; or the importance of a farm on the Greensand (with phosphate nodules) at these respective dates,—and no further argument will be necessary to establish the advantage of having in every instance of sale or purchase a thorough investigation of the geological features and mineral resources of estates.

To obviate the risk of parting with unknown wealth for no adequate equivalent, the minerals of an estate are sometimes reserved, and the mere surface or *solum* disposed of. This practice, while it guards the seller, not unfrequently becomes a source of extreme annoyance to the purchaser or his successors. It is true they have their surface damages for any roads or excavations that may be made in quest of the minerals; but there is none for loss of amenity by smoking iron-heaps, brick-clamps, waste mounds, and other unsightly adjuncts, while very often a rough and troublesome population is brought to the vicinity, and poor-rates increased by their improvidence as well as by the dangers of their occupation. It is true, no one can tell when certain minerals are to rise in value, or when worthless substances are to be utilised; and it seems hard that through such utilisation estates sold twenty years ago may now be worth three times the money then paid; but in face of such contingencies, it seems better, on the whole, that sales and purchases of estates should be entire and absolute—the sellers taking every precaution to have the highest price for their conjoint agricultural and mineral capabilities. Some mineral substances may fall into desuetude, and others may acquire new and unexpected values; but, generally speaking, in a mechanical and manufacturing country like Britain, the tendency will be towards a greater consumption, and consequently towards increased demand and higher prices. Taking this view, the seller of a mineral estate is justified in seeking a higher price, and the purchaser, on the other hand, equally safe in offering it.

The same remarks hold good with respect to mineral leases. A farm may be let for nineteen years, as is usual in Scotland, and yet at the end of the lease, if proper precautions have been taken as to cropping and rotation, the soil may be richer and more valuable; but at the end of a mineral lease the materials removed are gone, and for ever. No landed proprietor, therefore, who studies his own interest or the interest of his successors, should, in the increasing value of mineral produce in Britain, grant long leases; and in such leases as he grants, should always stipulate for a lordship proportionate to the market price of the substances disposed of. Millionaire iron and coal masters would have been fewer in number had landowners been sufficiently provident in the leasing of their mines and minerals.

In the preceding remarks we have restricted ourselves almost exclusively to the sale and purchase of estates in the British Islands, but the same precautions are equally necessary in the selection and purchase of land in our colonial possessions. It is not always fertile soil and surface amenity which should determine the settler's choice. The finest soil and situation, unless for town-lots, will never bring more than an average agricultural return; while some poor and forbidding tract may contain within it inexhaustible stores of minerals and metals, which will continue to rise in demand and value the more the population increases and settles down to commercial enterprise and industrial activity. A little geological knowledge, and a few months spent in prospecting along the sea-cliffs, up the river-banks, and over the rocky surfaces wherever these may be exposed, will always repay the colonial settler, even should he have to wait several years for the development of the mineral resources of the tract he has chosen. Nor does it require much geological skill to detect the presence of the more important minerals and metals. Coals and coaly shales soon reveal themselves in any section; ironstones show themselves by their oxidised or rusty surfaces, and are usually accompanied by springs or trickles of water leaving an ochrey deposit; limestones weather into whitish or whitish-brown surfaces, and are frequently accompanied by petrifying springs; copper ores show various tarnishes of green, reddish, or pavonine tints, and are accompanied by trickles having a strong styptic and coppery taste; lead ore or galena, by its leaden-grey colour and cubical cleavage; antimony ore, by its lighter-grey colour and long radiating crystals; while the metallic ores in general may be readily detected from stony minerals by their greater weight and metallic lustre in the fresh-made fracture.

It should be obvious, from what has been said in the preceding paragraphs, that every landed estate has a twofold value—one depending on its superficial qualities and their susceptibility of improvement, proximity to roads, public burdens, and access to markets; and another arising from its mineral resources, their nature and abundance, facilities of winning them, and amount and continuance of demand, existing and prospective. In selling or in purchasing landed property, these values should be respectively taken into account, and no reasonable trouble or expense withheld in approximating their amount by careful and competent surveys. In such surveys some knowledge of geology is indispensable, whether relating to the soils and subsoils above, or to the minerals and metals below. Nor, when these respective values have been ascertained, should it ever be forgotten that they differ in this important essential—namely, that while the superficial value is ever increasing by judicious treatment—draining, trenching, planting, &c.—the mineral value, by working, is ever diminishing, and in the end may be wholly extinguished. Than this, no fact can be more obvious, and yet it is too often disregarded in arranging for the interests of heirs and successors.

Works which may be consulted.

Brown's 'Book of the Landed Estate;' Lintern's 'Mineral Surveying and Valuing;' Hudson's 'Land Valuer's Assistant;' Donaldson 'On Landed Property.'

V.

GEOLOGY AND ARCHITECTURE.

PART I.—BUILDING AND DECORATIVE STONES.

THE relations of Geology to Architecture are at once intimate and important. All our building-stones, stones for internal decoration and sculpture, mortars and cements, concrete and artificial blocks, are obtained directly or indirectly from the crust of the earth. It is not merely shelter and defence that man seeks from his structures; he has æsthetic tastes, and hence beauty of colour and texture, and capability of being fashioned and combined for the production of general effect, become important properties in the architectural materials with which he has to deal. The stone suitable for the massive fortress may be unfitted for the lighter mansion, and the material adapted for the country villa might be unsightly in the city street; while tints in keeping with the plain frontage of a warehouse might ill accord with the ornamental fretwork of a cathedral church. Besides, the stone that will endure under a dry and equable climate may waste and weather away under a humid one; while that which will retain its colour and freshness in the air of the country may get dingy and corroded under the carbonated atmosphere of a manufacturing town. Nor is it alone colour and texture and general durability that have to be studied; the modes of bedding and tooling and dressing suited to different stones are also important elements for consideration, as what might tone down the colour in one, and mask the rough texture of another, might altogether be a disfigurement to a third. Again, toughness or resistance to strain and pressure is paramount in stones for lofty and heavy structures, the hardest texture not being always that which will endure the highest crushing power. Another consideration is the structure or natural masonry of the rock in the earth's crust —whether it be thick-bedded, flaggy or slaty, tabular, jointed, or columnar—as on this structure depends its capability of being raised in blocks of sufficient size for any special requirement.

These and many kindred considerations have to be taken into account by the architect and builder; but so far as our present purpose is concerned, the lithology of the materials which they have most frequently to deal with may be arranged under the following heads: 1. Building-Stones; 2. Stones for Decoration and Sculpture; 3. Limes, Mortars, and Cements; and 4. Concretes and Artificial Stones.

I.—BUILDING-STONES.

In building-stones for edifices (other than those of docks, piers, and breakwaters, to be noticed under Civil Engineering, Chap. VII.), the main requisites are beauty of colour and texture, durability, and facility of being dressed and tooled. These qualities vary very much in different rocks, some freestones being of beautiful colour and texture, and very readily quarried and tooled, but far from durable; some granites and porphyries extremely durable and of pleasing tints and lustre, but expensive in dressing; and others, like some grey grits and greenstones, both durable and easily tooled, but very sombre and unsightly in colour. In noticing these and other varieties, we shall dwell mainly on the building-stones of our own islands, only touching, by way of illustration, on those of other countries, whether modern or ancient. And first of the Granites, Porphyries, Greenstones, Felstones, Basalts, and other kindred rocks of igneous origin and of pyro-crystalline or pyro-plastic texture.

The Granites and Porphyries.

The granites, which were early used, especially in Egypt, for monoliths and gigantic sculptures, form a numerous family, differing widely in colour, texture, and durability. In our own country they have come largely into use within the present century, both for structural and decorative purposes. This is chiefly owing to their durability and susceptibility of fine polish, but partly also to the invention of mechanical appliances by which their dressing can be facilitated. They differ considerably in their mineral composition, colour, texture, and facility of being raised in large blocks, but are all old igneous rocks, amorphous or tabular in structure, crystalline in texture, and occur chiefly associated with our most ancient hill-ranges, though in some regions they burst through strata as recent as the Jurassic and Cretaceous. Certain stratiform granites are regarded by some geologists as of metamorphic origin, but undoubtedly the great majority of the family are pyrogenous and eruptive; and seeing that both igneous and aqueous rocks are alike subject to metamorphism, it matters little to the economic geologist whether the granites are old transformed sediments or altered eruptions.

Their essential ingredients are quartz, felspar, mica, and hornblende, in varying proportions; and their adventitious or accessory minerals are garnet, tourmaline, beryl, rock-crystal, and iron pyrites. By *essential* ingredients are meant those which constitute the mass of the rock; by the *adventitious* are those which occur rarely, and generally in fissures and druses. There may be two or more felspars, and two or more micas, in the same granite, but generally the granites are described as *fine-grained*, *medium-grained*, or *large-grained*, or as *porphyritic*, when, like that of Shap in Westmoreland, they contain large and independent crystals of felspar scattered through the mass. The ultimate analysis of a granite may consist, for example, of 69 silica, 15 alumina, 6 oxide of iron, a trace of oxide of manganese, 2 lime, 1 magnesia, 4 potash, 3 soda, and 1 water; but this gives no idea either of its colour, texture, resistance to pressure, or durability. The silica is partly free, partly in the felspar and mica—the lime, soda, and potash partly in the felspar and partly in the mica—and the magnesia in the mica. The colour, texture, susceptibility of polish, resistance to pressure, and durability, depend upon the size and arrangement of the several ingredients—the granites most liable to decay being those containing an excess of lime, iron, or soda in the felspar and mica. Those containing large crystals of mica are unfitted, of course, for architectural purposes; and the same may be said of varieties in which soda-felspar, and very deep-red (iron) felspar, predominate.

The granites are quarried, for the most part, from hillsides and other rising grounds, have little or no superficial covering, are blasted for smaller purposes, but cut with wedge and mallet for larger blocks and monoliths. In most quarries the rock has a rudely-jointed or tabular structure, but in some instances it is massive, and capable of yielding blocks of large dimensions. Like other rocks, it can be squared and dressed with greater facility when newly raised and in possession of its "quarry-water;" and this, according to the texture of the rock, may vary from 5 to 1 per cent of its weight. Some granites of open texture are capable of absorbing as much, it is said, as from 2 to 3 gallons per cubic yard, and those absorbing the most are the least to be relied upon for their durability. The specific gravity of ordinary granites ranges from 2.6 to 2.8;

a cubic foot weighs from 164 to 169 lb.; and from experiments on inch cubes, the crushing force varied, according to the texture and composition, from 3000 up to 13,000 lb. The following are some of the best known and most esteemed varieties:—

Common Granite consists of quartz, felspar, and mica; and, as the felspar may be whitish or reddish, and the mica black, brown, or silvery, is of various colours, of various textures, and is that which is most abundantly employed in ordinary architecture. The granites of Aberdeenshire belong to this variety, whether grey, like that of Cove, Rubislaw, Dancing Cairn, and Tyrebagger; reddish and warm-tinted, like that of Stirling-hill, near Peterhead; bluish-grey and somewhat porphyritic, like that of Cairngall; or white and largely granular, like that of New Pitsligo. Of this kind also are the greyish granites of Inverary and Oban in Argyle, the pink-tinted medium-grained granite of Mull, the softer greyish-white granites of Dalbeattie in Kirkcudbright and Creetown in Wigtownshire, the light-grey of Wicklow and Wexford in Ireland, the darker-grey of County Down, the rose-pink of Mount Sorel in Leicestershire, the whitish of Cornwall, the bluish-grey of Hay Tor in Devon, and the dark-blue of Jersey. When small or medium-grained, ordinary granite tools well, takes on a fine hammered surface or polish, stands any amount of pressure, and resists the action of the weather. The better buildings of Aberdeen, and portions of some of the public edifices of London, Dublin, Liverpool, &c., may be taken as examples of its fitness for architectural purposes. Without fine tooling, however, and merely rough-dressed and in large courses, it has by no means an attractive appearance. One objection to the granites—and more to the granites than the syenites—is, that they suffer severely from fire; a conflagration that scarcely affects a sandstone destroying altogether the surface and texture of a granite.

Porphyritic Granite (as already explained) is the term applied to those varieties in which larger and distinct crystals of felspar are interspersed through the mass. These granites are more frequently used for decorative than for ordinary buildings, and some of them, when properly disposed, produce a very pleasing effect. The granite of Shap in Westmoreland, now coming largely into use, is one of the most beautiful, consisting in some portions of a reddish-brown, and in others of a light-brown base, with large interspersed crystals of flesh-coloured felspar. Some of the Dartmoor granites are also porphyritic, the base being of a whitish-grey colour, with large oblong crystals of whiter felspar — the "horse-teeth" of the quarrymen.

Most of the Galway granites, and that of the island of Arranmore, are also porphyritic, consisting of a greyish or greenish-grey base, with large imbedded crystals of reddish felspar. As decorative stones, many of the porphyritic granites are worthy of wider attention.

Graphic Granite, found principally in veins, consists of quartz and felspar arranged in lamellar form, and is so called from the quartz appearing in the cross fracture like cuneiform letters. It is found in Banffshire, in the Urals, and other localities, but from its rarity and small size is used only for minor ornaments.

Generally speaking, the granites are too expensive for the majority of buildings, except in towns (Aberdeen) where they are the only available rocks; and are employed more as accessory dressings and decorations, as will be seen under the second section of the present chapter. For bridges, piers, lighthouses, parapets, dock-gates, sea-walls, and similar heavy structures (see Civil Engineering), their hardness, toughness, and weight render them especially suitable; and to these and street purposes the great bulk of the granite raised in the United Kingdom is at the present time applied.

Syenite and Syenitic Granite are two names somewhat loosely employed by geologists. A true syenite (from Syenè in Upper Egypt) is a binary admixture of felspar and hornblende; a syenitic granite, a compound of quartz, felspar, and hornblende, and not unfrequently of quartz, felspar, hornblende, and mica. The syenitic granites are, on the whole, tougher and more compact than the ordinary granites, take on a fine polish, and are exceedingly durable. They occur less abundantly in nature; but their rarer use most frequently arises from the darker tints imparted to them by the hornblende. The Channel Islands, Mount Sorel in Leicestershire, Wales, Donegal, Argyleshire, and Skye, are localities where they occur in masses fit for economic employment.

The Porphyries form a numerous and very varied family of pyrogenous rocks. The term porphyry (Gr. *porphyreos*, reddish purple) was originally applied to a rock from Upper Egypt, consisting of a reddish or reddish-brown felspathic base with thickly interspersed crystals of white-coloured felspar, and largely used for sculptural purposes. This term is now employed by geologists to denote any rock (whatever its colour) which contains imbedded crystals distinct from the main mass or matrix, though, properly speaking, it ought to be restricted to those having a felspathic base.

The porphyries generally occur as dykes and eruptive masses intersecting the older schists and slates, and are usually much fissured and jointed, and for this reason incapable of being raised in massive monoliths like the granites. In our own country they are found cutting through the Cambrian, Silurian, and Devonian rocks of Ireland, Wales, Devon, and Cornwall, the Lake District, the Southern Uplands and Northern Highlands of Scotland. On the Continent, the old rocks of Scandinavia, of Germany, France, Italy, and Greece, are intersected by similar porphyries—some of which are much prized for ornamental objects. Beautiful vases of large size (Museum of Economic Geology) are occasionally fashioned from the dark-coloured porphyries of Norway. Those found in the British Islands belong to the following two main varieties:—

The *Quartziferous Porphyries*, in which the matrix is a finely granular or micro-crystalline compound of quartz and felspar, with independent crystals of quartz and felspar thickly interspersed; and the *Felstone Porphyries*, in which the basis is a compact or pasty felspar, with independent crystals of felspar scattered throughout. Both varieties appear in many tints—red, flesh-coloured, fawn-coloured, black, bluish-black, and bluish-green; and both varieties may contain, in subordinate quantities, other crystals than those enumerated above. Some fine varieties, and fit for ornamental purposes, occur at Luxullian and Bodmin in Cornwall, in North Wales, at Lambay Isle off the east coast of Ireland, at Blair-Athole, Potarch on the Dee, and at Lucklaw in Fifeshire. Incapable of being raised in large blocks, they are polished only for minor ornaments—their principal use in Britain being for causeway-stones and road-metal, for which their hardness and toughness render them specially suitable, as noticed under the chapter on Civil Engineering. Though chiefly used for road-material, in some districts they are employed in the building of country mansions, farmsteads, and walls; and when properly dressed and coursed make a very fair structure (especially the fawn-coloured sorts), and are perfectly indestructible.

Basalts, Greenstones, Felstones, &c.

The basalts, greenstones or whinstones, felstones or claystones, constitute a numerous class of rocks; and we employ these old and well-known names in preference to a number of recently imported Continental terms which refer to minute and unimportant distinctions, and by which no ordinary observer could distinguish them in the field. They all belong to what are generally known as *trappean* or *trap-rocks*, and consist in the main of felspar, augite, hornblende, and hypersthene, with accidental enclosures of iron pyrites, olivine, and other rarer minerals. As rock-masses they occur in dykes, in eruptive bosses, in interstratified sheets, and intrusive insertions, among all the stratified systems, from the Cambrian to the Tertiary inclusive. Some of them, like the basalts and greenstones, are columnar or subcolumnar in structure (hence seldom capable of being raised in large monoliths); most of them are micro-crystalline in texture, and only the felstones and highly felspathic greenstones are pasty or compact. The specific gravity of these rocks varies from 2.4 to 2.9 or upwards; they weigh from 168 to 180 lb. per cubic foot; resist a crushing power, according to their texture, from 20,000 to 30,000 lb. on one-inch cubes; and are generally little absorbent of water, say from 6 to 8 oz. per cubic foot.

They are mostly dark-coloured—black, bluish-black, greenish-black, and greyish-black in the basalts and greenstones, and only in the felstones fawn-coloured, reddish, or purplish. Their dingy colour is against them for street architecture; and yet we have seen country mansions and cottages of well-coursed greenstone when relieved by white sandstone dressings—rybats, sills, and lintels—have a very pretty and pleasing effect. The ancient Egyptians and Hindoos occasionally used the finer-grained basalts (anamesites) for sculptural purposes, examples of which may be seen in several of our public museums. In our own country, basalts, greenstones, and felstones are mainly employed (see chapter on Civil Engineering) as road-materials, for which purpose they cannot be excelled.

Closely allied to the basalts and greenstones, both in origin and composition, are the *Lavas*, of which, strictly speaking, we have no examples in the British Islands. In Italy, Auvergne, and the Rhine district, lavas of closer texture have been employed in building; but their main use now, as in former years, has been materials for streets and roadways.

The Slates and Schists.

Intermediate between the igneous and sedimentary rocks stand the metamorphic slates and schists—the clay-slates, chlorite-schists, mica-schists, and gneisses. These old rocks generally occur in a slaty or fissile state, and are better adapted for roofing, paving, and other slab-purposes, than for building; and yet some of the compacter beds of the Silurian (the greywackès) make not a bad building-stone (Keswick, Kendal, Hawick, Galashiels), being flat-bedded, and easily squared and jointed. Where obtainable, a frontage of this sort is greatly improved by light-coloured sandstone dressings. In some districts, where sandstones and limestones are scarce, the mica-schists, gneisses, and chlorite-schists are employed for building purposes; but though tough and durable, they seldom produce anything like a satisfactory effect.

As slabstones for linings, cisterns, pavements, and the like, the clay-slates, being easily planed and jointed, are very useful, but their chief value consists in their fitness for roofing purposes. From many districts (Bangor, Carnarvon, Llangollen, Portmadoc, &c.) in Wales; from Delabole in Cornwall; Tavistock, Ashburton, Staverton, &c., in Devon; from Ireleth, Coniston, Honister, Windermere, &c., in the Lake country; from Killaloe and Valencia in Ireland; and from Esdaile, Ballachulish, and Birnam, in Scotland,—slates of all sizes, thickness, colours, and durability can be obtained, and the modes in which they can be fashioned and arranged for architectural effect is one of their main recommendations. For thinness, lightness, and straightness the Welsh slates are unequalled, but the Irish and the Lake district varieties are harder, heavier, tougher, and more durable; while for strength and solidity the Scotch are perhaps superior to either. Objections are sometimes taken to Scotch and other slates containing cubical iron-pyrites. It is true these occasionally weather out, leaving empty spaces or even holes in the slate; but we have seen the cubes in a Ballachulish roof as fresh and glittering after a century's exposure as the day they were first laid on. A good slate is little absorbent of water, cuts freely but toughly, weighs from 160 to 180 lb. per cubic foot, and should resist a crushing weight of from 20,000 to 25,000 lb. A great deal of effect can be produced by the shaping and arrangement of roofing-slate; and luckily for the architect, almost every colour —black, blue, green, red, purple, and creamy-white * — is readily at his command.

What are known as *Tilestones* are not slates in the lithological sense of the term, but merely thin-bedded flaggy sandstones obtained from various systems—the Old Red, Carboniferous, Permian, Oolite, and Wealden. In the high-pitched roofs of old castles and cathedrals some of these tilestones have a fine effect; but their great weight, compared with that of clay-slate, is the chief objection to them on flat-roofed

* Some years ago a cream-coloured variety of great beauty was discovered at Lethnot in Forfarshire, but the difficulty of bringing it into market has since caused the quarry to be abandoned.

modern structures. Their greater thickness, however, renders the interior of a house warmer in winter and cooler in summer than the ordinary Welsh slates, and this, in a fitful climate like Britain, is no mean recommendation. They are still used in some country districts—Forfar, Dumfries, Westmoreland, West Riding, Gloucestershire, &c.; the thinner splitting of the flags being effected by exposing them edgeways to the frosts of winter.

Sandstones, Grits, Freestones.

We come now to the truly sedimentary rocks, which differ widely from the pyrogenous and metamorphic, alike in mineral composition, structure, and texture. These include the sandstones, flagstones, grits, and conglomerates, as well as the limestones, which, though often of organic origin, are still to a great extent sedimentary and stratified.

The *sandstones* and *grits* constitute a numerous family, and as old shore-sediments, occur in almost every formation—the Old Red, Carboniferous, New Red, Jurassic, and Wealden. They consist for the most part of grains of quartz consolidated by pressure, and cemented by silica, lime, or oxide of iron; and frequently contain scales of mica, and not unfrequently carbonaceous particles scattered through the mass. They appear in all colours — white, black, grey, greenish-grey, red, brown, fawn-coloured, and yellow; and these colours sometimes fade, and sometimes become intensified by exposure to the weather. In structure, some are thick-bedded and homogeneous, and others thin-bedded, laminated, and flaggy: the former constitute the "post" or "liver-rock," the latter the "flagstones" and "pavement-beds" of the quarrier. In texture they occur in every degree of fineness, from particles scarcely perceptible to the naked eye, to grains as large as a pea—in other words, from fine-grained soft *sandstones* to coarse-grained silicious *grits*. As mixed rocks they consist of several ingredients, and, as the case may be, are spoken of as *silicious*, *quartzose*, *micaceous*, *calcareous*, *argillaceous*, *ferruginous*, *bituminous*, and *carbonaceous*.

In chemical composition the sandstones vary extremely, and no two strata even from the same quarry will yield perhaps the same results. The following are analyses of some well-known varieties, as given in the Report of the Commissioners for the selection of stone for the new Houses of Parliament :—

	Craigleith.	Darley Dale.	Heddon.	Kenton.	Mansfield.
Silica, . .	98.3	96.40	95.1	93.1	49.4
Carb. lime, .	1.1	0.36	0.8	2.0	26.5
Carb. magnesia,	0.0	0.0	0.0	0.0	16.1
Iron, alumina,	0.6	1.30	2.3	4.4	3.2
Water and loss,	0.0	1.94	1.8	0.5	4.8

In specific gravity the sandstones and grits vary from 2 to 2.6; in weight per cubic foot, from 130 to 160 lb.; in absorbent power, from 1 to 8 or 9 lb. of water per cubic foot; and their resistance to pressure, from so low a figure as 500 lb. to 8000 lb. for the cubic inch. Indeed, many of the sandstones, from their softness and rapidity of disintegration when exposed to the weather, are altogether unfit for building, while others are so hard and silicious as to be better adapted for road-material than for the purposes of architecture. A great deal, however, depends upon the mode of tooling and bedding—that is, upon the crushing and loosening of the surface particles in dressing, and upon the laying of the stone in its natural bedding or stratification. Much of the beauty of sandstone depends on its tooling—notching, scabbling, pearling, broaching, droving, or polishing, as the case may be; and no laminated variety should be bedded otherwise than it was in the quarry, or the result will be flaking or peeling off in course of time, under the frosts of winter. Tooling or dressing is an important feature in the preparation of sandstones for ashlar fronts; for while polishing will bring out the beauty of one variety, vertical droving may be more suitable for a second, and parallel broaching or pearling may mask the grain or spottings of a third. For rustic work in basements and the like, nothing can excel a strong homogeneous sandstone.

In selecting sandstones, the finer-grained, the more homogeneous in texture, the least absorbent of water, and the freest from lime and iron, should be preferred. All blocks containing balls or nodules of sulphide of iron (iron-pyrites), should be carefully rejected, as in a few years such nodules oxidise, become blackish-brown, unsightly stains, and finally weather out into cavities.* The builder cannot have a better test of the durability of a sandstone than by observing it in the face of exposed cliffs and old quarries; its absorbent nature he can test by experiment; and in the case of a new variety, important information may be obtained by subjecting it to the process of M. Brard. This process consists in boiling small cubes of the stones to be tested in a saturated solution of sulphate of soda (Glauber's salt), and then suspending them for four or five days in the open air. As they dry they become covered with an efflorescence of crystals, which must be successively washed off till the efflorescence ceases. If the stone resists the decomposing action of damp and frost, the salt does not force out any portions of the stone with it; on the other hand, if it

* For want of selection, some of the finest frontages in Edinburgh exhibit such stains, and one church at the junction of Bristo Street and Forrest Road is absolutely pock-pitted with these unsightly blotches.

yields to this action, small particles will be perceived to separate themselves, and the cube will gradually lose its angles and sharp edges. The amount of this disintegration affords, according to the author of the process, a criterion of what would be produced in course of time by the action of the weather.

In the typical *Siluria* (Eastern Wales) of Sir Roderick Murchison, several tough-grained sandstones and grits are noted in the Geological Survey, but these, as far as we are aware, are not raised except for local and minor purposes. In other Silurian tracts, metamorphism generally prevails to such an extent as to convert the sandstones into jointed silicious grits and quartzites, unfitted for the requirements of the builder.

The sandstones of the *Old Red and Devonian Systems* vary very much in composition, colour, and durability, and usually present themselves in three available forms—the compact liver-rock for building, the flagstones for paving, and the tilestones for roofing. The tilestones of Hereford, Forfar, and Caithness, are of reddish, rusty-grey, and bluish-grey tints, and when carefully selected stand the weather well, some of these used on ecclesiastical buildings of the fifteenth century being still fresh and serviceable. The flagstones of Caithness and Forfar are well and widely known, and though used in internal floorings, &c., are much more extensively employed for street purposes, under which head they are treated in the chapter on Geology and Civil Engineering. The sandstones proper vary very much in texture, and are of many colours—brick-red, chocolate-red, rusty-grey, yellow, and creamy-white. Some of the Hereford and Monmouth beds are said not to be durable; but many of the Perth and Forfar rocks tool well and stand well, and the same may be said of those of Cork and Kerry —Carmylie, Leysmill, Turin, Glammis, Milnefield, Moncrieff, &c., furnishing good examples. The main objection to them is their dull rusty-grey tints, and the frequent embedding of pebbles or nodules of foreign matter. As they are tough and strong, however, and can be raised in blocks of any size, they are well fitted for harbours, sea-walls, and heavy structures, as may be seen in the docks of Dundee. The brick-red beds from the middle formation are generally less durable, though some of the Ross-shire (Munlochy) and Dumbarton beds stand fairly; but the creamy-white and yellow strata of the upper formation form most beautiful and durable building-blocks, as at Elgin, Kembach in Fife, and Denholm-Hill in Roxburghshire. Like other sandstones, those of the Old Red stand the test of time very variously, as may be seen in the old ecclesiastical structures of Elgin, Arbroath, Dunblane, Dryburgh, Melrose, Kelso, and Jedburgh, in Scotland; in Tintern Abbey, the Castle of Chepstowe, in England; and in the Round Tower of Ardmore, Ballymoney Castle, and other structures in Ireland.

The sandstones of the *Carboniferous System*, from their extensive development in Britain, are more largely employed than those of the Old Red, and are also much more varied in colour, texture, and durability. In colour they vary from white and whitish-grey to tints of greenish-grey, yellow, buff, brown, and red; in texture, from the finest and closest grain to coarse-grained quartzose and pebbly-quartzose grits; and in durability, from rocks that will crumble down in a few years to others that will endure for ages. They occur chiefly as thick-bedded "liver" rocks; though many fields yield flagstones of unequalled size and quality, as the millstone-grit and Gannister beds of Yorkshire, Derby, and Lancashire, the lower coal-measures of Edinburgh, and the lower coal-measures and millstone-grit of Carlow, Mayo, &c., in Ireland. These flagstones, however, will be noticed as road-material under the head of Civil Engineering; and here we direct attention chiefly to the thick-bedded sandstones used in building, and such as may be seen in Edinburgh, Glasgow, St Andrews, Newcastle, Leeds, Sheffield, Bradford, Manchester, and other towns situated on or near to the coal-formation. Many of the coal-measure sandstones may be raised in blocks of large size, are easily squared and tooled, and from their agreeable tints are employed not only in carboniferous areas, but in other and distant districts. We may notice in detail some of the better known and more esteemed varieties:—

The sandstones of Glasgow (Bishopbriggs, Giffnock, Dowanhill, &c.) are of whitish tints, of medium texture, are easily squared and tooled, and of excellent quality, as may be seen in the structures of that city, from the old Cathedral down to the new University buildings, the modern warehouse, and suburban villa.

Those of Stirlingshire (Polmaise, Dunmore, Plean, Bannockburn, &c.) are of yellower and warmer tints, of fine texture, and stand well, as may be seen in Stirling Castle, Cambuskenneth Abbey, and all the modern structures in the district. They are now largely carried to other localities, and even for frontages to London.

Those of Edinburgh and Linlithgowshire (Craigleith, Ravelston, Redhall, Bellfield, Craigmillar, Joppa, Binney, Humbie, &c.) have all a high reputation, vary in shades from white to reddish-brown, are fine in texture, and of tried durability, as may be witnessed in the old baronial mansions of these counties, and in all the streets and public edifices, as well as elegant suburban villas, of the Scotch metropolis. The stones from Craigleith and Binney are carried to other districts of the country, and occasionally exported to the Continent.

The sandstones of Fifeshire (Cullalo, Burntisland, St Andrews, &c.) appear in tints varying from the purest white to creamy yellow, are fine and rather soft in texture, but harden on exposure to the weather. The white rock of Cullalo (used in Fettes Hospital, Edinburgh) is an excellent stone, and has been exported to the Continent; and that of St Andrews and neighbourhood, when carefully selected, produces a very satisfactory effect, and lasts well, as may be seen in the old cathedral and St Regulus' tower, erected in the ninth century. A variety of fine-grained *black* sandstone occurs at Carnock, near Dunfermline, which, when well designed and sculptured, has a very appropriate effect in tombstones and sepulchral monuments.

Those of Newcastle (Elswick, Gosforth, Heddon, Kenton, &c.) are whitish-grey sandstones, rather rough and open in texture, and not especially durable, as may be seen in the old walls and churches of the town. Some, however, like those of Black Pasture on the North Tyne, and used in the pedestal of George Stephenson's monument, are of excellent quality—the blocks in the Roman Wall from that quarry standing hard and fresh after an exposure of seventeen centuries. The beds quarried for millstones are of a finer and more equable texture.

Some of the sandstones of Durham (Felling, Pensher, Leamside, Stenton, &c.) are rather finer in the grain, tougher, and more argillaceous than those of Newcastle, but unless carefully chosen are also liable to weather and decay. Examples may be seen in Durham Cathedral, Barnard Castle, &c.; and in several of the modern structures of Sunderland.

The sandstones of Yorkshire differ much, according as they are raised from the millstone-grit or from the finer grained Gannister beds. The former yields coarse-grained, massive, greyish grits, which can be raised in large blocks (Leeds, Sheffield, &c.), fitted for heavy and durable structures. The Gannister beds, on the other hand (valley of the Aire, Bradford, Halifax, Huddersfield, &c.), are fine-grained, greenish-grey or yellowish-grey, flaggy beds, capable of being used either for building or for flagstones, as may be favourably seen in the recent public structures of Bradford. On the whole, Yorkshire is rich in carboniferous sandstones, which are employed not only in its own populous towns, but carried to the towns of adjacent counties.

Several of the grits and sandstones of Derbyshire make handsome building-stones, being of medium grain, of whitish or lightish-brown colours, and of tried durability. Bakewell Edge, used in Chatsworth Castle and Buxton Crescent, Duffield Bank and Morley Moor, in the public buildings of Derby, and Darley Dale in Darley Abbey and Stancliffe Hall may be taken as examples. The same remarks apply to the grits and sandstones of Lancashire, Gloucester, Staffordshire, and other adjacent carboniferous areas, all of which yield building-stones of varied texture, colour, and durability.

The sandstones of the *Permian or Lower New Red* are usually of red and purplish tints, rather open and soft in texture, and of no great durability. When carefully selected, however, both building-blocks and flagstones of fair quality can be obtained from the formation, as may be seen at Lochar Briggs and Corncockle, Dumfriesshire; along the Eden near Carlisle; at Penrith and St Bees, in Cumberland; and at Furness, in North Lancashire. The towns of Dumfries, Carlisle, and Penrith, the Castle of Penrith, and the Abbeys of Lincluden, Furness, and Calder, may be taken as examples.

The sandstones of the *Trias or Upper New Red* appear in various tints—light-red, brownish-grey, white, and whitish-yellow—are of varied texture and consistency, and, in consequence, of as varied durability. Many of the lower beds are soft, mottled, and worthless. The middle beds are of better quality, and occur largely in Lancashire, Cheshire, Staffordshire, and Worcestershire. Some of the lower beds are quarried in the neighbourhood of Liverpool, and employed in the buildings of that town; but the upper and finer beds are (according to the Geological Survey) extensively raised and used in the construction of many of the churches and mansions of the midland counties. The quarries of Grinshill, near Shrewsbury; of Hollington, near Uttoxeter; Ombersley and Hadley, near Worcester; Park, near Tixall, in Staffordshire; Peckforton, in Cheshire; and Manley, near Dunham, in Cheshire, are spoken of as yielding blocks of superior quality—those of Hadley being employed in the restoration of Worcester Cathedral, and those of Manley, in that of Chester. These sandstones, however, are not comparable to those of the carboniferous system in point of texture and durability, and even the best of them require very careful selection.

The sandstones of Lossiemouth and Cummingstone, in Morayshire (from their organic remains, regarded as of Triassic age) are of a superior quality—the former whitish, fine-grained, thick-bedded, and capable of being raised in large blocks; the latter brownish, fine-grained, thin-bedded, and affording very fair and flat-surfaced flagstones.

The sandstones of the *Oolitic and Cretaceous Systems* are of rarer occurrence, and are only locally and partially employed for building purposes. The best known of these are, perhaps, those of Aislaby near Whitby, a light-brown, medium-grained, serviceable stone, from the Lias; those of Calverly, near Tunbridge Wells, and Horsham from the Wealden; and the hard and fine-grained calciferous sandstone of Tisbury in Wiltshire. Those of Aislaby and Tisbury are superior freestones—the former employed in Whitby Abbey, the latter in Salisbury and other places in the county. The Whitby sandstones have a high reputation, and are used not only in the locality, but carried to London, Cambridge, Exeter, and other towns.

Limestones and Marbles.

The limestones or calcareous rocks, employed in building, are not so extensively developed in Britain as the sandstones, nor are they generally made use of even in the districts where they occur. This arises partly from their unattractive tints, and partly from the difficulty of dressing and tooling them with effect; the exception being some of the Oolitic and Magnesian varieties, which are both pleasing in colour and easily manipulated. Again, though standing well in the pure air of the country, many of them waste under the carbonated atmosphere of towns; and even the best of them, after a few years' exposure, have a bleached and cold appearance. They are found in all the geological systems, but in Britain most abundantly in the Devonian, Carboniferous, Permian, and Oolitic. Those occurring among the Metamorphic rocks are generally marbles of crystalline texture, and some of the Devonian and Carboniferous limestones are also polished for decorative purposes; but under the present head we refer only to those employed by the builder.

In structure the limestones are often jointed, and incapable of being raised in large blocks; in texture they vary from earthy to compact and subcrystalline, but, owing to their organic origin, uniformity of texture is frequently interrupted by the remains of corals, shells, encrinites, and other exuviæ. Many, however, of the Devonshire, Derbyshire, Yorkshire, and Westmoreland limestones are thick-bedded and homogeneous, and can be raised in blocks of great size and solidity. As ordinary limestones, they consist mainly of carbonate of lime, but dolomitic or Magnesian limestones consist of carbonate of magnesia and carbonate of lime, while throughout the whole family there may be argillaceous, silicious, ferruginous, and bituminous varieties. A family consisting of such members as chalk, oolite, dolomite, compact limestone, and crystalline marbles, must necessarily vary much in density, absorption, and resistance to pressure; and hence such experiments as have been made must be received as applicable only to the rocks to which they relate.

The limestones of the *Metamorphic System* are found chiefly in the Scottish Highlands, and are usually greyish crystalline varieties, or bluish and greenish veined varieties—either raised for mortar and agricultural purposes, or occasionally as "marbles," to be noticed under another head. None of them are used as building-stones; and indeed, their paucity, the high angles at which they lie, and their distance from fuel, renders it often cheaper to bring lime from Carboniferous districts than to raise and calcine them in the counties (Banff, Aberdeen, Kincardine, Perth, and Forfar) where they occur.

The limestones of the *Silurian System* are developed chiefly in Wales—the Lake district and the southern uplands of Scotland containing only a few sporadic and unimportant patches. Unless for country uses—fences and farmsteads—none of them are raised for better-class buildings, though the Wenlock beds are largely quarried for mortar, agricultural, and other purposes.

The limestones of the *Devonian System* are, as the name implies, mainly restricted to Devonshire. The calcareous beds of the Old Red Sandstone proper are limited and irregular, often silicious and concretionary, and seldom quarried unless on a very small scale for mortar and agriculture. The Devonshire limestones, though perhaps better known as marbles, make also, when neatly squared and tooled, an excellent and durable building-stone. Plymouth, Torquay, Exeter, and many of the smaller towns in South Devon, contain structures of these limestones which are at once durable and of handsome appearance. They are strictly marine limestones, often coralline, and frequently veined and mottled—their prevailing tints being a light bluish-grey, with veins of white and creamy yellow. Reddish varieties are found in two or three localities, but these are chiefly raised for internal decoration—shafts, slabs, and chimney-pieces.

The limestones of the *Carboniferous System* are largely developed, both in thickness and extent, in England and Ireland; but in Scotland the beds are thin and irregular, and scarcely suffice the local demands for mortar, the blast-furnace, and agriculture. In Derbyshire, Yorkshire, North Lancashire, and Westmoreland, there is a vast development of limestone, several hundred feet in thickness, and covering many square miles in extent. In North and South Wales there are similar though less extensive developments; and in Ireland the greater portion of the central plain is occupied by limestones of the Carboniferous epoch. Several of these limestones are used as ornamental marbles (to be noticed under another section); the great bulk of them are quarried for the blast-furnace, for mortars, cements, agriculture, road-making, bleaching, tanning, gas purification, and other industrial purposes; while only a small proportion is raised for building. They vary extremely in composition—some containing upwards of 90 per cent of carbonate of lime, with minor proportions of silica, alumina, and oxide of iron; some containing from 10 to 15 per cent of carbonate of magnesia and passing into dolomites; and others embodying such a large proportion of silica and alumina as to pass into cherts and hydraulic limestones. The following are analyses of a few varieties by the late Professor Johnston:—

	Durham.	Cumbld.	Yorksh.	Derbysh.	Fifesh.
Carb. lime, .	95.06	94.86	94.56	95.95	66.00
Sulph. do., .	—	0.23	0.32	0.24	—
Phosph. do., .	—	—	0.33	—	—
Carb. magn., .	2.46	1.26	2.32	0.54	9.45
Silica, . .	1.32	2.92	1.29	2.06	13.—
Alumina & iron,	1.00	0.73	1.18	1.21	8.71
Water, . .	—	—	—	—	1.90
Bitumen, .	trace	trace	—	trace	0.94

As already stated, the unattractive colours of these mountain limestones, and the difficulty of tooling them, is against their wider adoption; but many of them make strong, substantial structures, and would be more generally employed, were it not for the abundance of available sandstones with which they are associated in Carboniferous districts. As it is, many country mansions, public institutions, churches, and hotels in the counties above mentioned (Derbyshire, West Riding, N. Lancashire, Westmoreland, Glamorganshire, &c.), are constructed of them; and in Ireland they have been similarly used from the time of the round towers downwards. Perhaps they appear to most advantage, whether in tooled courses or in rustic work, when accompanied by sandstone corners, rybats, and lintels. But even without these adjuncts, when their colour is light, and proper care bestowed on the size, arrangement, and tooling of the courses, they make handsome structures in the pure air of the country, as may be seen in several of the old castles, churches, and public buildings in the districts above referred to.

The limestones of the *Permian System* are mainly Magnesian—that is, consist of carbonates of lime and magnesia, with varying proportions of silica, alumina, and iron. If the silica is in excess they become calcareous sandstones, generally of hard and close texture; but when it constitutes only a small percentage, they are regarded as magnesian limestones. Many limestones in other formations contain small amounts of magnesia, but only those containing above 15 or 18 per cent are entitled to the name of "Magnesian." The more crystalline or dolomitic they are in texture, the more durable they become; and those are most to be relied upon in which the lime and magnesia occur in nearly equivalent proportions. Generally, however, they exhibit great variety of texture and composition, even in the same quarry, and therefore require very careful and skilled selection. They derive their warm yellowish tints from the oxide of iron, assuming deeper tints as that ingredient prevails. In specific gravity they vary from 2 to 2.66; are much more absorbent of water than the sandstones; weigh from 128 lb. to 152 lb. a cubic foot; and, in the more crystalline varieties, withstand a considerable crushing power. The following are analyses as given in the Commissioners' Report on Building-Stones, and by Richardson:—

	Bolsover.	Huddlestone.	Roach Abbey.	Park Nook.	Fulwell.
Carb. lime, .	51.1	54.19	57.5	55.7	62.80
Carb. magn., .	40.2	41.37	39.4	41.6	32.75
Silica, . .	3.6	2.53	0.8	0.0	trace
Iron, Alumina,	1.8	0.30	0.4	0.4	2.30
Water and loss,	3.3	1.61	1.6	2.3	2.15

In England (for they do not occur either in Scotland or Ireland) these magnesian limestones occupy considerable areas in Durham, Yorkshire, Derby, and Notts, and appear in many varying beds (earthy, laminated, compact, concretionary, and crystalline), the whole series being from 200 to 300 feet in thickness. In Durham they are seldom used as building-stones, unless for rude walls and inferior structures. In Yorkshire they are, and have been, more largely raised at various places near Tadcaster, Sherborne, Doncaster, and Auston, and employed in various structures, but generally with varying results, as may be witnessed in the ecclesiastical buildings of York, Doncaster, Hull, Beverley, Selby, Ripon, and various parts of Lincolnshire. In Derbyshire the Bolsover Moor quarries, employed in the new Houses of Parliament, yield stones of varying quality—some wasting and worthless, and others of fair durability. On the other hand, the celebrated quarries of Mansfield, in Nottinghamshire, yield a silicious dolomite, of hard, close-grained, and enduring texture. Few rocks, indeed, vary so much in texture and durability as the magnesian limestones of England. In the same quarry, beds of tried excellence are frequently associated with others which look as well, but are worthless; hence the skilled and watchful care that is requisite in selection. It is not only that they differ in composition—the magnesia ranging from 45 down to 10 per cent and under—but that they vary in textural aggregation from hard, compact, and crystalline beds to others that are so soft and earthy as to yield readily to the nail.

The Oolitic limestones or calcareous freestones of the *Jurassic System* are largely employed for architectural purposes in the midland and southern counties of England, being pleasing in colour, easily raised and tooled, and of fair durability when close-grained and homogeneous in texture. They are generally of whitish, cream-coloured, or light-brown tints; vary in texture from compact small-grained roestones to peastones, and from peastones to coarse-grained, shelly, and coralline ragstones; can be raised in blocks of any size; and though soft when newly quarried, acquire hardness and toughness on exposure. Occurring in four zones of the system—the Inferior Oolite, the Great or Bath Oolite, the Coralline Oolite, and the Portland stone—they necessarily present great variety of colour and quality; hence it is only the denser and finer-grained beds that are worked in their respective localities.

The *Inferior Oolite*, which is largely developed in the Cotswold Hills, yields some fine-grained, compact, white or light-yellow beds, that are quarried at many places along the range—Leckhampton near Cheltenham, Painswick, Breckhampton, Ingleborough, &c. The *Bath Oolite* is still more largely quarried, as well as raised from subterranean workings, along the Somerset and Wiltshire hills—Stroud, Box, Chippenham, Doulting, &c.—and yields a fine, close-grained, whitish stone, which can be raised in blocks of any size, and though soft enough when first extracted to be cut with the saw, yet soon hardens on exposure. As this zone trends eastward through Oxfordshire, Northamptonshire, and Lincolnshire, it assumes browner and richer tints, and is quarried at several localities—the quarries of Barnac and Casterton in Northamptonshire, of Ketton near Stamford, Haydor near Grantham, and Ancaster near Sleaford, being often referred to as yielding blocks of great size, pleasing tints, and tried durability. The *Coralline Oolite*, being inferior in texture and durability, is seldom used as a building-stone; but the *Portland Beds* have been long and largely quarried, and extensively employed in most of the public structures of London (St Paul's Cathedral and other churches), and in several of those of Dublin, as well as in many of the more important buildings in the south of England. When the Commissioners reported, in 1839, there were 56 quarries in the island, employing 240 quarrymen, and raising annually about 24,000 tons of stone; and notwithstanding the greater competition with the Bath oolites, the demand, we believe, still continues.

Throughout the whole zone of these Oolites, which stretches, in varying breadth, from Dorset to Scarborough, they have been, and are still, extensively employed in ecclesiastical structures, manor-houses, and public edifices in towns. When carefully selected, and not exposed to the carbonated atmosphere of cities and manufacturing towns, many of them are of fair durability; but even the best of them are not to be compared in this respect with the silicious grits and sandstones. For internal purposes, however, their pure colours, their lightness, and the facility with which they can be carved, render them especially adapted; hence the extensive use of such fine-grained varieties as those of Painswick, Box, and Caen in Normandy. In specific gravity the Oolites vary from 2 to 2.5; a cubic foot weighs, when dry, from 125 to 150 lb.; when dry they absorb from 8 to 10 per cent of their weight of water; and in composition they are nearly pure carbonates of lime with minor proportions of carbonates of magnesia, silica, and iron. That of Bath, according to Daniell and Wheatstone,* consists of carb. lime 94.52, carb. mag. 2.50, iron and alumina 1.20, water and loss 1.78; and that of Portland,

* Report of Commissioners on Building-Stones.

carb. lime 95.16, carb. mag. 1.20, silica 1.20, iron and alumina 0.50, water and loss 1.94.

With the exception of the compact calcareous stone from Beer, in Devonshire, which has been employed in several local churches, and the Kentish Rag, which is quarried at several places along the outcrop of the Lower Greensand, there are no limestones worthy of notice employed in Britain for building purposes from the *Cretaceous and Tertiary Systems*, though they are largely employed in France and other foreign countries. Indeed, it is to tertiary limestones that Brussels and Paris owe much of their architectural beauty; while the nummulitic beds have been used along their course as an available building-stone from the time of the Great Pyramid down to the present day.

II.—STONES FOR DECORATION AND SCULPTURE.

Under this head we embrace such stones as are susceptible of a fine polish, and which are employed more for internal decoration and sculpture than for external buildings. It is true that many buildings are exteriorly ornamented with carvings and sculptures, but most of the stones used for interior decorations—alabasters, marbles, serpentines, &c.—would fare badly if exposed to the weather of a severe and variable climate. It is to those more exclusively devoted to ornamentation, therefore, that we devote the present section; and first of the pyrogenous rocks.

The Granites, Porphyries, Basalts, &c.

Of recent years the *Granites* have come largely into use for external and internal pillars and pilasters, for mantelpieces, pedestals, vases, drinking fountains, graveyard monuments, and sarcophagi. This adoption has arisen partly from their sparkle and beauty, and the high polish of which they are susceptible, partly from their great durability, and partly also from the invention of mechanical appliances by which such hard substances can be expeditiously and cheaply prepared. The granites of Aberdeen (Rubislaw, Stirling Hill, and Cairngall), of Mull, Dalbeattie, Shap, Dartmore, Wicklow, and Galway, are amongst the most esteemed varieties; and there is scarcely a public building in any of our large towns, a first-class mansion-house, or fashionable cemetery, in which they may not be witnessed. It is needless to point to examples where the use is so frequent, and where year after year it is becoming more general as the wealth of the country increases, and as more effective machinery is invented for raising, cutting, and polishing the material. Having various shades of colour, various sizes of grain, and being capable of being raised in blocks of any dimensions (as already noticed under Building-Stones), the British Granites afford great variety of choice, from the warmer tints suitable to a banqueting-hall, to the sombre and colder hues more appropriate to the monumental obelisk.

The *Porphyries*, for the reasons stated in the preceding section, are very seldom employed in the United Kingdom for decorative purposes. This is not for want of beautiful tints or susceptibility to polish, but chiefly from their fissured and fractured structure, which renders them incapable of being raised in suitable blocks. Notwithstanding this drawback, they are occasionally used for smaller pedestals, vases, and the like, and several of them produce very fine effects. Indeed, were proper attention paid to the porphyries, some of the Cornish and Scotch varieties would, for internal decoration, compete successfully with the granites. In Scotland several of the porphyries, syenites, and syenitic greenstones are dressed and polished for curling-stones, on some varieties of which (Ailsa Craig and Blairgowrie, for example) connoisseurs set an especial value.

The finer-grained *Basalts*, though successfully carved in ancient India and the East, are seldom, if ever, attempted in Britain; and yet their dark colours, dull surface, and known durability, render them specially suitable for some kinds of ornamentation. Of the trap-rocks, few, indeed, are suitable for decorative or sculptural purposes; and yet we have seen very handsome vases and minor ornaments fashioned of the variolitic *amygdaloid* of Glenfarg in Perthshire, and of the black-spotted olive-green variety of Hallyards in Fifeshire.

Slates and Serpentines.

The *Slates*, though they can be raised in slabs of any size, and cut into any form, are not susceptible of a high polish, and consequently are not used for decorative purposes, save when japanned or enamelled. In this state they are now extensively employed for chimney-pieces and table-slabs; and very fair imitations of marbles (especially black), serpentines, and porphyries can be produced at a much smaller cost than the real materials. Being harder and tougher, the slates can withstand a much greater amount of tear and wear than either the serpentines or marbles. Abundant supplies of slab-slates, of great size and varying thickness, can be obtained from Valencia, Wales, and Windermere—the Irish varieties being preferred by some for their toughness and greater regularity of grain, the Welsh for their smoother surface and easier manipulation.

The *Serpentines*, so called from their mottled, serpent-skin-like appearance, are silicio-magnesian rocks of metamorphic origin—arising apparently from the transmutation of magnesian limestones or other closely related strata. As the name implies, they are variegated in colour (green, grey, dark red, or brown), and often clouded, striped, or veined; are rather soft and sectile; have a dull, splintery fracture; and like most magnesian minerals, feel greasy to the touch. Their average composition may be set down as 40 silica, 40 magnesia, and 13 water, with varying proportions of iron-peroxide, and traces of other colouring matter. Besides the common serpentine, known also as *ophite* or *ophiolite*, mineralogists distinguish *noble serpentine*, usually of some shade of green, translucent, and having a resinous lustre; *marmolite* or foliated serpentine; *picrolite* or fibrous serpentine; and *chrysolite* or asbestiform serpentine, of a fine oil-green colour and silky lustre.

"Of all the stones used for decorative purposes in architecture," says Mr Hull, in his work on building and decorative stones, "none surpasses in general estimation some of the varieties of serpentine. This is due both to the richness and variety of its colouring, and its capability of receiving a fine polish. It is not, however, adapted to outdoor use, especially in the smoky or gaseous atmosphere of cities; for being acted on by hydrochloric and sulphuric acids, it is liable either to decay, or to become tarnished on the surface. But for indoor decorations, and the construction of slender shafts, pilasters, pedestals, vases, inlaid slabs for walls, and ornaments of various kinds, serpentine is often employed with successful results."

Available serpentines occur in Cornwall and Anglesea in England; in the counties of Banff, Aberdeen, Perth, and Forfar, in Scotland; and in Galway and Donegal in Ireland. The most esteemed are the greenish-coloured of Galway, known to marble-cutters as "Connemara marble" or "Irish green;" the reddish, mottled, and clouded varieties of Lizard Point; and the red and deep-green variety of Portsoy. At present the serpentines of Connemara and the Lizard are extensively in use; but that of Portsoy has been little employed, and only for minor ornaments, during the current century. At one time, however, it was exported to the Continent, and according to Mr Hay Cunninghame ('Geognosy of Banffshire') was used in decorating apartments in the palace of Louis the Fourteenth, under the title of Scottish marble — *Verde d'Ecosse.*

The serpentines (*verde antique* of the ancients) occur abundantly among the metamorphic or crystalline rocks of most countries—France, Germany, Italy, Greece, the Urals, Egypt, India, Canada, and N. America, yielding many varieties well fitted for architectural decoration, as well as for the production of articles of elegance and utility.

Limestones, Marbles, Alabasters, &c.

Under decorative *limestones*, we include such rocks as the Caen Oolite, which, being of fine texture and uniform colour, can be cut and carved into the most delicate and elaborate ornamentation. For internal carvings, and especially in ecclesiastical structures, few rocks can compete with this stone; hence its extensive use in Britain, though very fair blocks for similar purposes can be obtained from the Box, Painswick, and Portland quarries. These limestones do not take a glossy polish like serpentines and marbles, but they are cheaply worked in comparison, harden on exposure, and when broken or injured can be renewed with wonderful facility. Pillars, niches, statuettes, screens, altar-pieces, pedestals, pulpits, &c., in churches; and chimney-pieces, pedestals, pediments, and the like, in public halls,—are abundantly chiselled from these limestones.

Of all the ornamental and decorative stones, the *marbles* are the most abundant and varied, and at the same time the most extensively employed. Any rock susceptible of a fine polish is termed "marble" by the stone-cutter; hence we hear of "Connemara marble," which is a true serpentine; and of "Sicilian marble," which is often a brecciated lava. The term, however, should be, and is, restricted by geologists to limestones capable of receiving a polish, and frequently exhibiting a variety of colours in veins and blotches. We have thus *uni-coloured* marbles, such as pure blacks and whites; and *party-coloured* sorts, deriving their tints from accidental minerals, from metallic oxides, giving them a veined or clouded appearance, or from shells, encrinites, corals, and other organisms which impart a variety of "figure" as well as of hue. Every country has its own peculiar marbles, and almost every age has had its own whims and fancies for certain varieties. These varieties are almost endless—Greece, Italy, Belgium, France, Spain, Britain, the United States, and Canada, each yielding esteemed sorts, differing in colour, figure, lustre, and susceptibility of polish.

The following are a few of the better known and more esteemed varieties, ancient and modern: *Carrara*, pure white, saccharoid, and semi-transparent; highly esteemed for statuary purposes. *Parian*, of a waxy cream-colour, also crystalline, and employed in statuary. *Giallo-antico*, yellow, and mixed with a small proportion of hydrate of iron; used for ornamental purposes. *Sienna*, a rich yellowish-brown, with lighter veins and cloudings. *Rosso-antico*, a deep blood-red, less or more veined. *Mandelato*, a light-red, veined and clouded. *Verde antique*, a cloudy green, mixed with serpentine, or serpentine itself. *Cipolino*, a mixture of talcose schist with white saccharoidal marble. *Bardiglia*, a bluish-grey variety, with bold black veins and cloudings. *Lumachello* or *fire-marble*, a dark-brown variety, having brilliant chatoyant reflections, which it owes to the nacreous matter of enclosed shells. *Black marbles*, like those of Derbyshire, Dent, and Kilkenny, deriving their dark colours from bitumen. *Encrinal marbles*, like those of Dent in Yorkshire and other carboniferous districts, deriving their "figure" from the stems and joints of encrinites. *Shell marbles*, like those of Purbeck and Petworth in Dorset and Sussex, and Kingsbarns in Fife, receiving their "figure" from the component shells of univalves and bivalves.

The marbles are amongst the most varied and useful of rocks, whether for external structures or for internal decoration. They are sufficiently durable in dry and pure atmospheres; can be raised, for the most part, in blocks of any size; and are easily tooled and polished. As building-stones, they are unsuited for our climate; hence their use is principally confined to chimney-pieces, toilet and table slabs, inlaid works, mosaic pavements, portico and hall pillars, pedestals, busts, statues, and groups of statuary. Statuary marbles of the finest hue and texture are brought from Italy and Greece (Carrara and Paros), as are also many of the party-coloured varieties for internal decoration. Some beautiful marbles are also obtained from Belgium and France, but several useful sorts are derived from the formations of our own Islands—Metamorphic, Devonian, Carboniferous, Oolitic, and Wealden—and to these we shall briefly advert.

The *Metamorphic* or *Primary marbles* of Britain are chiefly confined to the Scottish Highlands, and none of them have ever been worked to any extent for decorative purposes. They are found in beds of moderate thickness among the crystalline schists, which extend across the country from sea to sea, and are generally of grey or bluish-grey colours, with dove-coloured cloudings and occasional veins and blotches of green and yellow. They occur in Iona, at Assynt, Glen Tilt, Ballachulish, Clunie, Kirkmichael, Banchory, and other places; and though some, like Assynt and Glen Tilt, were at one time in use, they are now quarried solely for mortar and agricultural purposes. A pretty pinkish variety, with interspersed dark-green crystals of sahlite, is found in the island of Tiree; but, so far as we are aware, it has never been worked to any extent for economic purposes, nor, indeed, is there any available amount of it.

The Devonian or Devonshire marbles, on the other hand, are pretty extensively quarried, and consist of several varieties well adapted for chimney-pieces, pilasters, columns, inlaid slabs, mosaic-work, and other useful and ornamental purposes. The South Devon marbles, which are worked at Plymouth, St Mary's Church, Babbacombe, Totness, Newton Bushel, and other places, are of various shades of grey, with veins of white and yellow, occasionally reddish or flesh-coloured, with deeper veinings, and not unfrequently coralline or "madrepore." The marbles of St Mary's Church near Torquay, and Ipplepen near Totness, are much esteemed, and sent to all parts of the country. The North Devon marbles, though not so extensively quarried, present some useful varieties, having a black ground irregularly traversed with bold white veinings. Chudley, Staverton, and Berry Pomeroy, are mentioned by Mr Hunt, of the Museum of Practical Geology, as localities.

The *Carboniferous Limestones* of the United Kingdom yield a great many marbles; but, with the exception of the pure black varieties, their colours are dull and uninviting, blues and greys being the prevailing tints. Their "figure," as the marble-worker terms it, is often their distinguishing peculiarity; and this is imparted by imbedded fossils, such as corals, encrinites, and shells—hence such technical designations as "encrinal" and "entrochal," "shelly" and "mussel," "bird's-eye" and "dog's-tooth," Though cheaply produced, the carboniferous marbles, with the exception of the black, are not in great request, their duller tints and want of lustre compared with the more crystalline limestones, their softness and doubtful durability, militating much against them. Notwithstanding these drawbacks, available marbles are procured in England from Ashford, Matlock, Bakewell, and other places in Derbyshire; from Dent in Yorkshire; from Kendal in Westmoreland; from Anglesea, and from Poolwash, Port St Mary, and Scarlett, in the Isle of Man. Perhaps of these the best known and most esteemed are the black of Ashford, Matlock, and Dent; the brown or "rosewood" of Bakewell; the encrinal of Dent; and the grey-shelly and encrinal of Poolwash. In Scotland, the mountain limestone, being thin and poorly developed, affords no marbles; but about the beginning of the century a shelly or "mussel marble" was worked at Kingsbarns in Fife from the lower measures of the carboniferous system. In Ireland, on the other hand, where the mountain limestone is so extensively developed, there occur several excellent marbles — black in Kilkenny and Galway; grey, coralline, and encrinal in Cork, King's County, and Tipperary; reddish and variegated in Armagh; red and mottled in Limerick; and other veined and mottled sorts (reddish, cream-yellow, white, and brown) in several other counties. Indeed, according to Dr Kane's 'Industrial Resources of Ireland' and the Reports of the Geological Survey, the country is rich in available marbles, presenting greater beauty and variety than those from the carboniferous limestone of England.

From the *Secondary Systems* of England (for these are not developed to any appreciable extent in Ireland or Scotland) only one or two marbles are obtained, and those of very limited and local occurrence. The shelly laminated limestone of Whichwood Forest in Oxfordshire seems at one time to have been worked as a marble; hence its designation in the oolitic system as the "forest marble." The thin fresh-water limestones of the Purbeck and Wealden formations were also at one time more extensively raised than now, as may be seen in the internal decorations and monuments of many of the old ecclesiastical buildings of the south of England. These marbles (known as Sussex, Petworth, Purbeck, and Paludina marble) are of a dull-grey colour, almost entirely composed of the shells of paludina, to the whorls of which they owe their figure—rarely exceed a foot in thickness, and are now very seldom used, and only in the slender shaftings of pulpits and other church decorations.

Of *Alabaster*—which by some is said to derive its name from the Greek *alabastron*, an ink or perfume vase, and by others from *Alabastron*, a town in Egypt famous for the manufacture of such vases — there are two well-known varieties, — the gypseous and the calcareous. The former is a semi-transparent granular-crystalline variety of gypsum, or *sulphate of lime*, of various colours, but most esteemed when of a pure snow-white, and usually compact enough to stand the turning-lathe; the latter is a *carbonate of lime* (oriental alabaster), usually white or yellowish-white, and found as a stalactite or stalagmite. The gypseous alabaster is a mineral of common occurrence in secondary and tertiary formations (Cheshire, Worcester, Germany, Switzerland, the Tyrol, Montmartre near Paris, Volterra in Tuscany, &c.), and, being soft and readily turned by the lathe, is manufactured into vases, statuettes, cups, and other domestic ornaments. Very few of the British alabasters are sufficiently pure and transparent for the finer ornaments; but masses of pale-pink and lighter shades are found—as at Grantham, Newark-on-Trent, and other places—which are used as adjuncts in pulpits, tombs, screens, and similar sculptured works. The headquarters of sculpturing in alabaster are in Florence, Volterra, Pisa, and other towns of central Italy. This beautiful and semi-transparent variety of gypsum must not be confounded with the common massive sulphate of lime (plaster of Paris or stucco-rock), which is not used with us as an ornamental stone, though in ancient times the purer and more compact sorts were employed in Nineveh, Egypt, Tuscany, &c., for sculptured wall-slabs, sarcophagi, cinereal urns, and other kindred purposes. The modern uses of common gypsum are noticed under the head of mortars and cements (Chap. VI.), and also under that of mineral manures (Chap. III.), to which, for further information, the reader is referred.

Another beautiful variety of gypsum is the *fibrous*, known also as *satin-spar*, from its fine, glossy, and glistening lustre when cut and polished. It is found in thin veins and layers traversing beds of common gypsum, and is pretty largely manufactured into minor ornaments, such as cups, vases, necklaces, bracelets, and the like. Some very pure bands occur in the gypsum of Chellaston Hill, near Derby, where, as well as at Bakewell, Matlock, and Buxton, it is fashioned into the above-named articles.

Fluor-spar, which occurs in various colours—blue, purple, green, and yellow—is another calcareous mineral employed in the fabrication of minor ornaments. It is found both crystallised and crypto-crystalline in masses, not as an independent rock, but in veins and drusy cavities, in several formations, and in many countries. The variety most usually employed is "Blue John" or "Derbyshire spar;" and in several towns of that county it is fashioned, with rather pretty effect, into cups, vases, jars, obelisks, and various minor ornaments. Like alabaster, it is occasionally employed as an adjunct in sculptured work; but, like alabaster and satin-spar, it is easily tarnished and far from durable. The gypsums rarely exceed 2 in the scale of hardness, and the fluors are about 5; and all, especially the pure white alabasters, require to be kept under glass shades to preserve their colour, lustre, and brilliancy.

Rock-crystal, Agate, Jasper, &c.

The rock-crystals, agates, jaspers, and other silicious stones, though frequently employed in inlaid work and fashioned into minor ornaments, come more appropriately under the head of Precious Stones (Chap. XVI.), where ample details will be found respecting their geological nature and occurrence. They seldom appear in masses of any magnitude, but are found in crystals, geodes, stalagmitic incrustations, and concretionary nodules. From this circumstance they are only fitted for smaller articles—cups, boxes, vases, caskets, toilet-trays, knife-handles, and the like; or, when sliced and polished, for several varieties of inlaid work, for which their hardness, variegated colours, and fine polish, render them extremely suitable. Though some beautiful specimens of cairngorm, agate, and jasper are found in Britain, Banffshire, Kincardineshire, Forfarshire, and Ayrshire,* the finer and larger silicious stones are obtained from Brazil, Quito, Northern United States, Canada, Siberia, India and Ceylon, Egypt, Italy and Switzerland. Their hardness renders their preparation expensive; hence the comparative rarity and greater value of objects fashioned from rock-crystal, agate, carnelian, chalcedony, and jasper, compared with those from marble, alabaster, fluor, or other soft and less durable material.

Under this head we might also notice *jade*, *eclogite*, *garnet-rock*, and other silicio-magnesian and silicio-aluminous rocks, which are frequently employed in ornamentation; but these, perhaps, will better be deferred till we come to treat of the precious stones in another chapter. Occasionally the *septaria* or *bettle-stones* (argillo-ferruginous nodules) of the coal and other formations, when of large size and sufficient solidity, are sliced for ornamental table-tops, and produce a fair effect. So also are the large silicio-calcareous *fossil-trunks* of Cold-

* The yellow mottled jaspers of Ayrshire, and the red, banded, and mottled varieties found along the shores of Forfar, Kincardine, and Banff, make fair inlayings when well polished and assorted, though the nodules rarely exceed eight or ten inches in diameter.

stream, with their concentric rings, rays, and mottlings; and the rolled flint conglomerate or *puddingstone* of Herefordshire; and not unfrequently blocks of *cannel-coal*, like that of Wigan and Wemyss, are cut, polished, and fashioned into tables, seats, vases, and other articles of fancy furniture. Such substances as these, however, have a local rather than a general interest.

Here we may likewise advert to the *Malachites* or green carbonates of copper, which fall to be considered more fully as Precious Stones in a succeeding chapter (XVI.) When found in large and solid masses, as in the Urals, Northern States of America, and Burra Burra in Australia, they are successfully worked, by inlaying, into vases, tables, caskets, timepiece-stands, fireplaces, and other objects of internal decoration and ornament. The irregularly concentric layers of different shades of green occurring in the concretions produce, when skilfully sliced and united, a very rich effect, as was witnessed on a large scale in the Russian department of the Industrial Exhibition of 1851. From her possession of the Urals, Russia is still the headquarters of malachite manufactures.

Such is an outline—and it is merely a sketch in outline—of the stony substances employed in architecture and architectural ornaments. To have done justice to the subject from a builder's point of view would have required a volume; but enough, perhaps, has been given to show how intimate and important are the relations which subsist between geology and the art of the architect. Though deficient in some of the ornamental stones, we possess within these islands abundance of building materials, at once beautiful and durable, and fitted for the requirements of every structure—temple, tower, or palace; suburban villa, rural cottage, or country mansion; street-front, warehouse, or factory; fortress, sea-pier, or dock-wall. And if it be that many of our public buildings are a reproach to us, and not to be compared, either in elegance, dimensions, or durability, with those of ancient Greece and Rome, it is not that we are wanting in materials or in skill to construct them, but because we live in an age of makeshifts, which seeks nothing beyond the necessities of present requirements. Our granites, sandstones, limestones, and calcareous freestones give ample choice for every variety of structure, while our roofing-slates and flagstones furnish adjuncts unexcelled by those of any other country. It is true we are deficient in some of the finer stones for internal decoration; but even in this respect much more might be made of the granites, porphyries, serpentines, and marbles we possess, if sufficient time and labour—or what is the same thing, sufficient outlay—were spent on their preparation.

So far as Geology is concerned, it has as yet but slenderly discharged its duty to the builder and architect. It has busied itself, and properly enough, with mapping out formations, making sections, and defining palæontological zones; but it has done comparatively little in the way of pointing out the economic materials in these formations, or of indicating their relative values and appropriateness for special industrial purposes. It is one thing to determine the position, strike, dip, and thickness of a limestone, for example; but it is another thing, and one of paramount importance, to indicate its special mineral character, so that some reliable inference can be drawn as to its fitness for building, for mortar, for flux, for hydraulic cement, or for other industrial applications. Until geological surveys supply this desideratum in a regular and systematic manner, they are only partially fulfilling their function. It is surely as important to direct attention to rocks and minerals that may bear on the industrial purposes of civilised life, as it is to describe and dwell upon the remains of a life that has passed away. Both have their importance; but the one need not be exclusively studied to the detriment of the other. Above all, it is the duty of the economic geologist to note these things—ever acting under the impression that much as may have been utilised, there are still many substances in the earth's crust which can be turned to account in the increasing requirements of modern civilisation.

Works which may be consulted.

Hull's 'Treatise on the Building and Ornamental Stones of Great Britain and Foreign Countries;' Gwilt's 'Encyclopedia of Architecture, Historical, Theoretical, and Practical'—Papworth's Edition; Report of Commissioners on Building-Stones for the New Houses of Parliament, 1839 and 1845.

VI.

GEOLOGY AND ARCHITECTURE.

PART II.—MORTARS, CONCRETES, AND CEMENTS.

THE invention and preparation of mortars and cements form an essential department of architecture. It is not enough that we select stones of pleasing tints and durable texture; we must have some material capable of binding them together in one compact and substantial structure. Mere tooling and squaring may do for cyclopean walls; well-worked clay may give a certain amount of solidity to lowly erections; and bitumen, where obtainable, may give coherence to a pile: but what is specially needed is a substance easily applied, and which, in course of time, will undergo such a mineral change as to bind together with stony consistence. Such, in general, are the limes, mortars, and cements of the builder—*mineral pastes*, if we may so speak—which, when well prepared and tempered, become often tougher and harder than the blocks they are employed to cement. These preparations, though very numerous, and many of them patented, may be conveniently arranged for description into Mortars, common and hydraulic; Cements, water and oil; and Concretes or Artificial Stones. Their ingredients are all, of course, obtained from the mineral kingdom—the great secret of their efficiency depending on the treatment of the raw materials, and the proportions of their admixture.

I.—LIMES AND MORTARS.

The limestones which lie at the foundation of all these preparations are abundantly diffused through the stratified formations, there being scarcely a system which does not present one or more horizons of calcareous deposits. Indeed, every system from the oldest to the most recent has its limestones: the Metamorphic, its crystalline marbles; the Silurian, its coralline and shelly beds; the Old Red, its cornstones; the Devonian, its coralline and shelly marbles; the Carboniferous, its coralline, encrinal, shelly, and fresh-water beds; the Permian, its dolomites; the Trias, its muschelkalks and gypsums; the Jurassic, its oolites; the Wealden, its shelly bands; the Cretaceous, its chalks; the Tertiary, its gypseous and nummulitic strata; and the Post-Tertiary, its lacustrine marls. In Britain, the most of these are abundantly developed; and for its area few countries can boast of such a varied and available supply. As mixed rocks they vary, of course, in composition, some being almost pure carbonates, some dolomitic or magnesian, and others sulphates or gypsums; while these varieties may again be less or more silicious, argillaceous, ferruginous, or bituminous.

Whatever the varieties, or in whatever formations they may occur, the most of these limestones come to the surface in long stretches of outcrop, and are consequently quarried in open workings; hence the numerous openings, great and small, on the chalks, oolites, magnesian limestones, and mountain limestones of England, and the mountain limestones of Ireland. England and Ireland are magnificently supplied with limestones; Scotland but scantily so, and hence the more frequent recourse to mining of it in that country, as well as to its importation from the north of England and Antrim. In treating of these limestones in the present chapter, they may be conveniently considered under two main sections,—1st, those suitable for ordinary building and plastering purposes; and 2dly, those which are hydraulic, or harden and set under water.

Mortar Limestones.

The limestones best adapted for common or air-setting mortars, are the carbonates which are free from silica, alumina, and iron. These, as already stated, are very abundant; and, after being quarried and broken into moderate-sized pieces, are calcined, either in temporary or in continual kilns,—that is, in open kilns which are blown out till the calcined charge has been removed, or in draw-kilns, where the removal and charging proceed continuously. To avoid carriage, it is desirable to have the kilns as central as possible to the face of the quarries; and the longer the stone has been exposed to the air, the less fuel will it require to drive off the inherent moisture or quarry-water. The fuel employed in calcination is ordinary pit-coal (1 ton to 4 or 5 tons of limestone), and in remote districts peat and brushwood; but for some sorts of limestone, impure or shaly coals (while also much cheaper) are better adapted than the pure coals, as burning the stone more slowly and equally, as well as keeping it open and preventing slagging and sintering. More kiln-dust may be produced by the use of these slaty coals, but fewer cores and slags will be found among the lime.

When properly burnt—that is, when not slagged or covered with a silicious glaze by too sudden ignition—the limestone loses its carbonic acid, and is converted into caustic or quick lime (protoxide of calcium)—100 parts of the raw stone yielding 56 of burnt lime. This caustic lime is next slaked with water (1 volume of water to 3 of lime), when it falls down, with violent evolution of heat, into a greyish, bluish, or brownish powder, according to the original colour of the limestone. By the application of more water it is converted into a pulp or paste; and this pulp, thoroughly incorporated with three or four times its own volume of clean sharp sand, constitutes the common or air mortar of the builder. The proportion of sand should vary, of course, with the richness or "fatness" of the lime—2 or 2½ parts being sufficient for some poor limes, while some fat varieties will stand as much as 4 or 5 parts, and be improved by that proportion. The purer the carbonate the fatter the slaked lime.

A great deal has been said and written by builders about the properties and admixtures of sand and lime, which would be out of place to repeat in a work on Economic Geology; but this much may be observed as essential to a good hard-setting mortar: first, the more rapidly and completely it falls to powder on being slaked, the better the lime; and secondly, the sharper and cleaner, the better the sand. A lime that falls slowly and unequally is never satisfactory, either for mortar or for plaster,—preventing cohesion in the one case, and causing blistering in the other. A sand containing earthy impurities interferes with the chemical union of the lime and silica; sea or shore sand impregnated with salt is likely to cause deliquescence or efflorescence; and it is only clean pit or river sand that can produce the finest mortar. The old-fashioned plan of covering slaked lime with turf, and allowing it to lie a twelvemonth, was more effective in reducing it to powder than the modern hasty method of crushing and pugging; and the older mode of using large gritty sand and stony fragments was infinitely superior to the mixture of earthy rubbish which, under the misnomer of "sand," is now used to the extent of four, five, or even six parts of the admixture. In many modern buildings the mortar and stones never cohere; in taking down old baronial halls and ecclesiastical structures the blocks often give way before the mortar. So cohesive, indeed, are some of these olden walls, that explosives have to be employed in their demolition and severance. The ancient builder aimed at substantiality and permanence; the modern mason seems contented with mere face-up and temporary effect. We are aware that some modern architects prefer freshly-slaked lime—and, no doubt, when of prime quality and thoroughly incorporated with good sand, it may set well and solidify; but we have ample proofs of the efficacy of the olden system even when, as Pliny mentions, "the specifications provided that no slaked lime less than three years old should be used by the contractors." The olden plan of *grouting*—viz., rendering the mortar sufficiently liquid to penetrate every pore and crevice of the interior packing, and then pouring it in at intervals as the walls advanced—also greatly assisted to strengthen and solidify the edifices of our ancestors, and might well be revived at the present day.

Along with these air-setting mortars may be noticed the *ordinary plasters* used for smoothing and finishing interior walls and ceilings. These plasters are generally prepared from the finest limes and sands, extra care being taken in the sifting and incorporating of the materials. As several coatings are usually applied, the finer are laid on last, the ultimate surface often consisting of a "floating" of creamy consistence. The extra manipulation of plaster-lime, its admixture with tan-yard hair to give it greater consistence, and the like, are matters that belong to the artificer and not to the geologist.

Recently, there has been brought into notice a new composition under the name of *Selenitic Cement*, which is in fact an intimate admixture of hydraulic lime, gypsum, and silicious sand. Any hydraulic limestone of fair quality is calcined and mixed with five per cent or thereby of dehydrated gypsum; the two are thoroughly incorporated by being ground to a fine powder, and then worked up (by hand or machinery) with five or six parts of clean sharp sand into a cement. When laid on as plaster, it sets, dries, and hardens in the space of twenty-four hours, and can be finished off with a fine "floating" in course of the following day. It thus presents great advantages over the slow-drying ordinary plaster and its successive coatings, and can be applied to brick and stone walls without any admixture of hair. It can also be used, according to the inventors (Stuart & Co., Edinburgh), for building, in imitation of stone, and for concretes, at a price little more than that of common mortar.

Plaster of Paris, so largely employed in France both for external and internal work, but with us chiefly for interior mouldings and ornamentation, is derived from common gypsum or sulphate of lime. Gypsum occurs in several formations; but in Europe it is found mainly in the Trias and Tertiary,—its presence in beds of great purity in the Wealden being a recent discovery of the Sub-Wealden borings. In Britain, available supplies can be obtained from Chellaston in Derbyshire, Syston in Leicestershire, Tutbury in Staffordshire, Droitwich in Worcestershire, Cardiff in Glamorganshire, and at Kirkby Thore in Westmoreland, the beds being of various colours, texture, and purity. Being baked in ovens to discharge its water of crystallisation, it falls into a soft white powder (the plaster of Paris of commerce); and this powder, when worked into a paste with water, though plastic and pliable for a while, soon sets hard with considerable strength and solidity. This faculty of setting quickly renders it available for plaster-mouldings and other internal decorations in architecture, as well as in taking casts and making moulds for the sculptor, potter, stereotyper, and other workers in metals.

When mixed with glue instead of water, plaster of Paris becomes *stucco*, in which state it is also very widely and variously employed for architectural ornamentation. "If, instead of being used with water," says Professor Ansted, "plaster of Paris, in fine powder, is thrown into a vessel containing a saturated solution of alum, borax, and sulphate of potash, and after soaking for some time is taken and rebaked, once more powdered, and then moistened with a solution of alum, a hard plaster is obtained that takes a high polish. This plaster is called *Keene's Cement*, if made with alum; *Parian*, with borax; and *Martin's*, with pearl ash." Besides these there are many other cements prepared from plaster of Paris, with various admixtures and colouring matters, in order to produce imitations of marbles, serpentines, porphyries, and granites; and when skilfully manipulated, their effect is by no means unpleasing. Such cements are not suitable for hydraulic purposes, nor for exposure to the weather, but answer very well as stuccos for internal decoration.

From what has been here stated respecting mortars, plasters, and stuccos, it will be seen that ordinary limestones, gypsums, and silicious sands, are their main and essential ingredients. Mineral salts to harden, mineral pigments to colour, or pounded minerals to give them additional lustre and sparkle, are mere secondary adjuncts, though, like the prime ingredients, derived also from the rocky crust. The whole secret of their efficacy lies in their composition and technical treatment; and as this composition is entirely a matter of mineral admixture, the architect and manufacturer cannot fail to receive important assistance from a knowledge of the geological nature and occurrence of the raw materials.

Hydraulic Limestones.

Hydraulic or water-setting limestones do not occur so abundantly in Britain as the mortar or air-setting varieties; and yet there is a fair supply in the Lias, besides several beds in the Carboniferous system, which are ignorantly regarded as "bastard limestones," and consequently turned to no industrial account. Limes, when drawn from the kiln and slaked, are usually spoken of as rich or fat, poor, medium, hydraulic, and highly hydraulic. Thus, when falling rapidly to quicklime, they are *rich;* when falling only after 8 or 10 minutes, they are *poor;* when they require 15 or 20 minutes, they are *medium;* when requiring an hour or more, they are regarded as *hydraulic;* and when requiring, it may be, several days to break up, they are *highly* or *energetically hydraulic.* Such hydraulic limestones are found to contain proportions of silica, alumina, and iron; or, in other words, they are argillaceous limestones, impregnated less or more with oxide of iron. The Lias of England, which stretches across the country from Whitby on the north-east, to Lyme Regis in the south-west, is our main repository of water-setting limestones (blue lias); but available beds also occur among the carboniferous limestones of Flintshire (Henblas), Northumberland, Lanarkshire (Arden, Hurlett), East of Fife (Blebo, &c.), and in the Lothians, at Dunbar, Cousland, and other places. Such beds may be distinguished in the field by their tougher and earthier texture—never being so crystalline as mortar-limestones—by their not effervescing so violently under acids, and by their weathering more slowly into a deeper brown surface.

Some of the argillo-calcareous ironstones known as "curl" or "cone in cone," containing about 10 per cent of iron, are also used (Coalbrook Dale) in the manufacture of hydraulic cements; and the "septaria" or argillo-calcareous nodules from the Lower Lias and London Clay are well known to cement-makers for their strong and energetic hydraulicity.

When treated with muriatic acid, a limestone that leaves about 10 per cent of insoluble matter forms, according to M. Lipowitz ('Manufacture of Cements'), a tolerable hydraulic lime; but when leaving from 20 to 30 per cent, such a lime will not slake after burning without first being powdered, after which process it often produces the best hydraulic mortar. After calcination and slaking, such limestones as the blue lias require careful screening to remove unburnt cores, not more than 1½ of sand to 1 of lime, and are often improved in hydraulicity by the addition of a small percentage of pounded furnace-clinkers. But while this hydraulicity, or power of setting under water, is natural to some limestones, it may be imparted to all by the artificial addition, in proper proportions, of clay, iron oxide, and other kindred ingredients. Indeed, at the present time, the greater portion of our hydraulic cements are manufactured by admixture, and not by calcination of naturally formed limestones. Still, whether natural or artifical, all the ingredients are obtained from the mineral kingdom, and in this way come under the consideration of the economic geologist.

II.—CEMENTS AND MASTICS.

To enter at any length upon the manufacture of hydraulic cements, of which there are scores in the market, would be to encroach upon the domain of technology. Every manufacturer has less or more his own methods, and his own proportions of admixture, though lime, silica, alumina, and iron enter into the composition of the whole. Thus, lime with ferruginous clay, lime with calcareous river-mud, lime with clay and iron-filings, lime with clay and pounded furnace-ashes, lime with pounded bricks, lime with trass, an old volcanic earth of Germany (Andernach), and lime with pozzuolana, a recent volcanic tufa of Italy (Pozzuoli), are common admixtures. One essential point in all is the proper proportions and thorough incorporation of the materials, their due calcination, and the grinding of them when fresh from the kiln. Some manufacturers pack into casks as the powder falls from the millstones, under the impression that it is injured by exposure to air and moisture; others expose it for several days to cool or sweat; but all agree that continued exposure to air and moisture is detrimental to its ultimate hydraulicity.

However numerous these hydraulic cements, lime, clay, and oxide of iron are their main ingredients—the lime ranging from 50 to 80 per cent, the clay from 25 to 40, and the iron oxide from 3 to 14—the efficiency of the admixture depending upon the proportions and treatment of the materials. Thus, to mention two or three by way of illustration :—

Portland Cement (from its resemblance in colour to Portland stone), so largely manufactured on the Thames and Tyne, consists of about 80 parts rich lime or chalk, and 20 river-mud or clay, incorporated in the wet way, dried, calcined, and reduced to powder. *Roman Cement*, so energetically hydraulic, is manufactured from pozzuolana, a volcanic ash, and lime, or from lime and trass, a tertiary earth, also of volcanic origin. In such instances the iron oxide occurs in the clay, river-mud, and volcanic earth, and according to its amount, gives a fainter or richer tint to the prepared cement. The calcareous muds or clays of tidal rivers, from their being impregnated with sodium salts, are thought by some to increase the hydraulicity; hence the value attached to cements manufactured from such river-muds as those of the Medway, Thames, and Humber; other manufacturers question the utility of any saline admixture, and insist that an equally efficient cement is manufactured from the lime and clay alone. Another, and the last of these hydraulic mortars we shall mention, is *Parker's*, made from the argillo-calcareous nodules or *septaria* of the London clay, found at the Isle of Sheppy, Harwich, and other parts along the south-eastern coast of England. These nodules, as well as the septaria from the Lower Lias, are in fact naturally hydraulic limestones, and when well selected and prepared, furnish a quick-setting, strong, and durable cement.

According to the researches of Dr Karl Newmann, the original amount of clay and iron oxide is nearly the same in all good cements, though the percentage of these respective ingredients may differ considerably in different makes. From this he concludes that the clay and oxide of iron supplement each other within certain limits; but that the latter in one proportion or another is indispensable to the manufacture of a strong-setting and reliable material.

What are termed *Mastics* or *Mastic Cements* are preparations of a very similar nature, the medium for mixing the pounded brick-dust, limestone, and sand being oil instead of water. They are used chiefly as external coatings or finishings, and never in bulk as mortars. As in the case of the water-cements, there are several varieties, the chief uses of both being to exclude damp, to produce smooth surfaces on inferior materials in imitation of building-stone, or to furnish stuccos and plasters, for internal decoration, in resemblance of marbles and other ornamental stones. By whatever name they are known, or to whatever uses they are applied, mineralogically speaking, they are very much alike in composition—lime, silica, and alumina in various proportions, and in different states of calcination, together with litharge, or red protoxide of lead, being the prime or essential ingredients. These thoroughly dried, pulverised, and brought to the consistence of plaster by linseed-oil, constitute the majority of the mastics of commerce.

The *bituminous* or *asphaltic cements* constitute another class of mineral preparations which are gradually coming into wider use for footpaths, courtyards, and street pavements, as well as for foundations, covering for arches, and other purposes where damp is sought to be excluded. They are either prepared from natural asphalts, such as those of the Dead Sea, Albania, Trinidad, Texas, Seyssel, and Val de Travers, or from artificial, obtained from the distillation of coal-tars, or the coal-tars themselves. The bitumens are pretty widely distributed,—some, like Trinidad, being natural distillations from beds of lignite; others, like Seyssel, exudations of a similar nature but of older date; and others, again, like Val de Travers, intimately incorporated with calcareous matter, and likely to be partly of animal and partly of vegetable origin. These asphalts, whether natural or artificial, are melted in movable caldrons, and laid on hot, without admixture if for building purposes; but if for roads and pavements, incorporated with stony debris, and spread over a bed of concrete or mortar, well rubbed in with the trowel to exclude air-bubbles and produce an even surface, and finished with a powdering of fine silicious sand. When carefully bedded and manipulated, some varieties, like the Val de Travers, produce a clean, dry, and durable surface, but far too smooth for streets, even where they are perfectly level. Cabmen, cartmen, and carriage-drivers all condemn them, and avoid them where they possibly can.

Besides these hydraulic, mastic, and bituminous cements, there are dozens of others employed in the arts and manufactures, each handicraft having its own special preparation; hence such terms as plumbers' cement, lapidaries' cement, opticians' cement, iron cement, and diamond cement. Few of these are of strictly mineral composition—oils, gums, resins, glues, and the like, being among the ingredients employed, and thus they belong to chemistry and technology rather than to applied geology. Those requiring information of this kind may consult with advantage such works as Ure's 'Dictionary of the Arts and Manufactures,' Wagner's 'Technology,' and Cooley's 'Cyclopedia of Practical Receipts.'

III.—CONCRETES AND ARTIFICIAL STONES.

Since the preparation of hard-setting cements has become so general, concretes, concrete buildings, and concrete blocks, are also coming more and more into use. No doubt, the art of concrete-work is still in its infancy; but considering what has been accomplished in the way of foundations, breakwaters, sea-walls, and the like, there can be no question as to its fitness for structures where mass and solidity are the main objects in view. One great drawback to its use is the expense of cement as compared with that of ordinary mortar, and this has been considerably augmented during the last two or three years by the high price of coals—every stage of cement-manufacture involving a consumption of fuel.

Concrete—that is, an intimate admixture of gravel, pebbles, or broken stones with Portland or other cement—is now extensively used for foundations, footpaths, kitchen-floors, and courtyards; and when well prepared and carefully laid down, is at once clean, dry, and durable. It can be spread in one continuous mass, or prepared in bricks or squares and laid down like flagstones, to which, in some situations, it is preferable alike for its light colour and its imperviousness to moisture. It also makes a capital foundation for causeway-stones, and some varieties have been tried as surface-material for streets and roadways. These, like Mitchell's experiment on George IV. Bridge, Edinburgh, wear well, are clean, free from dust in summer and mud in winter, and diminish greatly the traction; but George IV. Bridge is level, and their smoothness (affording no firm footing to horses) renders them unsuitable where there is any perceptible gradient. There is no reason, however, considering their cleanliness, dryness, and durability, why cements and concretes, either wholly or as adjuncts, should not be more extensively employed in the construction of streets and roadways.

Concrete walls, and especially for cottages and houses not exceeding two storeys high, are coming more and more into use. In some instances the concrete is packed within boarding faces forming one solid mass of wall; in others it is shaped into bricks or blocks, and built in the usual manner. In general the matrix is composed of pebbly and shingly fragments; but stones reduced to suitable sizes by crushing-machines make a more solid fabric ; and in the neighbourhood of Newcastle and other iron-making districts the slag from the blast-furnaces is occasionally crushed and employed with satisfactory results. Considering the mounds of furnace-slag that lie unutilised and a disfigurement to every ironstone district, and considering, also, the efficacy of our stone-crushers, much greater use might be made of this waste product, not only in concrete building, but as metal for by-roads, for railway ballast, and for foundations for macadamising.

From its impervious nature, concrete is also well adapted for culverts, sewers, and other underground structures, becoming hard and durable where common mortar-buildings would, in the course of a few years, disintegrate and decay. In some instances *concrete piping* has been attempted ; and as it can be formed in one continuous tube without break or union, is capable of resisting great pressure, and is, moreover, a clean and sweet material, it seems well adapted for the leading of water from a distance.

Concrete blocks or artificial stones have, of recent years, come extensively into use for the erection of piers, breakwaters, sea-walls, foundations for docks and bridges, and similar heavy structures. They can be fashioned of any shape and prepared of any size, there being no limit to their bulk but that of machinery sufficiently powerful to lift and transport them. In some respects blocks of granite or silicious gritstone would be preferable, but these are not obtainable in many places, save at enormous expense, while concrete blocks can be prepared in any situation and at a comparatively moderate cost. The cement can be transported to any part of the world, and there are few situations where gravel, shingle, or broken stones cannot be obtained for the matrix. Such blocks have been employed with satisfactory results in piers and sea-walls in many parts of the world, and especially in Holland, France, and in our own country, as at Dublin, Dover, Plymouth, and Tynemouth. Even lighthouses, like that recently erected by Sir John Coode on La Corbière, a dangerous rock lying off the south-west extremity of Jersey, have been constructed of concrete made of local rubble and Portland cement.

In some instances gravel and shingle are used for the matrix, in some a mixture of gravel and stone-chippings, and in others angular fragments of hard rocks prepared by stone-crushing machinery. At Tynemouth, chippings and rubbly blocks of the subcrystalline magnesian limestone of the neighbourhood are employed with success; and indeed, from fractured blocks we have witnessed, we should say that angular fragments make a tougher and more compact concrete than water-worn pebbles—the cohesion between the cement and the rough surfaces of the former being more thorough than between the smooth and impervious surfaces of the latter. The cement employed is generally some variety of Portland, tempered with shore or river sand—river or pit sand setting more quickly, it is said, than sea-sand; but in either case the setting is sufficiently hard in the course of a few days to allow the blocks to be removed from their frames and deposited, if need be, in their structural destination.

The manufacture of such blocks near the spot where they are to be used is an immense boon to the civil engineer, rendering practicable the erection of sea-works in situations to which the carriage of natural stones of equal weight and dimensions would have been financially impossible. With the exception of copings and finishings, the most gigantic sea-works can be wholly constructed of these artificial blocks, and this with a cheapness and celerity not otherwise attainable. Even at Aberdeen, with granite everywhere beneath and around it, the concrete block has superseded the natural stone; and the same result is likely to follow wherever bulk and weight of block is a main desideratum. In some quiet waters the concrete may be more cheaply shot down against wooden facings, and allowed to harden in mass; but this is seldom attainable, and rarely or never meets with the approval of our most experienced engineers. And yet the foundations of the breakwater pier at Douglas, Isle of Man, have been successfully formed by putting down concrete in mass, within timber frames fixed upon the rock in the bottom of the bay. Notwithstanding the success of several experiments of this kind, the setting and ripening of the material in the open air, though slower and more expensive, is by far the more certain method; and it is astonishing how soon blocks of ten, twenty, or even thirty tons in weight, can be removed from the frames in which they are compounded.

Apoenite, or *Ransome's Patent Stone*, is another product which has recently received much attention, alike from its beauty and strength, and the ingenuity displayed in its preparation. It is now coming into use both as a building and decorative material—chimney-pieces, balustrades, vases, fountains, tombstones, paving-slabs, ashlars, and general architecture. It is likewise manufactured into grindstones, cutting-discs, scythe-stones, and similar articles. It is essentially a sandstone, grit-stone, or emery-stone, according to the nature of the substance employed. The composition, characteristics, and process of manufacture will be best given, however, in the words of the patentee: "It is in reality a sandstone, whose silicious particles are bound together by a cement of silicate of lime, a mineral substance well known to be of the most indestructible nature. Its composition, mechanically and chemically, is precisely that of the best building-stones that are known—such as Craigleith and some varieties of Yorkshire stones—which are able successfully to resist the most trying air and climate on the seaside and in smoky towns. Its fracture shows perfect homogeneity, so that it is admirably adapted for carving with chisels. It can be moulded into the most delicate forms while in a soft state, and can be surface-dressed or finished when hard if desired. Its plasticity during the first process of manufacture enables it to be used with very great economy in all elaborate mouldings and repeated ornamentations; and the perfect truth of its lines and arrises, in even very long scantlings, renders it appropriate for all kinds of string-courses, cornices, and copings.

"The process of manufacture is based upon one of the most beautiful of chemical reactions. Flints are first dissolved by means of caustic alkali under high pressure, so as to form silicate of soda, a kind of water-glass. This viscous and tenacious substance is then rapidly mixed with a proportion of very fine and sharp silicious sand in a pug-mill, so as to form a soft plastic mass, which can be moulded into any shape that is desired. The soft stone is next immersed in a bath of chloride of calcium solution, which is made to penetrate every pore by means of hydraulic or atmospheric pressure. Whenever this solution comes into contact with the silicate of soda, the two liquids are mutually and instantaneously decomposed, the silica taking possession of the calcium, and forming the hard solid silicate of lime, and the soda uniting with the chlorine to form chloride of sodium in a small quantity. Instead, then, of the particles of sand being covered with a thin film of the liquid silicate of soda, they are covered and united together with a film of solid silicate of lime, one of the most indestructible substances known. The small quantity of soluble chloride of sodium—one of the results of decomposition—is then washed out of the stone by a douche of clean water or by hydraulic pressure, its complete removal being insured by chemical tests. The stone is then dried, and is fit for use."

More recently, Mr Ransome has succeeded without the use of chloride of calcium, and the subsequent washings which its use involves. This he has been enabled to do by the discovery of a silicious mineral near Farnham in Surrey, which is readily soluble in a solution of caustic soda, at a moderately low temperature.* By this latter process he combines a portion of the Farnham stone, or soluble silica, with a solution of silicate of soda or potash, lime, sand, alumina, or other convenient and suitable materials, which, when intimately mixed, are moulded into the required form as heretofore, and allowed to harden gradually, as silicate of lime is formed by the combination of the ingredients present. The mass then becomes thoroughly indurated and converted into a compact stone, capable of sustaining extraordinary pressure, and increasing in hardness with age.

The chemical actions which effect these results appear to be as under. When the materials are mixed together, the silicate of soda is decomposed; the silicic acid, being liberated, combines with the lime, and forms a compound silicate of lime and alumina; while a portion of soda, in a caustic condition, is set free. This caustic soda immediately seizes upon the soluble silica (from Farnham), and thus forms a fresh supply of silicate of soda, which is in its turn decomposed by a further quantity of lime, and so on. The result is, that the caustic soda is gradually fixed, and none remains to be removed by washing or other process.

This apoenite can be manufactured in blocks of any size or form, of any texture—according to the fineness of the sand—and of any colour. By using emery instead of sand, discs of unrivalled cutting-power are manufactured by the same process, and at rates which render them cheap compared with natural grindstones. The factory is at East Greenwich, and is said to turn out a large amount of finished material, both useful and ornamental. The products we have seen are certainly of great beauty, the moulded ornamentations being as sharp and clean as if they had come from the chisel of an artist.

Another artificial stone at one time in use, but now discontinued, was that of the Messrs Chance of Birmingham, produced by running into moulds the fused basalt or "Rowley Rag" of the Rowley Hills, near Dudley in South Staffordshire. Any basalt, greenstone, or clinkstone, containing a sufficiency

* This mineral is the "*Malm Rock*" of Surrey—a pale-cream-coloured, fine-grained, soft sandstone found in the Upper Greensand, and containing 40.30 per cent of soluble silica, 41.23 insoluble silica, with 15 alumina, &c.

of felspar to render it fusible, will answer the purpose; and the melted material may be moulded into building-blocks, pavement-tiles, or architectural ornaments. The natural rock is melted in a reverberatory furnace, and when in a sufficiently fluid state is poured into moulds of sand incased in iron boxes, these moulds having been previously raised to a red heat in ovens suitable for the purpose. The object to be attained in heating the moulds previous to their reception of the fluid material is to retard the rate of cooling, as the result of slow cooling is a hard, strong, and stony substance, closely resembling the natural stone; while the result of rapid cooling is a dark brittle glass or obsidian. Though the manufacture of fused blocks at Birmingham has been discontinued for several years, the fact is worth recording, as showing not only the capability of the materials employed, but as throwing additional light on the nature and characteristics of the fire-formed rocks. Some specimens before us exhibit great strength and hardness, as well as sharpness and delicacy in ornamentation.

Other artificial stones have been attempted with bases of Portland and various hard-setting cements; but, having all a pasty and plaster-like surface, and wanting the texture and sharpness of finish which belong to the real material, they have never met with anything like commercial success. They are, in fact, to the sandstones what painted imitations are to the veritable granites.

The limes, mortars, cements, and concretes adverted to in the preceding pages are substances of vast importance to the architect and civil engineer. The finest building is of little value without a cohesive and durable mortar; and until we are wealthy and luxurious enough to panel our interior walls with marbles, serpentines, and other ornamental stones, plasters, stuccos, and cements, of beautiful texture and colour, will continue to be in requirement. In a country like ours, where heavy structures—bridges, docks, piers, sea-walls, breakwaters, lighthouses, and the like—are essential to commercial and maritime enterprise, concretes and hydraulic mortars of great strength and energy become more and more a necessity. Like the stones with which they are associated or to which they are applied, their ingredients are all obtained from the mineral kingdom—limestones, gypsums, silicious sands, clays, calcareous muds, oxides of iron, and the like, being the principal substances employed in their preparation. The treatment of these materials and the proportions of their admixture belong to technology; but their mineral nature, mode of occurrence, and available abundance, are matters which come within the scope of Economic Geology, and on which the geologist should be prepared to render his ready and willing assistance. The more minutely and skilfully detailed our geological surveys, the more will the arts and manufactures reap advantage from their perusal. The notification of the *mineral character* of a limestone is surely as important as regards its use as the description of its *organic remains* is in respect to its history. "*Ex inutili utilitas*" should ever be the motto of the practical geologist.

Works which may be consulted.

Gwilt's 'Encyclopedia of Architecture, Historical, Theoretical, and Practical'—Papworth's Edition; Wagner's 'Handbook of Chemical Technology'—Crooke's Edition; Reid's 'Practical Treatise on the Manufacture of Portland Cement;' Ure's 'Dictionary of Arts and Manufactures'—Hunt's Edition; Burnell's 'Rudimentary Treatise on Limes, Cements, Mortars, Concretes'—Weale's Series; Cooley's 'Cyclopedia of Practical Receipts;' Knapp's 'Chemical Technology.'

VII.

GEOLOGY AND CIVIL ENGINEERING.

As practised in Britain, civil engineering is a wide and somewhat irregular profession. On one side we find it merging into that of the architect and builder; on another, into that of the mechanical engineer; and on a third, into that of the mining engineer and excavator. In making roads, constructing railways, canals, docks, and harbours, deepening and widening navigable rivers, bringing in supplies of water to towns, and the like, the engineer has at once to excavate and tunnel, to build and embank, and to adopt many mechanical contrivances. In this way it becomes impossible to define with precision the field of his operations, though approximately it may be considered under the following heads—namely, Road-making, Railway Construction, Construction of Canals, Construction of Docks and Harbours, River Improvement, and Water-Supply of Towns. All of these, for their successful accomplishment, require a great deal of scientific skill and intelligent forethought; and all the more, that works—bridges, lighthouses, breakwaters, and tunnels—are now constructed on a scale of magnitude which, half a century ago, would have been deemed impossible. In the present chapter we restrict ourselves to their geological bearings, adverting to the rock-materials with which the engineer has usually to deal, the lithological difficulties he may have to encounter, and the utilisation of the products that may be revealed in the course of his tunnellings and excavations. It is obvious he cannot proceed a step in any of these operations without coming in contact with mineral substances and geological phenomena, and his work, in most instances, will be executed with greater facility, certainty, and success, the more intimately he is acquainted with the nature of the substances which lie in his way, and which he may be called upon to remove, to utilise, or to protect.

I.—ROAD-MAKING.

In the construction of ordinary highways, the civil engineer, geologically speaking, has before him three things of prime importance—choice of route, nature of gradients as requiring excavation and embankment, and suitability of material for bottoming and macadamising. In Britain, where many of the roads are of ancient date, and originally intended for pack-horses and not for carriages, they are generally "up hill and down dale" over dry tracts, and very unsuitable for modern requirements. When such roads have to be improved in their gradients, it is usually by a series of "cuttings" and "embankments;" and some skill is required not only in excavating the rock-material, but in seeing how far the whole or any portion of it can be utilised, either in the construction of the road and the embankments, or as an article of sale in the neighbourhood—be it sandstone, limestone, greenstone, or granite. But where a new route of easy gradients has to be chosen, the engineer, from his geological knowledge of the district, may often show great skill in avoiding expensive cuttings; in making cuttings, which, though expensive, may more than repay themselves by the utilisation of the excavated rocks; and in keeping clear of peaty and marshy hollows for his embankments, which are never stable till the soft boggy sludge is squeezed out, as it were, by three or four times the amount of carried material that would have been required on a firmer bottom. In choosing a new route, shortness, easy gradients, and the requirements of the district are, no doubt, prime considerations; but in some instances it may be worth while to deviate from the selected track in order to come in closer proximity to quarries, clay-pits, and coal-fields—the increased traffic arising from which may become a source of income for the permanent maintenance of the highway. Highways are the arteries of a country's commerce, and a good system of roads suitable for all requirements, present and prospective, is one of the most essential elements of national prosperity and development.

Road-Cuttings.

Having selected a route, the engineer has next to inquire what excavations, what embankments, and what bridges will be necessary to render the road of easy traction as to gradients. In the matter of excavation, it requires some skill, according as the cutting may be through tough boulder-clay—through an admixture of drift sands and clays, which are apt to slip by the percolation of water—through greenstones and basalts, which, though expensive to remove, may be utilised as road-material—or through sandstones and limestones, which may be applied to the erection of bridges and retaining walls. Some acquaintance with the structure of rocks will also be of use to the engineer, in as far as these may be jointed or full of "backs and cutters," like some limestones; columnar or subcolumnar, like basalts and greenstones; tabular, as granites; or in alternate hard and soft strata, as sandstones and shales. Every formation has its own lie and structure, and excavating in accordance with these is always the cheapest and most expeditious method. Where the material is of uniform character, little care is needed either as regards retaining walls or slope of excavation; but where the material is of unequal durability, as alternations of sands and clays, of sandstones, shales, and clays, the weathering of the softer beds is sure to ensue, and should be protected by facing-up immediately after excavation. From want of this precaution—and especially in railway cuttings—much after-expense has often been entailed, and that not till obstructions and accidents have happened through slips and falls—such contingencies of themselves costing ten times the amount of any walling-up that might have been at first adopted. Some care is also necessary when excavations pass through strata at high angles, so as to prevent slips from the rising side; and when water-bearing beds occur, free egress must be made for the outflow, which otherwise would, in process of time, bring down the strongest retaining wall. Where cuttings pass through rocks suitable for building or for roads, a free face should be kept, if possible, for future quarrying—the situation being so available, not only for the working, but for the removal of the quarried material. A quarry in close proximity to a road or railway is always more valuable (other things being equal) than one situated at a distance, the expense of cartage, loading, and unloading adding considerably to the price of the raised materials.

We have spoken of road-routes as they usually occur in the British Islands; but in mountainous countries a great deal of extra skill and precaution has to be exercised in winding and zigzagging, in scarping or tunnelling precipices, and in providing ample and substantial water-courses and culverts—the heavy rainfalls of these heights, and their steep inclinations, subjecting the highways to torrential forces altogether unknown in lowland regions.

Embankments and Bridges.

In the matter of embankments, little geological knowledge is required beyond ascertaining the nature of the foundations on which they are to rest, the facility with which the banking material may be obtained, and the angle of repose at which such material is likely to remain. Embankments across marshes and peat-mosses are frequently of difficult execution, requiring not only a vast amount of material, but sometimes subsiding for months and years till the soft underlying bed be thoroughly squeezed out or compressed. Besides calculating so that excavation and embankment shall balance each other as nearly as possible, the side-slopes or angle of repose should be studied, blocks and hard rocky debris resting at inclinations at which sand, clay, and soft earthy substances could not possibly remain. Embankments are artificial rock-formations, and the more uniformly the material can be "tipped" and assorted, the more compact, impervious to water, and less liable to "sits" and slips, will the mound become.

As with embankments so with bridges; their foundations require similar attention, and though their construction be chiefly a matter of masonry, yet some geological acquaintance with the situation and the nature of the materials to be employed cannot fail to be of advantage. Whatever the nature of the bridge, whether stone or girder, everything depends upon a secure foundation; and this, again, depends on the geological nature of the material to be built upon, be it solid rock, tough firm clay, or soft silts requiring concrete, piles, or other device to secure stability. The alluvia in river-valleys are often of great depth and of treacherous nature; and it is frequently more judicious to make a deviation to secure a rocky foundation than to persevere in a straight line over such superficial accumulations.

Road-Materials.

Touching road-materials, a great variety of substances are used in Britain, but the best of them will not make a smooth and durable highway unless they be laid on a good bottoming of rubble-stones, and these again on a well-drained surface. On a wet soil the road-metal sinks, becomes uneven, and wears irregularly, while in winter the moisture freezes and expands, and when thaw comes the surface is broken up and the consistency of the metal destroyed. In all cases the scarf-skin of agricultural soil should be removed, and, if not needed for levelling up, can be readily disposed of on the adjacent farms for composts and admixture.

In some districts where granites abound they are broken for road-metal, but if large-grained and highly felspathic they are easily crushed and reduced to clay. In others porphyries and felstones are employed, and many of these, from their hardness and toughness, stand well, though somewhat expensive in the breaking. In others, again, where traps prevail, greenstones and basalts are largely used, and when broken to proper size make by far the smoothest and most durable roadway. Of course there is great variety among these greenstones, but unless among the softer and more felspathic sorts, they are not only durable but cheaply procured. In some districts the harder pebbles (chiefly of quartz, porphyry, granite, &c.) from river-channels and the sea-shore, are employed, in others the harder and more silicious limestones and sandstones; in some the flints from the chalk, and in others near blast-furnaces the slag is broken by crushing-machines, and makes a fair though not very durable metal. In all cases of macadamising, thorough drainage and a good bottoming of rough rubble is indispensable; and when the metal is laid on, a heavy rolling down and consolidation with some sharp gravelly binding is equally necessary. Basalts, greenstones, felstones, and felstone-porphyries, make the smoothest and most durable metal, and now, since the introduction of efficient crushing-machines, should be sought after by the road-maker, even though requiring to be brought from considerable distances.

In the construction of street thoroughfares subjected to heavy and continuous traffic, and where macadamising would be all mud in winter and dust in summer, recourse must be had to causewaying either in rubble or in regular courses. The former may do for by-streets where the traffic is light; but for the great public thoroughfares of a commercial town nothing will serve save coursed blocks of granite, porphyry, or greenstone. Wooden blocks, concrete, and asphalt are at their best but indifferent substitutes, and wholly unsuited where the gradients are steep or even considerable. Granites like those of Aberdeen, Argyle, Dalbeattie, Creetown, Wicklow, the Channel Islands, &c., are largely used in all the thoroughfares of our principal cities, and make clean and durable streets; but some kinds of porphyry, like that from the Moorfoot Hills, and employed in Edinburgh, are harder and tougher, though from their tendency to wear smooth they require to be laid down in narrower courses. Greenstones are also largely used, and when properly coursed and bedded are almost as durable as granite. Good samples of greenstone-causewaying may be seen in Edinburgh (Ratho, Dalmahoy Crags, and Corstorphine Hills), in Glasgow (Croy and Kilpatrick Hills), in Newcastle (Christon Bank and Wall), in Leeds (Richmond), and, indeed, in most of our large towns where the rock can be obtained at a cheaper rate than granite. In some instances quartzites and hard silicious sandstones are employed: they stand well, but, from their tendency to wear smooth and slippery, require to be laid, like the Moorfoot porphyry, in narrow courses.

For the footpaths of our towns flagstones are in great request, and some of them held in high estimation. Those from the lower old red sandstone of Caithness are extremely hard and durable, and can be obtained of great size, and from one to nine or ten inches in thickness. Being very hard and close in texture they are apt to become too smooth; some contain nodules of iron sulphide which resist wear, and render the surface irregular and somewhat dangerous, and many of the harder and thinner sorts are apt to crack unless carefully bedded, as all of them require to be. They are, however, impervious, or nearly so, to water, and make a clean and easily kept footpath. About 10,000 tons are annually exported from the county, at a value of between £4000 and £5000. Those procured from the lower old red of Forfarshire and Perthshire enjoy also a high reputation; but from their softer, more laminated, and absorbent nature, are better fitted for inside than for outside pavements. Local supplies of flagstones are also obtained from the coal-formation in several counties (Fife, Edinburgh, and Lanark); but those from the millstone grit and Gannister beds of Yorkshire and Derbyshire are perhaps the best and most durable, and capable of being raised of great size and of any thickness. Supplies are also obtained from the new red sandstone of Dumfriesshire and Cumberland, which are of fine even grain, and though rather soft, wear well and equably. Flags of fair quality are also raised from the middle oolite, and from the Wealden in Sussex, but they want the largeness, smoothness of surface, and compactness of texture which characterise those from the old and new red sandstones. What is wanted in a good flagstone is variety in thickness and size, a straight and even surface or bedding, and a non-absorbent and compact texture—laminated varieties being apt to split or peel off under the influence of frost and moisture. In some country towns the footpaths are neatly laid with pebble-stones; and in the suburbs of Edinburgh the larger chips obtained in dressing the causeway-blocks are closely set on edge and beaten down to a smooth surface, thereby making a firm and durable material under the name of "Hornising," after a burgh surveyor of the name of Horne.

For kerb-stones, granite, greenstone, and some of the harder sandstones and limestones have long been used. The granites of Aberdeen, Kirkcudbright, Wigtown, and Wicklow, make excellent material; some of the hornblendic greenstones, as those of Queensferry on the Forth, and of Corstorphine and Ratho near Edinburgh, are equally suitable, and more cheaply tooled; while many of the harder limestones (Derby, York, Westmoreland, and Devon) square well, and are extensively employed in their respective areas. In some towns sandstones on edge are employed; but these, unless hard and uniform in texture, are apt to split up under the weather, and wear irregularly. A straight, durable, and well-set kerbstone is indispensable to a good street, not only in retaining the flagstones and maintaining the gutters, but in imparting an appearance of finish and stability to all the lines and turnings.

II.—RAILWAY CONSTRUCTION.

Many of the remarks on road-making are equally applicable to railway construction. The choice of route and study of gradients are determined in a great measure by the requirements of the district, though an engineer well acquainted with its geology and mineral resources may, with a little modification, not unfrequently add materially to the success of the undertaking. Where excavations and tunnellings are imperative, he will not only know better how to conduct these operations, but will be enabled to see how far the material excavated, or any portion of it, may be utilised on other portions of the line, either in walling, embanking, or building of bridges. From a study of the geological structure of the country passed through, he will also make provision for the development of its mineral resources, be these coals, metallic veins, building-stones, limestones, clays, or sands. The main line may not pass through all of these repositories, and yet it may be so planned that sidings and branch-lines can be conveniently attached in the event of subsequent requirement.

Cuttings and Tunnels.

In the matter of excavating, for example, whether in open cuttings or in tunnels, no proper estimate can be made of the expense without a knowledge of the nature of the rocks to be passed through. Homogeneous chalk rocks, limestones, alternations of sandstones and shales, masses of hard pebbly conglomerate, of gneiss, of greenstone, or granite, are things altogether different, not only requiring different amounts of labour, but different appliances for their successful excavation. A cutting through tough diluvial clay thickly studded with blocks and boulders may be as expensive as a cutting through

Cutting through Boulder-Clay, Linlithgowshire.

sandstone; and while the latter may be utilised as a building-stone, the former is only fit for the formation of an embankment. And even after excavation, one set of rocks—granites, greenstones, limestones, and compact sandstones—will resist the action of all weathers, and stand firm and secure, while another set—soft sandstones, shales, clays, and sands—will begin to disintegrate in a few months, and require facings-up or the further excavation of long flat slopes to render them secure. In passing along many of our railways where the cuttings are through glacial drifts—alternations of sands and clays, or nests of sand and gravel in boulder-clays—we frequently see the vast expense that has been incurred by subsequent reductions of the slope—the original having been left too steep and undrained; hence the frequent source of slips causing obstruction to the traffic and occasional accidents.

Again, in tunnelling, the structure of the rock, the inclination if stratified, the occurrence of faults, of water-bearing beds, and the like, are matters of prime importance, and no engineer can either estimate aright or construct aright who is incapable of appreciating such peculiarities in the rock-formations through which he has to pass. How different the tunnelling through the schists and granites of Mont Cenis, the chalk downs of Surrey, the oolites of Bath, the sandstones and shales of Glasgow, and the old red sandstone of Moncrieff Hill near Perth! Thick-bedded and homogeneous rocks may be cut through and left without any protection, while soft sandstones, clays, and shivery shales require archings of brick or stone at every step: horizontal or moderately inclined strata may be left without artificial protection, while highly inclined beds require underarching to secure stability. A tunnel through hard homogeneous rock, and expensive to excavate, may be cheaper in the long-run than one through soft and unequal strata, requiring to be cased with masonry; and a gain may often be made by a few hundred yards' deviation rather than force the way directly through rocks of difficult and dangerous removal. Where a survey has been made, a geological map may often afford the necessary information; where no map exists, the engineer must prospect the route for himself, or render his views securer by pittings and preliminary borings.

As tunnels are generally carried through hills and elevated grounds, there is always a greater risk of meeting in with dykes and necks, fissures and faults, than when cutting through lowland tracks. Unless on hills of denudation, where the rocks are of a hard and homogeneous character, tunnelled heights are for the most part of a broken nature; hence the necessity for extra precaution on the part of the engineer and contractor. A little outlay in feeling one's way at the outset is often trebly repaid by the prevention of unnecessary labour and expenditure in the long-run. And here it may be observed that tunnelling is now a very different operation from what it was twenty or five-and-twenty years ago. Then matters depended very much upon manual labour; whereas at the present day, mechanically impelled rock-drills, excavating machines, and new explosives, render the work at once cheaper, more expeditious, and satisfactory.

Embankments and Bridges.

The precautions necessary in the case of roadway embankments and bridges are much more imperative in the case of railways, where the operations are usually more numerous and extensive. Foundations, angles of slope, durability of material, and the like, are things of prime importance. A little extra outlay on the original construction is a trifle compared with subsequent alterations and repairs, requiring relifting of rails, and obstruction to, or even a temporary cessation of traffic. Again, in the utilisation of materials raised from cuttings and tunnels, the engineer should be careful that these are of a durable and lasting nature. Many of the sandstones and limestones that were excavated and applied to the building of retaining-walls, conduits, and fences, during the railway excitement of the forties and fifties, have since crumbled down to sand and mud, and have had to be replaced at treble expense by more durable material. We need not invidiously point to any particular line; the observer has only to use his own eyes, and especially in carboniferous districts, to be convinced of the truth of this statement. It is in vain to leave the choice of such materials to contractors: their main objects are expedition and profit, and not stability. The engineer should select the material and stipulate for its employment—seeing, through his inspectors, that the stipulations are honestly fulfilled.

Water-Supply.

As permanent water-supplies are required not only for locomotives but for station purposes, this requirement should be kept steadily in view by the railway engineer. This has been an expensive item on many lines, and one which, in several instances, might have been avoided by judicious foresight. In general, a fair supply may be obtained by sinking wells, by drawing it from adjacent streams and lakes, or by leading springs which have been struck in the cuttings and tunnels. Wherever it can be led along the line from higher grounds, even though somewhat distant, this mode should be adopted, the natural gravitation dispensing with all the expensive adjuncts of boring, sinking, and pumping. Pumping involves a continuous outlay; the purchase of water-right is often a heavy item; but the intercepting of a spring costs nothing beyond the original outlay of piping to conduct it.

III.—CONSTRUCTION OF CANALS.

In a flat country consisting chiefly of superficial accumulations and well supplied with water, there are few things in engineering so simple, geologically speaking, as the construction of a canal. But in a country of irregular surface, consisting of various rock-formations, indifferently supplied with water, or having the water already utilised, the task is one often requiring all the skill and ingenuity of the engineer. In the latter case it is not the shortest route that is sought, but winding and bending, to secure a uniform level at least expense; and even then it is not only cuttings and tunnels, aqueducts and embankments, that require his skill, but the question of a continuous water-supply to make good the waste through evaporation, leakage, loss at locks, and similar contingencies. All this requires some acquaintance with geology, and especially with the structure of the district through which the canal has to be conducted.

Cuttings and Tunnellings.

And, first, of cuttings and tunnellings. These may be through retentive clays and rocks requiring little attention as to puddling, or they may be through alternations of impervious and porous beds, the latter demanding much care to render them secure and water-tight. It may also happen that the excavation is carried along the sloping sides of a hill, where many feeders issue from the higher side, and yet more water might be carried off through the porous beds on the lower side were these not thoroughly stopped by puddling. In cuttings through fissured sandstones, jointed limestones, columnar basalts and greenstones, no matter how hard, a great deal of water is always lost by percolation, and thus the structure of the rocks becomes a matter of prime consideration to the engineer. Besides the water-bearing qualities of the rocks through which cuttings and tunnels are carried, the fitness of these rocks for facings, aqueducts, conduits, and other purposes connected with the undertaking, should be well considered, and much may be saved by lifting them in a methodical and quarryman-like manner. Indeed, all that was needed for successful road and railway excavations is equally necessary for canal cuttings—with this additional precaution, that the sides and bottom must be rendered impervious to water.

Embankments and Aqueducts.

In the matter of embankments and aqueducts, the same or even greater attention is required as in those for highways and railroads, both as regards solidity of foundations, durability of material, and angle of repose. The sinking of a foundation, or the slipping of an embankment on a roadway, affects only the spot at which the accident occurs; whereas on a canal it is at once a loss of water along the entire length, and destruction to the fields and property that lie in the way of the rush and overflow. While we write (July 1874), the newspapers record an outburst on a new deviation of the Monkland Canal, near Glasgow, the damage occasioned by which is estimated at £70,000 or £80,000, and this the result of a few hours' torrential violence. In puddling, great care should be bestowed on the toughness and plasticity of the material. Some clays are too earthy, others too sandy, and all require thorough tempering and ramming; for the least crevice through which a film of water can pass will in time get enlarged, not only causing leakage, but softening embankments and giving rise to slips and burstings. Alluvial or brick clays make sound enough puddling; but by far the strongest and toughest are those obtained from the boulder-clays, even should they require to be freed from the larger pebbles with which they are generally intermingled.

Water-Supply.

One of the most indispensable requisites in a good canal is an equable and continuous supply of water. There is always considerable waste through evaporation, leakages, locks, and other causes; and to compensate for this, a system of ponds or reservoirs at some higher level is indispensable. A knowledge of the rainfall and hydrographical features of the surrounding country is therefore necessary on the part of the engineer, and not unfrequently he has to fix his reservoirs at considerable distances from the line of canal. As the area of the compensation pond is rendered permanently useless for land purposes, cheap and waste tracts are usually sought after; and how far these ponds are fed by springs, by rain, and by runnels, and how far their sites are retentive of water, are paramount questions with the engineer. Rock-basins and reservoirs obtained by damming up hill-valleys (often at great expense) are not unfrequently found to be next to useless, the fissured structure of the former, and the old moraine character of the latter (gravels and rock-debris of the glacial period), being incapable of holding water, and allowing it to percolate as through a filter.

Canals are, no doubt, less sought after than they were during the early part of the century—the rapidity of the railway having superseded them for the conveyance of passengers and the greater bulk of mercantile traffic. Still, they afford cheap means of conveyance for heavy goods and bulky raw materials, and will ever be of use in carrying ship burthens from sea to sea without the expensive and deteriorating processes of unloading and reloading of cargo.

IV.—CONSTRUCTION OF DOCKS AND HARBOURS.

To a maritime country like Britain, there are few things so essential as commodious docks and harbours, protective breakwaters, and guiding lighthouses. The construction of these is, no doubt, to a great extent a matter of masonry; and yet in excavating, deepening, choice of material, and the like, there is much to be gained by some acquaintance with geology. In excavating docks and deepening harbours, an approximate estimate of expense can only be made through a knowledge of the material to be removed, whether sands and gravels, sandstones and shales, chalks or the harder limestones. A series of trial borings is usually made over the area to be excavated, and where these are taken at sufficiently frequent intervals, there can be little error as to the nature of the material to be removed. Some serious mistakes, however, have been made by not making these trials sufficiently numerous, and by not allowing some margin for change of material. Most of the stratified beds vary considerably, even in short spaces, in hardness and thickness; and among shore sands and gravels, some of them at considerable depth are found to be cemented into a "littoral concrete" of such hardness as to require blasting, instead of being removable by ordinary pick and shovel. A curious instance of a littoral concrete of this nature occurred in the excavation of the Albert Dock at Leith, causing considerable extra trouble and expense to the contractor; and not unfrequently floods of water from superficial sands cause much obstruction and delay. A lithological survey of the locality is always advisable; and he who knows most of the character of the formation on which it is situated, will be the most likely to avoid mistakes alike in pecuniary estimate and mode of operation.

Materials for Piers and Sea-Walls.

As to choice of material for piers, breakwaters, sea-walls, and lighthouses, much will depend on the geology of the district; that is, whether limestones, sandstones, greenstones, granites, or other sufficiently hard rocks, lie conveniently adjacent. While Aberdeen can avail herself of her granites, Dundee has recourse to the tough grey sandstones of the Old Red, Leith and Glasgow to the quartzose grits of the neighbourhood, the Clyde to greenstones, Plymouth to limestones, Liverpool to granites brought from a distance, and the Tyne and other ports to artificial blocks of concrete. In all cases, hardness, toughness, weight, and durability are the main requisites, considering the bumping and friction in docks and harbours, and the impact of waves and breakers on exposed sea-walls and breakwaters, where the blocks lose so much of their weight from being submerged in water. We have witnessed the effect of storms on sea-works at Wick, Lossiemouth, Anstruther, Granton, and Tynemouth, and their power of displacement and transport would seem incredible, were it not remembered that stones of ordinary specific gravity lose about a third of their weight in water, while the effective impact of waves occasionally amounts to 6000 lb. per square foot.* Whatever may form the main mass of masonry, there is no rock so suitable for facings, copings, and gateways, as a good medium-grained granite, which possesses at once hardness, toughness, and weight. Next in order are the silicious grits and sandstones, which, though not so hard nor heavy as the granites, still stand well, and can be raised in blocks of almost any size, like those used at the Dundee docks, the Albert Dock at Leith, and on the storm-walls of the Tynemouth piers. The limestones (compact dolomites and marbles) come next; but the greenstones and basalts are generally too brittle, and from their columnar or subcolumnar structure can rarely be raised in blocks of sufficient magnitude.

In all the works adverted to under the present section—piers, breakwaters, sea-walls, and lighthouses—security of foundation, great strength, and durability of material, are the main essentials; and the engineer well acquainted with the geology of the district and with the characters of the various rocks will be in a much better position to do justice to the undertaking than one who, however mechanically ingenious, is incapable of forming an estimate of these particulars. Nor is it rocks alone upon which he will be called to decide, but

* Mr Stevenson, in his experiments at Skerryvore Lighthouse (Western Hebrides), found the average force of the waves for the five summer months to be 611 lb. per square foot, and for the six winter months 2086 lb. He mentions that the Bell Rock Lighthouse, 112 feet high, is sometimes buried in spray from ground-swells when there is no wind; and that on the 20th November 1827, the spray was thrown to a height of 117 feet—equivalent to a pressure of 6000 lb., or nearly 3 tons, per square foot.

mortars, hydraulic cements, concretes, puddlings, and the like, all of which require some knowledge of rocks and minerals, and the methods of rendering them economically advantageous.

As building-stones, mortars, cements, and concretes have already been described in Chapters IV. and V., the information need not be repeated under the present section.

V.—RIVER IMPROVEMENT.

Under this head three things are usually required of the civil engineer: first, the deepening and straightening of tidal rivers, so as to improve their navigable qualities; second, the straightening and embanking of inland streams, so as to prevent their flooding the adjacent lands; and thirdly, the reclaiming and embankment of lowlands or levels from the sea.

Tidal Rivers.

In the first case, when the bed of the river consists of silts, sands, gravels, and other drift material, there is, generally speaking, little difficulty in deepening by dredging. Not unfrequently, however, these superficial matters overlie and mask dykes and ledges of rock which cross the channel, and then these require subaqueous blasting and more expensive methods of removal. Occasionally such obstructions are removed (as in the case of the Blosson Rock in the fairway of San Francisco harbour) by the ingenious plan of excavating a chamber in their mass, and then, by exploding the chamber, the crust of the rock is broken up and disappears in the excavation below. A careful survey of the country will generally reveal where such obstructions are likely to occur, and the methods of removal may be suggested by a study of their structure above ground. In the case of the Wear, for instance, which in its lower course flows over the magnesian limestone, harder dolomitic ledges may prove the obstruction to dredging; in the Tyne it may be harder strata of carboniferous sandstone; in the Tees triassic sandstones; and in the Clyde it may be a dyke or dykes of columnar greenstone which reticulate the rocks in that area. Again, in straightening the channel, as the windings of rivers occur most abundantly in alluvial tracts, there is usually little difficulty—the chief care being the retaining or embanking walls—their slope and security of foundation. When one looks at the improvements which have been recently effected on such rivers as the Clyde and

Tyne, and the vast facilities which these improvements have imparted to the commerce of their respective districts, and compares these with other tidal rivers now neglected, or with themselves as they were some thirty years ago, he cannot help regarding the subject of River Improvement as one of the most important that can engage the skill and ingenuity of the civil engineer.

Nor is it merely the dredging and widening of tidal rivers which should engage the attention of the engineer; there is much of a geological nature in reference to the direction and diversion of currents, the formation of shoals and banks, and the scouring away of bars, that should receive his consideration. The laws of running water are well understood; and if he can make the current prevent what the dredging-machine has to correct, he gains a mastery and a triumph. The scouring and carrying power of a current depends partly on its velocity and partly on its volume. Where in a navigable river it would not be desirable to increase the velocity, the volume might be increased, or at all events not diminished, by lessening the area of reception—a thing too frequently done by reclaiming and embanking. Wherever a large amount of tidal water can be admitted, the more effective will be the outflow in the removal of shoals and bars; and it is a most important point gained when the river can be made to maintain its own fairway without having recourse to the expensive operation of dredging.

Inland Streams.

The object in straightening and embanking inland streams is chiefly agricultural. In most of our lower valleys the streams wind much and flow sluggishly, and after heavy rains and sudden meltings of snow are apt to overflow their banks, to the injury of the adjoining crops. These valleys, besides, consist for the most part of rich alluvial soils, and hence their greater fertility and value. To prevent inundations is therefore the object of the engineer, and this he can effect partly by widening and straightening, so as to increase the flow, and partly by embanking, so as to restrain the swollen stream from spreading over the adjacent fields. Though apparently a simple operation, it requires some skill, not only in planning the line of embankments, but in constructing the embankments themselves so as to resist the current of the stream in its swollen and impetuous condition. The main points to be observed are—no undue contraction of the channel, but ample margin for heavy rainfalls and sudden snow-meltings; a gradually sloping embankment; and avoidance of sudden windings that might tend to divert the impetus of the current to undermine the opposite bank of the stream.

Sea-Embankments.

Closely related to the straightening and embanking of inland streams stands the recovery and embankment of land from the sea. Along most of our fens, levels, carses, and tidal estuaries, there is always a considerable margin of silt and low-lying land, little if at all above ordinary sea-level, and consequently liable to be inundated during flood-tides and storms. To reclaim and protect such lands, and further to increase their growth and elevation, are the objects of sea-embankments. Occasionally wood-and-wattle jetties are thrown out to intercept the silt; at other times a strong embankment, with sluices which intercept the tide, but permit the exit of water when the tide is back, is constructed; and not unfrequently the sluices are so arranged as to admit the muddy tide, with its burden of silt, and then, by closing them, to impound the water till the sediment has fallen and enriched the land. *Warping*, as this latter process is called, to elevate and enrich the surface—*embanking*, to protect it—and *intercepting*, to increase its area,—are the main objects in view; and all require considerable ingenuity and skill on the part of the engineer. A knowledge of the tidal set or current is indispensable to successful warping and embanking; and care should always be taken so to arrange the strength and slope of the walls as to render them proof against occasional abnormal tides and inundations. Geologically, nature is ever forming such fens, levels, and carses; and the object of the engineer is to facilitate nature's operations by inexpensive and efficient methods, so that a larger margin of rich and cultivable soil may be added to our agricultural area. Such recent additions may be witnessed along the Humber, the Lincolnshire Fens, the Lewes' Levels, Morecambe Bay, and the Friths of the Solway, the Clyde, Tay, Forth, and Eden, the means for securing them often exhibiting great ingenuity both in design and execution.

VI.—WATER AND WATER-SUPPLY.

Since the increase of our towns, and the larger consumption of water for domestic, sanitary, and manufacturing purposes, there are few questions that have more severely taxed the skill and ingenuity of the civil engineer than that of a pure, abundant, and continuous supply of water. It is not merely that he has to construct reservoirs, make tunnels, lay pipes, and erect aqueducts, but that, in conjunction with the chemist, he has to decide on the quality of the water, and determine the available quantity that can be obtained. It is clear that in discharge of these duties he must know something of the average rainfall over the area of catchment, the nature of the rocks from which the springs issue, the kind of formations through which he has to tunnel and on which he has to construct his reservoirs. The rainfall on the western side of our island, for instance, is more than double that on the eastern; the fall in a hilly district, with concave faces to the prevailing winds, greater than that on level tracts; and cold, morassy heights and woodlands are more favourable to rain than bare rocky regions. The major portion that falls on clayey and retentive soils is carried off at once by runnels and streams; while on porous and absorbent soils the major portion finds its way downwards to subterranean reservoirs and springs. The springs issuing from stratified formations always hold in solution more or less of the mineral ingredients of that formation; and pure water, by passing through a tunnel, may get contaminated by the mineral and metallic solutions which ooze from the beds of that excavation. A reservoir in tough boulder-clay will not lose a gallon of water save through evaporation; while another in glacial gravels or in fissured trap-rocks, may allow a very large proportion to escape by percolation. Even should he draw his supply from existing lakes, there are many subsidiary considerations requiring some knowledge of geology; and should he obtain it from artesian wells, he cannot proceed one step in safety without an intimate acquaintance with the conformation and water-bearing nature of the strata through which he has to bore. Seeing, then, that this branch of engineering is eminently geological, let us take up the several sources of water-supply *seriatim* and in detail.

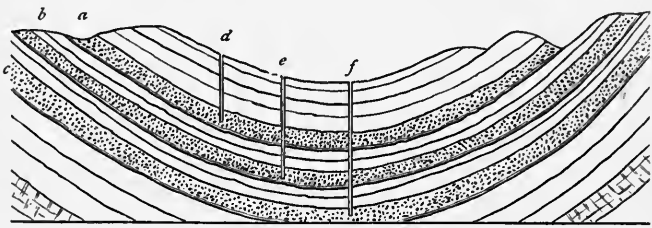
Springs and Surface-Wells.

One of the most obvious and available sources of water is that of springs; but as the amount discharged in any contiguous area is comparatively small, even when stored in reservoirs, it is clear that a purely spring supply is fitted only for towns having a limited population. Where adopted, the engineer has to decide on the qualities of the respective springs, excluding from his reservoir those that are too hard or impure, or diluting them, where possible, by admixture with surface-water. The nature of the rocks from which they issue, be it superficial drifts, limestones, sandstones and shales, slates, or granites, will assist him in determining their quality; and their variability or uniformity of temperature, indicating their surface or deep-seated nature, will lead him to pretty certain inferences as to the continuity of their discharge.

With regard to surface-wells, or even a series of them, their supply is too uncertain for large communities. In winter, or during years of unusual rainfall, the supply may be abundant, and yet during summer, or a series of dry summers, it may be scanty in the extreme. In fact, their certainty depends on the amount of rain; and their quality is always more variable than that of deep-seated springs and artesian wells—their mineral ingredients being diluted during the wet season, and concentrated during the dry. Besides, they are more liable to be contaminated with organic impurities — the permeation of decaying vegetable and animal matters from the surface being more readily effected in their case than in wells of a deeper description. Another circumstance to be noted is, that when first tapped, the supply from surface-wells is always more abundant than in subsequent years. Before being tapped the water-bearing sands and gravels are surcharged, as it were, with water, and when this has been reduced, the supply becomes immediately dependent on the amount of rainfall. From not noting this fact, some grave miscalculations have been made, and unnecessary expense incurred in erecting pumping-gear and laying pipes, greatly beyond the regular measure of supply. After a few years' pumping the supply becomes commensurate with the rainfall, and no sinking of additional wells or driving of connecting drifts will add a single gallon to the amount. The supply may be increased by deeper boring, but in that case the engineer runs the risk of deteriorating what he has already obtained, few water-bearing beds yielding precisely the same quality of water.

Artesian Wells.

For larger and more permanent supplies than surface-wells can afford, recourse must be had to deep borings, which are generally known by the name of *artesian wells*—from Artois in France, where the system has been largely followed, though borings of the same kind have been made in the East from a very early date. Before fixing on a site, the geological conformation and structure of the district should be sufficiently ascertained. In basin-shaped formations, or where the strata dip to a common centre or axis, it is clear the greatest lodgment of water will be towards that centre or axis. If the formation consists of alternations of impervious and water-bearing strata, the outcrops of the water-bearing beds will be the recipients of the rainfall, and when they get surcharged, the water will rise in any boring made in the basin to the same level as these outcrops. If the centre of the basin be higher than the recipient outcrops, the water will not rise to the surface; if lower, it will rise above the surface to the height of the outcrop, or nearly so, according to the saturation of the water-bearing beds. Thus, in the accompanying diagram of a geological trough or basin, if *a*, *b*, *c* be three water-bearing strata, the water in any boring (*d*) made to *a* will rise to the surface or slightly above it; in the boring *e* the water of *b* will rise considerably above the surface; while in the boring *f* the water contained in *c* will ascend with greater force and



Artesian Wells in Synclinal Strata.

to a greater height above the surface. Should it happen that the water contained in *a*, *b*, and *c* are of different qualities, that of *a* can be tubed off so as not to mingle with the supply from *b*, or both *a* and *b* may be tubed off so as not to impregnate that issuing from *c*. Artesian borings are now largely resorted to in favourable districts for water-supply—Paris, London, Southampton, Chicago, and other large towns having not only numerous borings, but borings of considerable magnitude, and often of great depth. As these wells are generally sunk through the younger sedimentary strata—Tertiary, Cretaceous, Oolite, and New Red Sandstone—there is no great difficulty to be encountered; and with proper mechanical appliances, bores from one to twenty inches can be readily executed—the machines of Mather and Platt, and of Kind and Chaudron, being capable of accomplishing diameters of much larger dimensions.

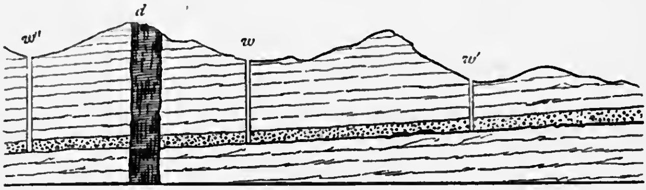
The following, from Hughes's 'Water-works,' may be taken as examples of the deep wells and borings in the London basin, many of them involving a large outlay not only in sinking and boring, but in building and tubing, besides the expense incurred in the erection and maintenance of pumping-gear and steam-engines :—

	Depth.	Average yield per day.
Meux Brewery, . .	343 feet	42,430 gallons.
Anchor Brewery, .	350 ,,	172,000 ,,
Trafalgar Square, .	384 ,,	580,000 ,,
Kensington Gardens, .	401 ,,	108,000 ,,
Whitbread's Brewery, .	408 ,,	144,720 ,,
Sion Brewery, . .	408 ,,	72,000 ,,
Cold Bath Fields, .	152 ,,	216,000 ,,
Greenwich Hospital, .	305 ,,	172,000 ,,
Woolwich, . . .	580 ,,	1,400,000 ,,

Deep Well-Borings.

Deep borings, differing from artesian wells proper, are frequently made in all formations in search of water. Where-ever the formation—be it Old Red, Carboniferous, or Jurassic—consists of alternating sandstones, limestones, shales, clays, and sand, it will have its impervious and water-bearing beds, and by boring to the latter, water in available volume may generally be obtained. The Cretaceous system has its chalks and greensands, the Oolite its freestones and ragstones, the Trias its waterstones, the Permian its porous limestones and sands, and the Carboniferous and Old Red their sandstones—all more or less water-bearing, and capable, when sunk to or bored to, of yielding available supplies. Indeed it is by pumping from such wells that many of the towns in the southern and midland counties of England derive the whole or the greater portion of their supply—London, Coventry, Birkenhead, Liverpool, Sunderland, South Shields, &c., being well-known instances. Depth for depth, strata at moderate angles of inclination yield a much larger supply than those at high angles, there being a more extensive sheet to the rise ; fields containing intercalated ash and trap beds are always precarious ; and areas unbroken by faults and fissures are more reliable than those interrupted by dykes and dislocations. Indeed, dykes and faults often act as natural dams, impounding all the water in the strata to the *rise*, and preventing its further percolation to the *dip*. The results of such obstruction are frequent and abundant springs along their lines, while the rest of the country is comparatively springless.

It is clear that if water-bearing beds dipping to the south be interrupted by an east and west dyke, the further percolation of the water southward will be arrested ; and thus an abundant supply may be obtained by boring on the north side of the dyke, while for a considerable distance to the south not a drop could be procured. In the accompanying sketch, the well *w* will yield the largest amount of water; *w′* a less supply, as being nearer the outcrop of the water-bearing bed; while *w″* on the other side of the dyke *d*, though the deepest, may not yield a single gallon. Notable illustrations of this fact have come under the author's notice in the well-borings on



Dyke and Deep Well-Borings.

either side of the Castle Mills Dyke, Edinburgh, and the Law Dyke of Dundee—in the latter case, £300 or £400 securing a copious supply from the north-east side, while an outlay of £1500 failed to obtain a single gallon from the south-west.

Before incurring the expense of deep borings, a careful survey of the field is always desirable, and that spot should be selected where the beds are least disturbed, and where the boring can command the largest sheet of water-bearing strata. The farther from the outcrop of any stratum, the larger and more continuous the supply from that stratum, provided no fissures nor interruptions intervene; and the nearer to any eruptive mass or dislocated area, the less the supply and the greater the uncertainty of procuring it. It should also be remembered that, as far as experience goes, the deeper the boring or sinking the drier the beds—the rainfall circulating chiefly within a film of the rocky crust not much exceeding 2000 or 2500 feet.

Lakes and Reservoirs.

In most of our larger towns the demand for water (40 or 50 gallons daily per head of the population) is by far too extensive to be supplied by springs or wells; and then the engineer must have recourse to lakes, streams, or reservoirs, situated in high gathering-grounds, and often at considerable distances. Pumping and filtering from some adjacent river is occasionally resorted to; but this method is expensive, and the water is usually inferior (though soft)—all our rivers getting more and more contaminated by the industrial processes of the country, and the increasing cultivation and manuring of the lands through which they flow. The great effort of modern engineering is to secure some hilly, pastoral region, where there is an abundant rainfall, little or no cultivation, one or more natural lakes,* or in the absence of these, some depressions and glens where the streams can be impounded by embankments, and a series of reservoirs established. This is now the ordinary mode of supply; most of our large towns—Glasgow, Edinburgh, Dundee, Newcastle, Leeds, Sheffield, Manchester, Liverpool, &c.—receiving their water in this manner from distant high grounds, and through an expensive system of reservoirs, compensation ponds, tunnellings, aqueducts, pipings, and filterings.

Such water-works require the highest skill on the part of the engineer—a knowledge of the nature, extent, and rainfall of the gathering-grounds, the quality of the water as affected by the formations of the district, the choice of sites for reservoirs, the strength of embankments, the character of the rocks to be tunnelled through—and, generally, a great deal of information, involving more or less some acquaintance with geology. There are wide differences between a gathering-ground of granite, one of schistose rocks, another of limestone, a fourth of sandstones, ironstones, and shales, and a fifth embracing tracts of peaty and boggy moorland. It may be necessary to lead in some springs and to exclude others; the rocks of one glen may be retentive and eminently suited for a reservoir, while those of another might be so porous as to cause perpetual leakage; the rocks and springs of one tunnelled aqueduct might be innocuous to the supply, while those of another might contaminate it with saline and metallic impurities. These and many similar circumstances will all come under the consideration and discrimination of the water-engineer; and it is just owing to the range of his knowledge and his aptitude to decide, why the works of one man turn out a success, and those of another a failure and perpetual source of expense and dissatisfaction.

The best training for a young engineer in matters of this kind is to make himself thoroughly acquainted with some of the best and most extensive water-works, such as those of New York (the Croton), of Glasgow (Loch Katrine), of Dundee (Lintrathen), of Manchester, Liverpool, and London; and from these as models to shape his own plans for any particular city

* An ingenious method of obtaining the purest supply from natural lakes is to drive a tunnel and shaft in the deeper portions where the water is still and limpid, while along shore it may be turbid and otherwise polluted. This plan, we understand, has been adopted in taking the water from Lake Michigan for the supply of Chicago.

he may be called upon to supply, always bearing in mind the specialities and requirements of that locality. As our towns increase, the more urgent becomes the necessity of a pure and copious supply of water; and it is no improbable event that London with her teeming millions may yet be compelled to draw from the lakes of Wales or of Westmoreland.

Nor is it alone means for providing our towns with a copious and wholesome supply of water which the engineer has to devise; he must also provide for the speedy removal of what has become waste and contaminated. An efficient system of sewerage is a necessary accompaniment to a satisfactory water-supply. As rapid a fall as he can command, the construction of durable and easily flushed sewers, the prevention or removal of noxious gases, the utilisation of the sewage, and its removal to the greatest possible distance, are subjects which all require much ingenuity and experience to cope with. Nor is some acquaintance with geology altogether unneeded. The soils, subsoils, and rocks through which the sewers have to be cut and carried, the materials for their construction, and the nature of the area intended for irrigation, are matters involving lithological as well as mechanical skill for their successful accomplishment.

From what has been said in the preceding paragraphs, it will be seen that the duties of the civil engineer are at once of a very onerous and miscellaneous nature. Whether he restricts himself to road-making, to railway construction, construction of canals, docks, and harbours, the improvement of navigable rivers, or to the water-supply of towns, he has much to observe, to calculate, and to provide for; and in all his provisions, circumstances involving some knowledge of geology are sure to occur and to demand his consideration. Indeed, he cannot proceed one step in safety without some acquaintance with rocks and rock-formations; and to rely on the knowledge of others is to place him at great disadvantage in any competitive scheme with others possessed of that information. A man cannot be thoroughly master of every branch of physical science; but so long as civil engineering covers such a wide field of operations, he who has the widest range of knowledge will always be the most comprehensive in his designs, and the most successful in their fulfilment. And these designs, be it remembered, are year after year assuming more varied and more gigantic dimensions. Tunnels are now carried through mountains, bridges across rivers and estuaries, piers and breakwaters into the sea, and lighthouses erected on reefs which our forefathers would have deemed impossible. They estimated their undertakings by thousands, our modern engineers not unfrequently calculate by millions.

Works which may be consulted.

Law and Burnell's 'Civil Engineering;' Rankine's 'Civil Engineering;' Burgoyne's 'Road Making and Maintenance;' Stephenson's 'Railway Construction;' Stevenson's 'Construction and Illumination of Lighthouses;' Hughes's 'Water-works for the Supply of Cities and Towns;' Burnell's 'Well-sinking, Boring, and Pump-work;' Prestwich's 'Water-bearing Strata of London.'

VIII.

GEOLOGY AND MINE ENGINEERING.

There is no profession that comes so intimately in contact with geological phenomena, or stands so much in need of a knowledge of geological truths, as that of the miner and mining engineer. It is true that mining was practised, and in many instances successfully, long before geology had shaped itself into a science; but even the most successful practice was local and limited, and wanted that grasp of general truths which could enable it to pronounce on other districts, and deal successfully with their altered phenomena. The discrimination of the same formation in distant localities, the varying nature of sedimentary deposits, the relations of the eruptive to the stratified rocks, and the laws regulating the direction, character, and effects of faults, dykes, and veins—these, and many kindred problems, can be solved only by a pretty extensive acquaintance with the facts and principles of geology. It is true that much in successful mining depends on mechanical appliances—sinking, lifting, hauling, pumping, and ventilation; but the most skilful appliances will not compensate for ignorance of the nature, position, variations, and interruptions of the substances the miner may be in quest of. It is in this way that a knowledge of geology becomes of use to the miner and mining engineer, whether working among stratified deposits like those of the coal-formation, or in metalliferous veins like those which traverse the older formations. The mining of a bed of coal and the mining of a vein of lead-ore are two very different and dissimilar operations, and the geological information applicable to the one may have slender bearing on the other. For this reason it will be necessary to treat Geology and Mine Engineering under several sub-heads, and the following are perhaps the most natural and intelligible—viz., Quarrying or Open-Working, Mining in Stratified Deposits, Mining in Veins, and Stream or Placer Working.

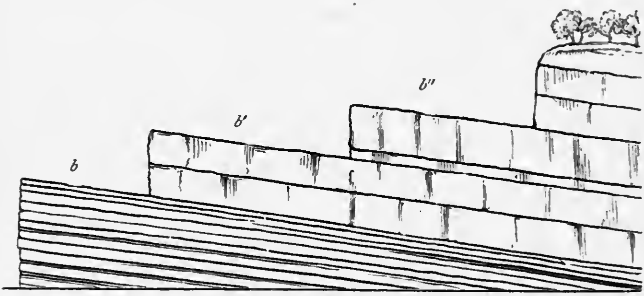
I.—QUARRYING OR OPEN-WORKING.

Quarrying or open-working is carried on both in stratified and unstratified rocks; but the methods followed in the one case differ considerably from those adopted in the other. The stratified rocks usually raised in Britain are sandstones, flagstones, slates, limestones, and marbles; the unstratified, basalts, greenstones, porphyries, and granites. We pass over sand-pits, clay-pits, and other superficial diggings, which, though often of considerable extent and local value, can scarcely be regarded as quarrying in the ordinary sense of the term. The stratified rocks are sought along their outcrops, or where they come to the surface; the unstratified are taken from hillsides, cliffs, and not unfrequently from intersecting dykes. But whether stratified or unstratified, there are some general considerations which should receive attention, both from proprietor and lessee, before the ground is broken. What, for example, is the nature of the rock? judging from its position and structure, can it be raised at moderate cost? is it durable and suitable for the purposes in view? is the demand likely to be permanent or merely temporary? is there sufficient supply to warrant preliminary outlay on opening, on suitable machinery, and on roads? are there facilities of transport by road, rail, canal, or harbour? These and similar questions should receive the attention of the quarryman if he means his undertaking to be more than a mere temporary, local, and limited burrowing.

Stratified Quarries.

In quarrying stratified rocks, the usual plan is to follow the dip till the superincumbent matter—"callow," "cover," "overburden," or "tirr" of the quarryman—becomes too thick and expensive to be removed, and then to follow the strike or outcrop; and thus long lines of old workings are to be witnessed on many of our hillsides. As removal of the cover or overburden is often an expensive part of the process, the quarryman should always endeavour, if possible, to utilise the material. When it consists of clay, it may be converted into bricks, as is sometimes done in the neighbourhood of Newcastle; when of shingly or rubbly debris, it may be used as road-metal; and in all cases it may be employed in filling up the old workings, and restoring again the agricultural surface. In some cases where the bed is valuable, and the "tirr" too thick to be profitably removed, mining is adopted, and then the usual plan is followed of removing a portion, and leaving other portions as pillars to support the roof. Such gallery-workings are most frequent in limestones, being unsuitable for freestones and flagstones, which have to be raised in large blocks for the builder. Burdiehouse and Starleyburn near Edinburgh, and Box near Bristol, may be pointed to as successful instances of stone-mining, the consideration of which belongs to the following rather than to the present section.

In sandstone quarries where there are beds of different qualities, and all saleable, it is usual to follow what is termed "bench or stage working"—that is, to keep the quarry open on one or more stages, so as always to have in readiness a



Bench or Stage Working.

supply of the different sorts. In the preceding sketch, *b b′ b″* represent three working stages,—the first, of flagstones; the second, of medium sandstones for ashlar; and the third, of strong thick-bedded sandstones, suited for basements, pedestals, columns, and other large purposes. Good free stages of this sort are always most cheaply worked, and attended with less waste of material, there being nothing so laborious and wasteful as tearing away in confined nooks and corners. For slates, flagstones, and large blocks of freestone, this mode of quarrying is indispensable; but where stones are sought merely for rubble-work, for the kiln, or for road-metal, blasting, or any other expeditious plan, may be adopted.

As many stratified rocks have a jointed structure, and all are less or more traversed by fissures having definite directions —the "backs and cutters" of the quarryman—these natural partings should be carefully studied as at once facilitating the working, and allowing the largest amount of available stones to be raised from the same space. In slate-quarries this is especially necessary; the unbroken jointed blocks always yielding, on splitting with wedge and mallet, the finest slabs and slates. And yet in many of these quarries, the waste of good material, through injudicious and reckless blasting, is simply disgraceful. Though not a very artistic operation, quarrying requires a certain amount of skill and care,—skill in following the natural lie or structure of the rock, so as at once to lessen labour, and to secure the greatest amount of useful stones from the same bed—and care to reject all faulty or doubtful portions. Though it is the duty of the architect and builder to select the materials suitable for special structures, yet valuable assistance may be rendered in the quarry by throwing aside blocks of unequal texture and blocks containing silicious concretions, nodules of iron sulphide, and other objectionable ingredients.

Another important point is always to keep a good free face in the quarry—that is, to allow no "redd" or rubbish to be shot nearer the face of the rock than 20 or 30 feet. Every proprietor of a valuable quarry should insist on this observance, otherwise a careless outgoing tenant may so choke up the face that a new lessee could not enter upon the workings without an outlay of several hundred pounds in removing the rubbish so accumulated. Indeed, we have known instances where it was thought easier and cheaper to open a new quarry, than to remove the waste and rubbish which years of careless or of selfish working had permitted to accumulate.

In stratified quarries of any depth, water is apt to collect, unless where the rock is sufficiently fissured and jointed to afford a natural drainage. Where there is sufficient declivity, a water-level can be driven; where there is a point in the neighbourhood lower than the bottom of the quarry, a siphon-pipe may be employed; but where the excavations are deeper than any of the surrounding land, recourse must be had to pumping.

The raising or lowering of large monoliths from their native beds is now a comparatively easy task—steam-cranes performing in a few minutes what formerly took hours to accomplish, and this often with severe strain and toil alike to men and horses. Indeed, vast improvements have recently been made in all the adjuncts of stone-quarrying—in lifting, drilling of blast-holes, the use of new explosives, and in the application of machinery to the sawing, planing, and polishing of the blocks and slabs when raised. A large modern quarry with its steam-cranes, steam-drills, sawing, planing, and polishing machinery, and electrically discharged explosives, more and more assumes the aspect of a factory; and it is only by such appliances that labour can be saved and the materials for high-class architecture reduced to a reasonable price. These, however, belong to the mechanical, and not to the geological, aspects of the subject.

Unstratified Quarries.

Quarrying for unstratified rocks, such as basalts, greenstones, granites, and porphyries, generally takes place in hillsides and the faces of cliffs, as well illustrated by our Vignette;* but occasionally in flat situations when the rocks occur as dykes intersecting the stratified formations. Though all hard and crystalline, their raising is greatly facilitated by their structure—the basalts being less or more columnar, the greenstones often sub-columnar, the granites tabular and cuboidal, and the porphyries always much fissured and jointed.

When a good roomy opening is once effected, the columns of basalt are not very difficult of removal, whether perpendicular in cliffs or horizontal in dykes. Being mainly raised for road purposes, the great secret is to get fairly behind the columns, when lever and mash-hammer will be all that is requisite to effect their removal and reduction. The columns are always separable, and though pentagonally or hexagonally interlocked in the mass, are easily removed when once a good free face has been given to the quarry.

The greenstones, also mainly used for road purposes, being only irregularly columnar and often massive or amorphous, require more labour, and for the most part are broken up by blasting. When raised for kerbstones, for which some varieties are admirably adapted, they are cut by wedge and hammer to prevent waste of material. In general, however, there is little waste in basalt and greenstone quarries, every chip and fragment being of use, if not for causeway coursers and kerbs, at least for macadamising.

The same remarks are applicable to the porphyries and felstones, which are usually much cracked and fissured, whether appearing in dykes or in eruptive masses. When raised for macadamising there is no waste, however blasted or broken up; but when coursers and large blocks are needed, the porphyries and felstones require some skill in hammering, as they are not

* From the Dalbeattie Quarries—the granite of which is easily squared and tooled—a large amount of material has of recent years been extracted, not only for street and tramway pavings, for dock and sea walls, as the Thames embankment, and for lighthouse structures, as the Great and Little Basses in Ceylon (the blocks of which were tooled and fitted before exportation), but also for ornamental architecture and monumental purposes.

only brittle in texture, but often full of flaws, or "dries" as they are termed by the workmen.

When a good open face can be obtained for granite, its tabular structure greatly assists its removal in moderately-sized blocks. When worked for road or street purposes, there is comparatively little waste in the quarry; but when slabs and monoliths for ornamental purposes are sought after, huge mounds of rock are frequently cast aside as rubbish. Of course it is not every block that will do for the polishing-table; but there seems often unnecessary waste of rock, and especially in a country where streets and roadways require so much material, and where there are cheap and efficient means of crushing it for macadamising. When raised for street and common building purposes, granites may be freely broken from the cliff by blasting; but where slabs, columns, and other monoliths of large size are required, the wedge, or a closely-set series of well-directed jumper-holes, must be employed, and even this with skill and a knowledge of the texture of the rock. Considering the rapidly extending use of granite for decorative purposes, quarries capable of yielding large and handsome blocks will gradually become more valuable; hence the greater skill and care that should be bestowed on working and cutting the material in the quarry.

Owing to the high and exposed situations of unstratified quarries, as well as to the jointed and fissured nature of the rocks, they are generally dry, and require little or no outlay in pumping or drainage. The great difficulty connected with granite-quarrying is the lifting and transporting of large monoliths; but in this respect, steam-cranes, tramways, and railways are giving greater facilities; while improvements in tools and machinery for cutting, dressing, and polishing, are yearly lessening the expense of the finished material. Take Shap, for example, with its single line and little locomotive drawing the blocks from their native crags in Wasdale to the works on the Carlisle and Lancaster railway, the blocks there dressed and polished by steam-machinery, and then the finished material carried by rail cheaply and expeditiously to any part of the kingdom. As at Shap, so at Aberdeen, Dalbeattie, Mull, and other districts, wonderful improvements have been effected within the last eight or ten years. Already, the wider use of granite for streets, docks, monuments, and ornamental purposes is the result of these improved appliances; and in all likelihood, within another generation, this beautiful and durable material will become an indispensable adjunct in all the higher efforts of modern architecture.

II.—MINING IN STRATIFIED ROCKS.

The stratified rocks most abundantly mined in Britain are coals, shales, fire-clays, ironstones, and limestones; and these, with the exception of some coals and ironstones in the Lias, Oolite, and Wealden, and some limestones in the Oolite and Old Red, are all obtained from the Carboniferous system. Occasionally these beds are approached from their outcrops in ravines and hillsides; and in former times such adits were more numerous than now; but, generally speaking, they are reached by shafts or pits sunk perpendicularly from the surface. The sinking of such shafts, the erection of machinery for pumping water and raising the minerals, and the fitting of apparatus for securing ventilation, are often attended with enormous expense;* hence the necessity of a thorough examination of the field before incurring any preliminary outlay. The object of such examination is to obtain some idea of the extent of the field; of the number, depth, and thickness of the workable beds; of the continuity and regularity of those beds, or how far they may be interrupted by thinnings-out, by faults, by dykes, and other disturbing phenomena. Of course irregularities will occur which cannot possibly be foreseen; but unless the district be altogether new and thickly masked by superficial matter, a great deal of useful information may be gleaned by a diligent and painstaking survey.

Preliminary Surveys.

In making preliminary examinations where there is no authentic geological map, the mineral surveyor has usually two sources of information at his command—the natural and the artificial. Instructive natural sections may often be obtained in sea-cliffs, in ravines, and in river-courses; artificial sections may be seen in road-cuttings, in railway tunnels, in well-sinkings, in quarries, and other similar excavations. Wherever a rock comes to the surface, or an outcrop is exposed in ditch or field-drain, the fact should be noted down, with dip and character of bed, as it is only by observations of this kind that a fair idea of the structure of the field can be arrived at. Having obtained, by such a survey, some notion of the extent of the field, the succession and thickness of the strata, their

* At some of the larger collieries in Durham and Northumberland, preliminary outlays for sinking, gearing, building, &c., of £50,000, £80,000, £100,000, and even £120,000, have been incurred before a single ton of coal could be brought to bank for the markets.

general dip or inclination, and how far, also, the area is a regular or disturbed one, the mining engineer may further supplement and corroborate his information by trial-pits and borings.

As deep borings are slow and expensive operations, great care should be taken in fixing their positions, and equal care bestowed on the "journal" of rocks passed through. The common cutting-chisel, in its descent, crushes everything to paste or powder, and great experience is required in reading from this the precise nature of the rocks passed through; and hence the partial reliability of many of the so-called "journals of borings." The introduction of such cutters as Herr Kind's free-fall, Beaumont's diamond-drill, and Mather and Platt's flat-rope apparatus, which not only make a wider bore, but secure a "core" of every stratum passed through, give perfect sections of the field, which cannot fail to be of infinite value to the mining engineer. And all the more valuable will they become that they are given in general geological language, and not in the technicalities of the district. *Plate*, *hazel*, *segger*, *clunch*, *batts*, *blaes*, *faikes*, &c., &c., are only intelligible in the localities where they are used; shale, bituminous shale, fire-clay, grit, sandstone, laminated sandstone, silicious limestone, and the like, are terms which every educated geologist can readily comprehend.

Sinking or Shafting.

Having fixed upon a site for the shaft, which may be 30 or 300 fathoms in depth, the process of sinking is usually a very tedious and expensive one. In some instances (and here we allude chiefly to coal-mining) there is a great thickness of superficial accumulations—rubbly debris, boulder-clays, and drift-sand; and as these are very treacherous, and often full of water, thereby necessitating strong walling and tubbing, such situations, if possible, should be avoided. Where there is merely tough boulder-clay resting on the strata, little danger need be apprehended; but where this clay is intercalated with drifts of sand—or worse, where it is underlaid by thick pre-glacial gravels—the sinker is almost certain to encounter slips from the sides and floods of water.

Having got through these clays and quicksands, he comes to the stratified beds; and these, in the coal-formation proper, consist of alternations of sandstones, shales, fire-clays, coals, ironstones, and limestones. No matter how deep the shaft, these are the normal rocks through which he has to pass. There may be varieties of sandstone, of shale, or of coal—

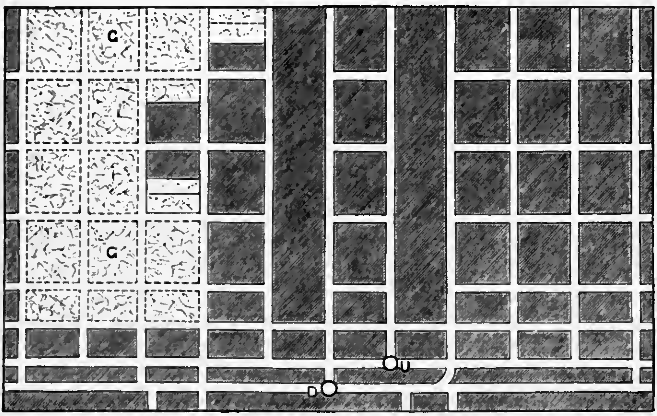
some hard, some soft, some tough, some tender—but such are the alternating beds of the coal-formation, whether one thousand or ten thousand feet in thickness. None of these rocks are difficult of excavation; but some of the softer sandstones are false-bedded or obliquely laminated, and apt to slip in, and many of the shales are short and tender (breezy, shivery, or brashy), and must be walled or planked to insure stability. Even in blasting through solid sandstone, care should be taken not to break or shake them unnecessarily, by placing the charge too near to the sides; and it will be found better in the long-run to pay a little more for extra hewing than to endanger the safety of the shaft by broken and tender walls. Occasionally in our coal-fields, and especially in those of Scotland, interstratified masses of basalt or whinstone are met with, and these, though making strong and durable walls when sunk through, are often troublesome and expensive, generally costing more per foot than the ordinary stratified rocks cost per fathom. When such masses are unexpectedly met with in sinking, the engineer should make every effort to discover whether they are interstratified or intrusive, or whether they may not be old necks of eruption —because, in the latter case, all further effort would be hopelessly useless.

When the Carboniferous strata are overlaid by any of the newer formations, as the Magnesian limestone in Durham, the Trias and Oolite in the midland counties, or the Chalk and Tertiary in Belgium, these softer and more varied beds require greater care, and entail a heavier outlay. Some of the Magnesian limestone beds in the neighbourhood of Sunderland are absolutely waterlogged, and require most expensive tubbing. The "waterstones" of the Trias are also troublesome, while some of the marls have little or no coherence. Indeed there are few sinkings in which tender or water-bearing beds do not occur, requiring either buildings of brick or stone, plankings of wood, or tubbings of cast-iron.

Winning the Stratum or Seam.

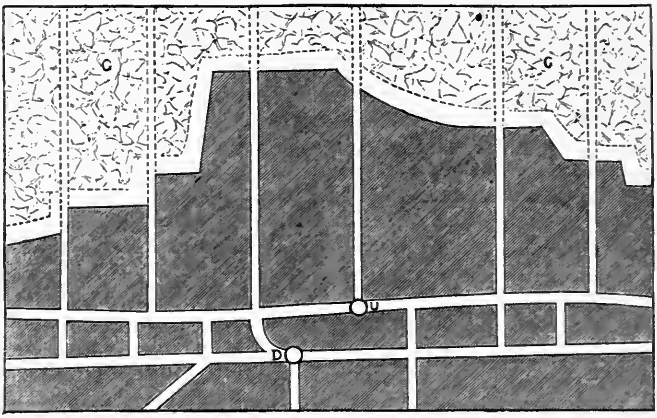
In winning any stratum, whether coal, shale, fire-clay, ironstone, limestone, or rock-salt, a great deal depends upon its hardness or softness, the nature of the roof and floor, the presence of water, and the occurrence of dangerous gases. Hard coals, like splint and cannel, require a different treatment from soft and tender ones; tough shales and fire-clays cannot be dealt with like jointed crystalline limestones; and a roof of short shivery shale cannot be trusted like one of a solid, stony nature. Wet winnings require different arrangements from dry ones; and "fiery seams," precautions that are altogether unneeded in the working of those that are free from explosive gases. Of course, some of these contingencies cannot be known till some progress has been made with the winning; but the moment they make their appearance, plans should be adopted to meet them—and these plans of a substantial and permanent kind, as being always safer and cheaper in the long-run than any tinkering and temporary expedients. Once a roof has shown symptoms of tenderness by occasional falls, or a seam of coal fieriness by occasional blowers, there should be no relaxation of carefulness on the part of the miner or mining engineer. There may have been no accident for months; but the very next stroke of the pick may bring about the catastrophe for which this temporary security, by lulling their watchfulness, has left them wholly unprepared. Much of this is, no doubt, technological, and belongs to the art of mining rather than to geology; but a knowledge of the structure and texture of the rocks with which he has to deal is ever of paramount importance to the mining engineer.

The same may be said of the modes of underground working—the laying out of main-ways, water-levels, air-courses or circuits of ventilation. And these, again, depend on the nature of the seams, whether they can be worked by the panel



Post-and-Stall Work.

method—post-and-stall, bord-and-pillar, stoop-and-room, of the miner—or by the long-work or long-wall method. In the former method the seam is hewn out in many *drifts*, *galleries*, or *bords*, separated from each other by wide ribs of coal. These again are crossed at right angles by similar bords, so as to leave square pillars of support, which vary in size according to the tenderness of the roof and coal, or the softness of the floor. When these galleries have reached the boundaries of the field, or as far as it is expedient to carry them, the next step is to remove the pillars, or as much of them as can be safely accomplished, by working back to the shaft and allowing the roof to subside—the excavated and deserted portion, now filled with debris constituting the *waste*, *goaf* or *gob* of the miner (G). In the latter method, the main-ways are carried out to the boundary, and then the whole of the coal is removed by working the face backwards to the shaft, care being taken to maintain a free and accessible face by packing or propping, and then ultimately to allow the roof to subside. In some cases, the working face is carried back from the shaft, and the ways maintained by build-



Long-wall Work.

ing, packing, and planking; but generally speaking, the former plan is preferred. In some coal-fields a combination of long-wall and bord-and-pillar is adopted—much depending, of course, upon the nature of the seam, roof, and floor. Again, where the seam lies at a high inclination, the main-ways are carried obliquely to the rise, in order to reduce the difficulty of ascent and descent—a matter of main importance when the angle of inclination exceeds 10 or 12 degrees.

Speaking of the comparative merits of the two methods, Mr Warrington Smyth, in his 'Treatise on Coal and Coal-Mining,' appropriately observes: "The great advantages of the *long-*

work method are, simplicity of plan (and consequently of ventilation), and the entire removal of all the coal,—added to which, under most circumstances, are greater safety to the men, and a larger proportion of *round* coal in comparison to *small* or *slack*—a matter which, considering the prices, is of vital importance in the selection of the mode of working. It has been mostly practised where the seams are thin, or where they contain a band of refuse; but neither condition is indispensable: for, on the one hand, coals of 6, 8, or 9 feet thick are at the present moment worked advantageously in this manner; and on the other, we have seen *bind* or *stone-debris* carried from one seam to another, or even taken down from the surface to assist in the packing where it was needful. Nor is it necessary that the roof be good, although the expense will be very different according to its fragility; but if the operations be carried on with sufficient smartness to push the working-place daily under a fresh or "green" roof, it may be managed upon this system, even when composed of mere fire-clay with slippery joints. Only a few years have passed since the long-wall was much decried, except in a few localities; but its manifest economy is gradually introducing it elsewhere; and even in some of the deepest Durham collieries it is successfully applied to the working off of their gigantic pillars; whilst in a few of the pits near Dudley it has been employed for removing bodily first the upper and afterwards the lower half of the 10-yard coal, with greatly increased yield of coal and security to life." To these remarks we may add the applicability of coal-cutting machines to the long-wall system, as one of its chief recommendations—these machines coming more and more into use alike on the score of economy and of freeing the miner from the most laborious and dangerous part of his duties.

And here it may be further observed, that with the yearly increasing consumption of mineral produce, the gradual increase of prices (coal in particular), and the certainty that the supply is limited, and must sooner or later come to an end, it should be the effort of every mining engineer to raise the largest possible amount from any one seam, or, what is the same thing, to leave the smallest possible portion of it beneath ground. Where the long-wall system can be practised with safety, nothing is left, and nothing more can be desired; but in the bord-and-pillar method, a large portion, even with the most daring and dexterous harrying or removing the pillars, is always left beyond reclaim; and it is certainly worth while to adopt the other method wherever it possibly can, with due regard to the safety of the miner.

But whatever system may be adopted to remove the seam—be it coal, fire-clay, shale, or ironstone—care should always be taken to study not only its own structure and texture, but the nature of the roof and floor by which it is bounded, so as at once to insure safety to the workman and prevent undue waste of the material. Some floors are soft, and rise or "creep" under the adjacent pressure, and may thus interfere with the ventilation. Some roofs of shale are slippery, or full of "slicks;" and others of sandstone are jointed and shivery, and thus require frequent proppings and packings to prevent falls. The whole secret of successful mining lies in raising the largest amount of material in the best condition from any given space, and that at the cheapest rate, and with the greatest safety to the miner. We say *the largest amount of material in the best condition;* for it must be admitted that in many of our coal-fields the structure of the seams is too little studied, and the result is a large amount of small coal and slack, which might be avoided by the adoption of more skilful methods.

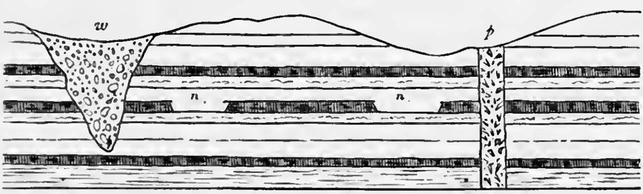
To secure these conditions of economy and safety, the mining engineer should make himself thoroughly acquainted with the structure of his field, noting every fault and dislocation, its amount of throw and direction—every dyke, its direction and effects on the adjacent strata, whether faulting or altering them—every thinning and thickening of strata—the nature of the beds at points where "blowers" of gas occur—and, in fine, every irregularity and unusual appearance that presents itself. These, carefully and distinctly noted on his working plans, will be guides and directions in all his future winnings; and it is simply for want of such plans that so many accidents occur, by breaking into old workings full of gas or water, and so much money is spent in trial-drifts, caution-borings, and the like, where nothing of the kind would have been needed had former experiences been properly plotted and registered as they ought to have been. No doubt things are now in a better condition in this respect than they were thirty or forty years ago; but much yet remains to be done and enforced as a national necessity.

Our coal-fields are limited, and, with an annual output of between 120,000,000 and 130,000,000 tons, are gradually becoming poorer, and seams now neglected, and boundaries between estates now left unworked, must sooner or later be fallen back upon. Under such circumstances, it would be no undue interference with private rights on the part of the Legislature not only to enforce minute plans and records of every working, but to regulate the extent or removal of boundaries, as well as the pumping of water, that may pervade two or more adjacent properties. What might never be done where individual interests come in conflict can be readily accomplished by general enactment. The law which regulates the agricultural drainage of contiguous estates in fens and levels, could surely be as advantageously applied to the drainage of contiguous mines.

Obstacles to be overcome.

We say nothing about main-ways, water-levels, air-courses, ventilation, pumping, haulage, the necessity of having access from seam to seam where more than one are worked from the same shaft, and the like—for these belong to mining in its purely technological aspects; but it may be remarked, that by prudent foresight, and the noting of mineral changes in the strata—many contingencies may be anticipated, and precautions taken to meet them successfully. There are generally some premonitory indications of the presence of water, of blowers of gas, of dykes, faults, thickenings and thinnings of strata—changes, for example, from cannels to ordinary coals, or from cannels to blackbands, and similar phenomena; and the engineer watchful of these indications must ever stand on a higher platform than one who fails to note them, or who is ignorant of their teachings even when observed.

The most frequent interruptions to coal-mining (and the same remarks apply to shales, ironstones, fire-clays, &c.), are *fissures*, *faults* or *dislocations*, which throw the strata out of their usual position; *soft dykes* filled in with debris from above; *hard dykes* injected with igneous rocks from below; *wash-outs*, *nips-out*, or *dead-grounds*, where the seam disappears for a certain space, and its place is taken by clayey, stony, or other debris; *fouls* from the infiltration of some foreign matter through rents and fissures; or *natural pits*, (*puits naturelles*) as in the Belgian

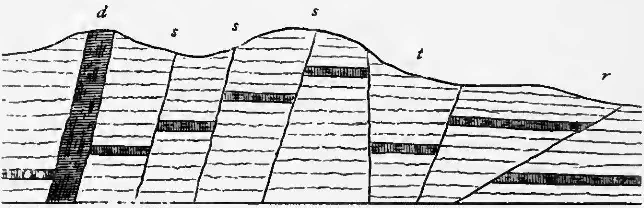


w Wash-out; *n n* Nips-out; *p* Natural Pits.

coal-field, where the strata disappear for circumscribed areas, their place being occupied by miscellaneous debris from above.

In the preceding diagram *w* represents a wash-out cutting deeply into the strata, and evidently an old pre-glacial stream-course; *n n* nips-out, apparently caused by runnels through the vegetable growth which formed the coal-seam; and *p* a natural pit or local subsidence of the strata, which may have been caused either by the removal of some subjacent bed or by the disintegration of some eruptive neck of trap-rock. Several of these give no indication of their presence till struck by the pick of the miner; some may be anticipated from changes in the texture of the coal, and the occurrence of strings and veins of calcareous spar, iron-pyrites, heavy spar, and the like; and others, again, as throws and trap-dykes, which traverse the country in linear directions for many miles, should be prepared for either from previous surveys of the field or from the plans of adjacent workings.

Still more frequent than the preceding, perhaps, are the "slips" and "throws" of the miner — *step-faults*, which at intervals throw the strata nearer and nearer the surface, till some are thrown out altogether and denuded; *trough-faults*,



d Dyke-fault; *s s s* Step-faults; *t* Trough-fault; *r* Reversed fault.

where a portion of the strata is thrown down between two adjacent faults; *overlap* or *reverse-faults*, where the strata are broken, and thrown, as it were, above themselves; and *dyke-faults*, where a dyke not only intersects the strata, but throws them up or down out of their usual position.

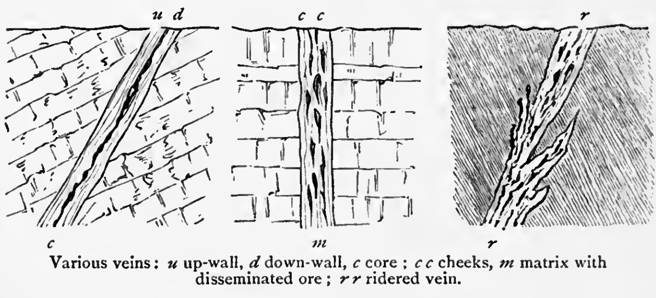
The practice of mining is no doubt surrounded by numerous difficulties; but it is astonishing how many of these may be overcome by an engineer thoroughly acquainted with the geological structure of his field, and ever on the alert to notice the nature, position, and direction of any changes that may occur in the strata through which he is driving.

In the preceding pages we have alluded chiefly to coal-mining; but the same remarks are more or less applicable to the winning of the shales, ironstones, fire-clays, and limestones which occur in the Carboniferous and other stratified systems. They may be thicker or thinner, softer or harder, than the coals; but the same necessity for sinking, unless they are taken from the same shaft, the same preparations for ventilation and getting rid of water, the same precautions for the maintenance of the roof and ways, and the same interruptions of dykes and faults, have all to be met, made, and provided for. And here, also, the questions of thick seams and thin seams, of compound seams, of flat seams, and highly inclined seams, of working to the dip or working to the rise, of winning upper seams or lower seams first, must all be taken into consideration by the mining engineer; and while exercising his own skill and judgment, he will ever be benefited by a wide acquaintance with the experiences of others, and the practice of other districts. No doubt there are differences among the ablest mining engineers as to their practice in these and other cases; but an intelligent observer, who carefully notes the modes of working in various districts, has resources to fall back upon in the event of difficulties, which cannot belong to the individual who ignorantly or bigotedly confines his observations to his own locality.

III.—MINING IN VEINS.

The methods of vein-mining differ widely from those of strata-mining—the latter being carried on in positions more or less horizontal, the former in positions less or more vertical. Defining a vein as a rent or fissure in the earth's crust filled with mineral or metallic matter, or with a combination of both, it is obvious that veins may differ in direction, in width, in their angle of inclination, or in the nature of the matter they contain. Such fissures may be produced by upheaval or by shrinkage, and may occur in stratified or unstratified rocks, or may pass through both. They may be filled by waste from above, by the permeation and segregation of mineral matter from their sides, or by infiltration of mineral and metallic matter from below. The filling of veins is one of the most obscure problems in geology, and may have been accomplished partly by chemical solution and replacement, partly by hydrothermal action, or partly by electro-magnetic currents, or it may have been by a combination of all of these acting slowly and continuously through ages of indefinite duration. Many hypotheses have been advanced; but what seems plausible for one district is inadequate to account for the phenomena of another; and it must be confessed that much has yet to be observed, and much more known of chemical geology, before any sufficient theory can be established. We have no means of imitating the slowly and gradually formed products of nature. What we accomplish in our laboratories is done quickly and by intensity of force; what nature has accomplished may have been brought about by the gentlest of forces acting through immeasurable periods. Our experiments may give an indication of nature's methods, but this is all; and with this, in the mean time, the scientific inquirer must be contented.

When filled with mineral matter alone, as quartz, calc-spar, fluor-spar, baryta, &c., these fissures are known as *mineral veins;* when filled partially or wholly with metallic ores, as *metalliferous veins* or *lodes;* and when filled with clay or rubbly matter from above, they are spoken of as *false* or *clay veins*—the *flukan* of the Cornish miner. They occur of all widths, from a line to several yards; are sometimes very uniform in thickness; and at others thicken and thin capriciously from narrow *nips* and *twitches* to expanded *bellies.* The angle at which they deviate from the perpendicular is designated their *hade* or *underlie;* the sides of the fissures their *cheeks* or *walls;* the upper side the *hanging* or *up wall,* and the lower the *foot* or *down wall.* The mineral matter in which the *ore* is incorporated is known as the *matrix, gangue, vein-stone,* or *vein-stuff;* and this may consist of quartz, calc-spar, fluor-spar, baryta, strontia, or other sparry matter, either indiscriminately mingled, or sometimes arranged in successive coatings parallel to the walls. The ore may be disseminated through-



Various veins: *u* up-wall, *d* down-wall, *c* core; *c c* cheeks, *m* matrix with disseminated ore; *r r* ridered vein.

out the matrix in minute *particles,* as gold in quartz; in parallel *threads, strings,* and *plates,* as with copper; in irregular *pockets* or *bunches,* as with lead and zinc; or it may be concentrated chiefly in regular parallel *courses,* or in a single *core,*—hence such designations as *stringy, bunchy,* and *branchy* veins. Occasionally portions of the walls or sides protrude or are projected into the vein, and when such portions are interlaced with threads and strings of valuable ore they are termed riders—and such a vein, in mining phraseology, is said to be *ridered.* The term is also applied to veins whose walls are occasionally so interlaced with threads and strings of ore as to render them worth working.

Lodes and veins occur most abundantly in highland or hilly regions and among the older rocks, from the granites and crystalline schists to the Carboniferous limestone inclusive—these systems having been longer subjected to fissuring, infiltration of mineral and metallic matter, and other metamorphosing agencies. In their direction or *bearing*, as it is technically termed, they are sometimes regular and persistent for miles; in other instances they branch off into two or more subordinate veins, and ultimately disappear in interlacing threads and strings. When parallel to the axis of upheaval they are spoken of as *right-running, rake, master*, or *champion* lodes, which in Britain have generally an easterly and westerly bearing; when at right angles to those they are termed *cross-courses*, often north and south magnetic; and when obliquely intersecting either of the preceding, as *contra* or *counter lodes.* Not unfrequently the intersecting vein faults or displaces the vein through which it crosses, and such displacements may vary from a few inches to as many yards. Besides the preceding,

v v, v' v', Faulted or Displaced Veins.

there are others known as *pipe-veins* or *carbonas*, which fill irregular pit-like cavities; *flat-veins*, which run horizontally, as between two beds of limestone; and *gash-veins*, which appear to have been fissures filled in with ores and vein-stuff from above. These gash-veins, which occur most frequently in Carboniferous limestones, must not be confounded with the *nests* and *fields* of Furness, which are merely irregular and often superficial deposits of hæmatite in the hollows and depressions of the limestones of that district. Of course every mining country has more or less its own terms and technicalities; and while we give the general, the special must be learned in the district to which they apply.

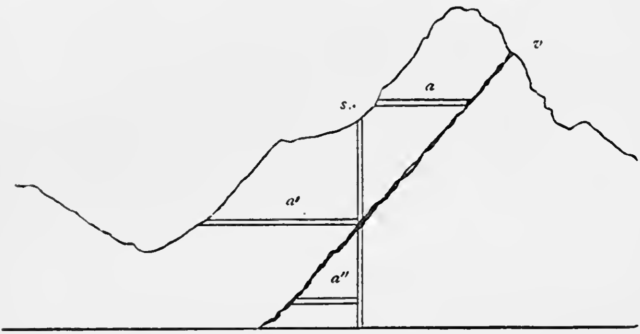
Searching or Prospecting.

Whatever the nature of the vein sought after, it is essential to have a preliminary searching or "prospecting," as it is termed, of the *country* or *ground.* For this purpose the miner may search the country for indications of veins in hill sides, precipices, and ravines; he may test the quality of springs, which generally hold in solution some of the materials through which they have passed; or he may examine the stream-drifts which have been worn and washed from the higher grounds, and which usually contain rolled fragments of the denuded veins. These *shoadstones*, be they of hæmatite, tin-ore, or auriferous quartz, become more numerous the nearer the vein is approached; and in this way *shoading*, as it is termed, becomes an important means not only of discovering veins, but of indicating the nature of the ores of which they are composed. Where none of these means are available, he may adopt the more expensive but the more certain method of *costeaning*—that is, of driving shallow drifts at right angles to the usual trend of the veins so as to intercept their outcrops; and from these decomposed outcrops or *gossan*, as it is termed in Cornwall, he can judge at once of the nature, thickness, and direction of a lode. Indeed, as this gossan is merely an altered portion of the *back* or upper part of a vein, it is often indicative, to the experienced miner, of the richness of the ore that lies below—and hence his expectations on the discovery of what he designates a "kindly gossan."

In Britain, as in other countries, the great vein-repositories are the older rocks—the metamorphic schists of the Scottish Highlands, as in the Breadalbane district; the Cambrians and Silurians of Cornwall, Devon, Wales, and the Lake country; and the thick-bedded Carboniferous limestones of Derby, York, North Lancashire, Westmoreland, and Durham. In the older schists, gold, silver, mercury, tin, copper, manganese, and iron prevail; in the mountain limestones, lead, zinc, antimony, and iron are abundant. Occasionally some of the metals occur in a free, *native*, or uncombined state, as gold, platinum, silver, mercury, copper, and arsenic: more frequently as *alloys*, as silver, antimony, cobalt, nickel, and iron, with arsenic; silver and nickel with antimony; lead, gold, silver, and bismuth, with tellurium; silver with mercury; and platinum with gold: and most abundantly as *ores*—that is, in a chemically combined state, as oxides, sulphides, carbonates, phosphates, and other kindred combinations. The metals peculiar, or supposed to be peculiar, to the respective systems, will be noticed in next section, and when we come to treat of the metallic ores in Chap. XVIII.; in the mean time we merely advert to the principal areas of our metalliferous vein-development. Having ascertained the vein-structure of the country, and the presence of the minerals or metals he is in search of, the miner can then proceed with some degree of certainty to their raising or extraction.

Working or Winning.

The working of veins depends very much on the structure of the country, whether it is abruptly hilly and irregular or disposed in broad massive table-lands. In the former case, the veins may be approached by a system of adits, and drained by water-levels; in the latter, shafts must be sunk and water got



Vein-Mining—Shaft and Adits.

quit of by pumping. In the accompanying sketch, the upper part of the vein *v* may be worked and drained by the adit *a*; the middle portion may be worked and drained by *a'*; while the lower portion is reached by a shaft *s* and adit *a''*, and drained by pumping up to the adit *a'*. In Cornwall, for example, both systems are followed on a gigantic scale—the shafts being frequently of great depths and the pumping-engines proverbial for their power, the adits of great size, and the water-levels often carried for many miles (in the case of the great Gwenaap, it is said, for 30 miles) across the country. In every case, however, the engineer must be guided in his methods by the structure of the ground, the frequency, the underlie, and the intersection of the veins—his main object being to accomplish his work cheaply, by avoiding unnecessary mining, by getting readily quit of water, by raising as little "deads" or waste rubbish as he can, and thus having the smallest possible amount of "attle" or non-metalliferous stuff from the dressing-tables. Ventilation is generally good in vein-mines, and there is no danger or interruption caused by the presence of explosive gases. When the underlie is small, the cheeks and walls are usually firm, and give little trouble; when it is great, the hanging wall requires not unfrequently pillaring and propping to prevent collapses. These and other minutiæ, however, belong more to the mechanical than to the geological functions of the mining engineer.

In following the veins, many phenomena will present themselves which cannot be anticipated; and, generally speaking, the most successful miner is he who has studied with discernment the peculiarities of his own immediate locality. Generalisations have, no doubt, been attempted by several engineers, but these refer chiefly to the field of their own experiences, and are often inappropriate and misleading when applied to other districts. For instance, it has been set down by some that veins grow poorer as they descend into the crust; but this has been disproved by ample experience in Australia, Peru, Central America, Mexico, and California. It is true, some auriferous veins are abundantly rich at the surface; but on this point it has been well observed by Mr Belt * (an experienced miner and commissioner at the gold-mines of Chontales in Nicaragua), that "the cause of these rich deposits near the surface does not appear to me to be that the lodes originally, before they were exposed to denudation, contained more gold in their upper portion than below, but to the effect of the decomposition and wearing down of the higher parts, and the concentration of the gold they contained in the lode below that worn away. We have seen that in the decomposed parts of the lode, the gold exists in loose fine grains. During the wet season water percolates freely from the surface down through the lodes, and the gold set free by the decomposition of the ore at the surface must be carried down in it, so that in the course of ages, during the gradual degradation and wearing away of the surface, there has, I believe, been an accumulation of loose gold in the upper part of the lodes from parts that originally stood much higher, and have now been worn away by the action of the elements."

Again, it has been observed when a vein passes from one rock-formation to another, as from slate to granite, it is usually richer at their contact; and farther, when veins cross each other, there is generally a fuller development of ore at their intersection. When a vein, however, passes through alternations of harder and softer rocks, as in the limestones and shales of the Carboniferous, it is often rich in the former, and is poor or altogether "nipped" in the latter. If, again, a vein splits into

* The Naturalist in Nicaragua, by Thomas Belt, F.G.S.

strings, either vertically or longitudinally, it is regarded as a sign of impoverishment, and not unfrequently this splitting or diffusion renders the vein unworkable.

It has been already mentioned that the Palæozoic systems and their associated igneous rocks are the great repositories of metalliferous veins in Britain; and it is from these ancient rocks that almost all our metals are derived. In a few instances (according to Professor Phillips), veins of small value, producing lead and copper, pass through the magnesian limestone; but not a single example is known of a true metallic vein in the oolitic, cretaceous, or tertiary system. The secondary rocks have been subjected to comparatively slight volcanic agency, and it is chiefly in and around igneous centres that veins most abound. It has also been attempted to associate the occurrence of certain metals with certain rocks, as gold with the older schists, tin with slates and granites, copper and silver with slates and porphyries, and lead, zinc, and antimony with limestones; but as yet such attempts to establish relations must be received merely as tentative, and as by no means established. It has been farther attempted to establish relations between the nature of the walls and that of the vein-stuff. It is true that quartz-veins occur most abundantly in silicious rocks, and calc-spars in limestones; but there are many veins in the older rocks which are filled with baryta and strontia, and many again in limestones which contain calc-spar, fluor-spar, rock-crystal, &c., either in successive layers or confusedly interblended.

Werner insists on the fact, that certain associations of minerals can be traced in veins; but the assertion must be received with reserve. He notices the concurrence of lead-glance, zinc-blende, and copper-pyrites; of cobalt, copper, nickel, and native bismuth; of tin, wolfram, tungsten, molybdena, and arsenical pyrites; of topaz, fluor-spar, apatite, schorl, mica, chlorite, and lithomarge; of brown ironstone, black ironstone, manganese, and heavy spar. He says, where tin occurs, ores of silver, lead, and cobalt, and vein-stuffs of heavy spar, calcareous spar, and gypsum, are rarely found. Cinnabar and other ores of mercury scarcely ever occur with the ores of other metals, except iron-ochre and iron-pyrites.

IV.—STREAM OR PLACER WORKING.

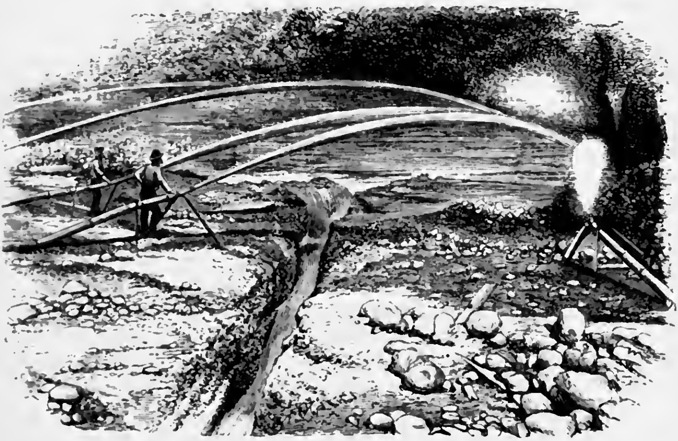
Stream or placer working consists in turning over, washing, and searching for metals, metallic ores, and minerals, the sands, gravels, and shingly debris which occur in river-valleys, and which have been worn and transported from the higher grounds. It is evident that the veins which traverse the higher grounds will be subjected to the same tear and wear as the rocks which contain them, and that in course of time the denuded portions will be carried by rain, streams, and freshets to the valleys below. If, for example, the vein be one of auriferous quartz, the veinstone will be more and more broken up as it is carried down by the stream; the debris will accumulate more in flats, and creeks, and eddies; and, generally speaking, the metal or orestone will, from its greater specific gravity, be the first to settle or subside in this downward course. In this way the stream-drifts become richer the nearer the vein is approached; and hence the practice of *shoading* for veins, as already alluded to. Stream-working is usually a simple process, and has been long practised in searching for gold, tinstone, and precious stones. And yet, simple as it appears to be, a great deal of skill may be shown in selecting the site for operations.

Wherever the course of a stream is interrupted by sudden bendings, creeks, and level reaches, there will the drifted matter accumulate in greater abundance. In course of time every river-valley changes less or more its conformation, and it is by a skilful calculation of what that conformation may have been in former ages that the placer-worker is frequently led to the richest accumulations. Where the deposits are shallow, little is required beyond shovelling, separating, washing, and sifting; but where they are of great thickness, and occasionally overlaid, as in Australia, with sheets of lava, not only digging, but mining in a rude way, has to be resorted to. The following, for example, is a section of an auriferous digging (Mr Cleghorn's) near Uralla in Queensland:—

Red rich clay, ...	5	feet.
Stiff red clay, ...	5	,,
Mottled clay—volcanic ashes, ...	20	,,
Basaltic lava, ...	35	,,
Brown laminated clay, ...	5	,,
Loose sand (decomposed quartz and granite), .	2½	,,
Black peaty clay, with numerous leaves and stems,	6½	,,
Loose sand (decomposed quartz and granite), .	2	,,
Finely laminated reddish clay, ...	1	,,
Loose sand (decomposed quartz and granite), with numerous crystalline pebbles and *a little gold*, .	15½	,,
Fine reddish clay, ...	½	,,
Loose sand (decomposed quartz and granite), with numerous pebbles—*the main gold deposit*, . .	4	,,
	102	,,

Granite, water-worn surface, with large granitic boulders.

One great essential in all workings of this kind is an abundant supply of water; and where this can be obtained not only are the washing and sifting facilitated, but, as in California, powerful jets can be directed against the face of the drifts at once to bring them down and to wash out the heavier and metalliferous material from the stony debris. In the earlier days of shallow placer-working, a pick, a spade, and an iron pan formed the full equipment of a gold-digger. By-and-by these were superseded by the rocker; the rocker by the Long-Tom or mercury-trough device, and the Arastra-mill or quartz-crusher of the Mexicans; and when deep-placer became a necessity, these simple contrivances gave place to the water-gun of the Californians. In that country, where auriferous gravels cover an area 50 miles in breadth and 300 in length, from 50 to 500 in thickness, nothing but the most powerful and rapid contrivances will suffice; and hence the new system of "flumes" or water-courses led for many miles from the higher grounds, and terminating in the nozzle of the water-gun. "From this 6-inch tube," says Professor B. Silliman, "is projected a stream of water, which is as solid as a bar of steel as it leaves the mouth of the gun and remains so for a distance of 200 feet, or until it impinges against the face of the bank. Through that the



Hydraulic Placer-Working—from a Photograph.

miner is enabled to throw a continuous stream without interruption, day and night, which is equal to a measurement of not less than 1500 to 1600 cubic feet of water, projected with a force equivalent to 140 feet of water in a second of time, with an impact equal to 1650 lb. You can understand this when I say that it is about equal to one-tenth the velocity of a cannon-ball." The preceding woodcut represents the process, the auriferous debris being carried off by a tail-flume to a lower level, there to undergo the further process of sifting and separation.

On the whole, stream or placer working, whether for metals, for ores, or for gems and precious stones, is a species of quarrying rather than of mining, and may occasionally be successfully carried on with the rudest appliances. It is always attended, however, with greater or less uncertainty; and though vast amounts of gold, tin, and precious stones have been obtained through its practice, it can never be regarded as a steady and regular species of industry. In the long-run the richest drifts get exhausted, and then the miner is driven to the veins from which they were derived, there to prosecute his calling in a settled and systematic manner.* In the mean time, the most extensive and productive stream-drifts are those of the Urals, India, Further India, New Zealand, Australia, Cape of Good Hope, Brazil, Mexico, California, and British Columbia—yielding not only native metals and metallic ores, but nearly all the gems and precious stones. Of recent years, digging for phosphatic nodules — the coprolites or "cops" of the worker—has become a considerable industry in the greensand and tertiary districts of England, and especially so in the Carolinas of North America.—See Mineral Manures.

To a country like Britain, and indeed to all other countries, in an age of so many mechanical appliances as the present, the subject of mine engineering is of the utmost importance. It is not only determining where certain minerals and metals are to be found, but in what abundance they occur, and with what facilities they can be obtained. It is evident, then, that the mining engineer should have a competent knowledge of the general principles of geology; should be able to adopt the safest and most economic method, whether it be vein-mining or strata-mining in which he is engaged; and at the same time be competent to decide on suitable means of lifting, pumping, and ventilation. The difficulties that beset the practice of mining are not only numerous and perplexing, but often sudden and unforeseen; and whoever from his superior knowledge is

* These remarks are scarcely applicable to California, where the area of auriferous gravels is so wide, and their depth so great as to extend downward 400 or 500 feet to river-courses of Pliocene, if not of Miocene epoch.

fertile in expedients, and prompt and decisive in action, is ever likely to be most successful. Of course different fields require different methods; but these differences are usually of minor importance, and most easily mastered by the engineer who is best acquainted with the general principles of his science.

Bearing this in mind, and remembering, also, the requirements of the recent Mines Regulation Act, it is scarcely creditable to Britain to have only one established School of Mines, and this situated in a locality where there is the least opportunity of illustrating the principles taught by appeals to actual practice. As matters stand, it is the duty of the working geologist to explain the principles of his science in the simplest language, and to note and describe every abnormal appearance in such a manner that the mining engineer may be prepared to contend with them should they make their appearance in the field of his operations. The more intimate his knowledge of principles the more successful his practice; and whilst it is mainly his function to win, it is the duty of the geologist to discover and describe the nature, position, abundance, and general condition of the substances which form the objects of these winnings.

"To bring the art of the miner," says Professor Phillips, "fairly within the circle of inductive philosophy—to give it more exact laws, based on a surer classification of phenomena —is an object of the highest concernment for humanity. On the command which man has acquired over the various properties of metallic matter has depended much of his civilisation, and a large part of his power over the forces of nature. If this command may be extended, these forces may be still more completely brought within the direction of the human mind. The way to do this is to carry science into the mines, and bring miners into the class-rooms of the professors of chemistry, geology, mineralogy, and mechanics. Practice will thus become method, and experience be exalted to theory."

Works which may be consulted.

Burgoyne's 'Blasting and Quarrying of Stone;' Smyth's 'Rudimentary Treatise on Coal and Coal-Mining;' Hyslop's 'Treatise on Mine Management;' Greenwell's 'Practical Treatise on Mine Engineering;' Wallace's 'Laws which regulate the Deposition of Lead Ore;' Forster's 'Treatise on a Section of the Strata from Newcastle-on-Tyne to Gross-Fell;' Henwood on Veins — 'Transactions of the Royal Geological Society of Cornwall;' Taylor's 'Report on Veins' —British Association, vol. ii.

IX.

HEAT AND LIGHT PRODUCING MATERIALS.

Of all the substances obtained from the crust of the earth, there are none so indispensable to the Arts and Manufactures—to man's mastery over the forces of nature—as the heat and light producers. Wood is, no doubt, the first and readiest source of fuel; but as population increases, and the soil is required for the growth of food-stuffs, the forests gradually decrease and become altogether incapable of affording an adequate supply. In eminently manufacturing and commercial communities like Britain, it is not fuel for the household alone, but fuel for the furnace, the forge, the steam-engine, the factory, and the thousand other purposes essential to our industrial activity and progress. Whatever the variety of coal, there is no heat-producer so powerful, so durable, or so serviceable, as that mineral. It lies at the foundation of our mechanical, manufacturing, and commercial greatness, which would speedily dwindle and perish on its exhaustion. And so with the light-producers: wood, vegetable and animal oils, fats, wax, gums, and resins, are limited in supply, and totally inadequate to modern requirements. Compare the lamps and candles of sixty years ago with the gases, paraffins, and other hydrocarbons obtained from gas-coals, oil-shales, and oil-wells, and nothing more is needed to show how much we depend on the mineral kingdom for light-producers at once cheap, brilliant, and eminently under control. To these heat and light producers we devote the present chapter—describing briefly their geological history, position, composition, and ascertained abundance.

I.—FOSSIL FUELS.

Peat.

Of the fuels obtained from the earth's crust the most obvious and accessible is *Peat*, whether fibrous, woody, or earthy. Peat is a product of temperate and coldly-temperate countries, and occupies extensive areas in our own islands, in Holland, Denmark, Germany, Russia, and Siberia, in the Old World; and in Canada, Hudson Bay territories, and Alaska, in the New. The colder latitudes of the southern hemisphere being chiefly occupied by the ocean, it has no great area for development, and appears in sporadic patches only in Patagonia and the Falkland Islands. It is strictly a vegetable accumulation—mosses, confervæ, equisetums, rushes, grasses, heaths, and other marsh plants, contributing to its growth—and occurs in all stages of consolidation, from the light fibrous *turf* of the surface, in which the several plants are apparent, to the dark compact *peat* below, in which the component species are with difficulty discernible. In some instances it has accumulated in boggy marshes, in others it occupies the sites of silted-up lakes; occasionally it has gathered over waterlogged and fallen forests, the decayed trees of which (oak, Scotch fir, birch, hazel, alder, &c.) it still encloses; and not unfrequently it appears on moist hill sides and high open moorlands. Many of the British peat-mosses are in a dead state, and undergoing waste and disintegration, and only a small proportion in a living or growing condition. This result has been brought about by drainage, felling of forests, and other causes affecting the rainfall and climate; but in other countries where human interference has been less felt, peat-mosses are still on the increase, and at different ratios, according as they are situated on hill sides, in swamps, or on exposed moorlands. It is very difficult to approximate the rate of growth; but in Britain many peat-bogs show an accumulation of from three to five feet since the time of the Roman invasion —now nearly eighteen hundred years ago.

Besides the ordinary terrestrial or surface peats, there occur along many parts of our own shores submarine peats or forest-growths, dipping away beneath the waters to an unknown extent, and varying from two to five feet in thickness. These submerged forests, as they are termed, appear in the Firths of Tay, Eden, and Forth, along the coasts of Northumberland, at the mouth of the Tees, along the Humber, at Bournemouth, the Solway, and also along the Devonshire, Lancashire, and other coasts. They are composed of a very compact and pure peat, enclosing enormous trunks of oak and fir, together with alder, hazel, birch, and other indigenous trees; and, from their great age and compression under twenty or thirty feet of marine clays, may be looked upon as intermediate between peat and lignite.

We have no mode of estimating the amount of peat available for fuel in the northern hemisphere; but several millions of acres occur in the British Islands from five to thirty feet in thickness; perhaps eight or ten hundred square miles in North America from five to twenty feet in thickness; about half this amount in Northern Europe; and certainly not less than ten or twelve hundred square miles in Northern Asia. Of course much of this is not available either as regards situation or quality; but a very large proportion, by suitable methods of pulping, drying, and compressing, could be utilised and employed as a fuel, whose effective heat would be about two-thirds of that of ordinary lignite, and certainly not less than half of that of average bituminous coals. In Southern Germany, where prepared peat is largely used for locomotive purposes, its heating power has been found to be equal to 60 per cent, or three-fifths that of ordinary coal.

In Highland and remote districts peat has been long used as a household fuel; and in other districts where it is abundant it has been, and is still, employed for kiln-drying by distillers. For these purposes it is simply dug and cut into brick-shaped blocks, dried in the sun of summer, and carted and stacked for future requirements. As it absorbs nearly twice its own weight in water, wet and sunless summers are unfavourable for its preparation; hence, in a fickle climate like Britain, the supply is irregular and uncertain. During the present century several expedients have been adopted for compressing the peat, partly to get rid of the moisture, and partly to render it more portable; but owing to the low price of coal, the objectionable odour of peat, and the difficulty of raising from it a quick and strong heat, none of these schemes have been attended with success. It is but fair to state, however, that some of the advocates of peat-fuel maintain that steam can be raised with it more quickly than with coal.

Now that coals (1873-74) have risen to treble their value of twenty years ago, a number of new methods have been proposed, and several of them patented, for converting peat into a cheap and suitable fuel. Some of these proceed by pulping, drying, and then compressing the mass into small blocks; some by pulping, drying, and mixing the peat with coal-slack; and others by pulping, drying, mixing with coal-slack, coal-tar, or crude paraffin oil, and then pressing into cakes or *briquettes*. Some of these processes—those of the Messrs Clayton of London, Macallum of Dunfermline, and others—are now under trial, but not as yet on a scale sufficiently large to admit of any decision as to their commercial success. There can be little doubt, however, that peat, which is merely coal in its incipient stages of mineralisation, might be extensively used as a fuel, and all the more that it is readily obtained, is an obstruction to agriculture, and often covers, as in the case of Blair-Drummond, a rich cultivable clay, which becomes available on its removal. The main obstacle to be overcome is the amount of inherent moisture. On an average, raw peat contains from 75 to 80 per cent of water, and air-dried as much as 25 per cent; and to reduce this quickly, and at the same time cheaply, to a minimum, is the great desideratum. Various methods—pulping, shredding, teasing, and exposure to currents of air and in heated chambers—are at present on trial in Britain,—Ross, Sutherland, Linlithgow, Dumfries, Westmoreland, and other counties; and so long as coals remain at existing prices, there is a fair chance for a prepared peat-fuel, not only for household consumption, but for other purposes where a strong blast is not brought to play upon it. S. Reynolds of Dublin reports that ordinary air-dried peat, containing 25 per cent of water, gives a calorific value of 65 per cent of Staffordshire coal in the Siemen's iron-furnace. Perhaps the average heating power of peat may be taken in the ratio of 2½ tons to 1 ton coal.

In countries having a dry summer climate, any amount of peat might be dried naturally, and at little expense; but in uncertain climates the only mode seems to be masticating, pressing into blocks, and then drying artifically under cover. The mechanical processes for the preparation of peat-fuel may be arranged into two classes—the wet process for simply densifying the raw material, and the dry process for compressing;* and under these plans, or modifications of them, large quantities of available fuel are manufactured in Canada, in Bavaria, Bohemia, the Netherlands, and other countries, at prices varying from 7 to 12 shillings a ton, and used not only for household consumption, but for locomotives, iron-smelting—for which, from its freedom from sulphur, &c., it seems well suited—and for other industrial purposes. In Holland, for instance, the preparation of peat-fuel is an important branch of the national industry—digging and drying, dredging, pulping, and compressing, being carried on at numerous works, to the amount, perhaps, of 40,000,000 tons per annum, and yielding a revenue to the Government of between £140,000 and £150,000. The subjoined tabulation exhibits some analyses of peat dried at 212°:—

* The machines of Schlicheysen in Germany, Eichorn in Bavaria, Rhader in Holland, Challeton de Brughat in France, and Danchell in England, are adapted to the wet process; those of Clayton and Exeter to that of the dry.

Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ashes.	
66.55	10.39	18.59	2.76	1.70	Fickenscher, Germany.
57.03	5.63	29.67	2.09	5.58	Regnault, France.
58.09	5.93	31.37	...	4.61	" "
57.79	6.11	30.77	...	5.33	" "
57.16	5.65	33.39	...	3.80	Mulder, Holland.
59.96	5.52	33.71	...	0.91	" "
50.85	4.64	30.25	...	14.25	" "
59.00	5.50	19.50	1.50	14.50	Johnstone, Scotland.

From these analyses it will be seen that the great defect of peat as a fuel lies in its relatively small proportion of carbon; and any process that tends to increase the amount, at a comparatively small cost, is in the right direction towards the utilisation of a substance which, at the present moment, is not only worthless, but in some instances positively detrimental. As dense peat made by any of the wet processes yields, when charred, a firm charcoal, it is in this way, perhaps, that the greatest economic advantages are yet to be obtained from the treatment of the substance by machinery. Indeed, the great heating power of peat-charcoal is admitted on all hands—the only objection to it being the amount of ash it produces.

Lignites and Brown-Coals.

The term *Lignite*, *Wood-coal*, or *Brown-coal*, is usually applied to those coals of tertiary and cretaceous age, in which the woody texture is still apparent, or but partially obliterated by mineralisation. In other words, lignites are masses of vegetable matter in stages of mineralisation intermediate between peats and bituminous coals—some having the component leaves and stems still legible, as in peat, and others being scarcely distinguishable from ordinary coals. Those in which the woody texture is still apparent, are familiarly known as "wood or board coals;" those finely laminated like compressed leaves, as "paper-coals;" and soft and earthy varieties, as "peat-coals." According to M. Fremy, lignites may be distinguished from wood and peat, on the one hand, by their complete solubility in nitric acid and hypochlorites; and from true coals, on the other, which are insoluble in hypochlorites, and but slowly attacked by nitric acid.

With the exception of the Bovey Tracey basin in Devonshire, we have no available lignites in Britain; but in France, Switzerland, Spain, Germany, Austria, Italy, Greece, Burmah, New Zealand, and North America, lignites occur in great variety, from peaty-looking "brown-coals," as they are called, to hard black bituminous seams, differing little in aspect or quality from the older coals. The Bovey beds, which occupy an area ten miles long by two and a half broad, are raised mainly for pottery purposes; but many of the foreign lignites (like those of Austria and Italy) are employed not only for domestic purposes, but for locomotives, for furnaces, and other industrial uses. The lignites of Austria have long been successfully used on the railways; and those of the Val d'Arno, in Tuscany, have recently been employed with success at the iron-works of San Giovanni for all the operations of puddling, forging, &c., as well as for steam-raising—their calorific power, when dried at 200°, being between 4400 and 4500. The great drawback to the majority of lignites is the amount of water they contain, being nearly 50 per cent when freshly dug, and about 10 per cent in an air-dry state; their offensive odour in burning; and their tendency to crumble down when exposed to the desiccating influences of the sun and air.

Generally speaking, they burn with much smoke and flame; are poorer in carbon or coke than common coal; bulk for bulk give much less heat; and leave for the most part a large residue of earthy ashes.

Geologically, lignites are merely old peat-beds, forest-growths, and swamp-growths; and, alternating, as many of them do, with sands, clays, and marly-shales, they require great care in mining. They are also, for the most part, more irregular in thickness and quality than the older coals, and for these reasons cannot be worked with the same certainty and commercial success. Notwithstanding these drawbacks, the more compact lignites are useful heat-producers, and will be more and more raised as railways are extended. The following analyses exhibit the composition of lignites from several countries, their specific gravities varying from .6 to 1.5 :—

Carbon.	Hydrogen.	Oxygen	Nitrogen.	Waste.	Ashes.	
59.90	4.66	15.99	1.08	13.43	4.64	Tasmania.
70.49	5.59	18.00	.93		4.99	France.
63.88	4.58	17.10	1.00		13.43	"
70.02	5.20	20.50	1.27		3.01	Switzerland.
61.20	5.00	23.50	1.28		9.02	Greece.
73.79	7.46	12.79	1.00		4.96	Bohemia.
70.12	3.19	7.59	"	3.63	15.47	Germany.
60.83	4.36	23.50	1.14	9.07	2.43	"
63.55	6.68	26.00	1.93		3.05	Persia.
47.46	4.50	32.00	1.03		14.95	Siberia.

Besides the common woody or coaly lignites, there are others of a pitchy nature, which soften even at a low heat, and are consequently unfit for fuel. Such singular beds are found in Arkansas and other districts of the United States, and used for the manufacture of lamp and lubricating oils—yielding about 68 gallons of crude oil per ton, with a large proportion of solid paraffin. Till lately, lignites were also distilled, on the Continent, for paraffin and its products; but now the large importations of American petroleum render the process altogether unprofitable.

Bituminous Coals.

As there are gradations from peat to lignites, so there are gradual passages from lignites to ordinary bituminous coal. Indeed, according to mineralogical systems, the Coal Family embraces peats, lignites, coals, anthracites, and graphites—the one passing gradually into the other, according to the degree of mineralisation they have undergone; or, in other words, according to their increasing amount of fixed carbon, and their decreasing amount of volatile ingredients. The following tabulation from Wagner's 'Technology' exhibits at a glance the successive stages and nature of this conversion :—

	Carbon.	Hydrogen.	Oxygen.
Wood, ...	52.65	5.25	42.10
Peat, ...	60.44	5.96	33.60
Lignite, ...	66.96	5.27	27.76
Earthy Brown Coal, .	74.20	5.89	19.90
Coal (secondary), . .	76.18	5.64	18.07
Coal (older), . . .	90.50	5.05	4.40
Anthracite, . . .	92.85	3 96	3.19

The bituminous coals are those which give off smoke and flame in burning, a long smoky flame being indicative of much free carbon, and a shorter and more luminous flame denoting that there will be much fixed carbon in the coke. The chief ingredient is carbon, in combination with varying proportions of hydrogen, oxygen, and nitrogen; and in all there exists a greater or less amount of earthy impurities, which, being incombustible, remain after burning as ashes. From their composition, which differs from vegetable or woody matter only in the diminished amount of its gaseous or volatile elements; from their internal structure, which, for the most part, exhibits to the naked eye, and almost always to the microscope, abundance of vegetable tissue; and from their lithological and other characteristics,—there can be no doubt of their vegetable origin. In other words, the bituminous coals, in all their varieties, are merely mineralised vegetation — vegetation which in part grew and was submerged *in situ* as peat-mosses, cypress-swamps, jungles, and forest-growths, and in part was *drifted* by rivers into the areas of deposit whose varied strata of sandstones, shales, fire-clays, coals, ironstones, and limestones now constitute our available coal-fields or coal-formations.

As the operations of nature are uniform and incessant, we have, of course, coals belonging to all geological periods;—non-bituminous *graphites* and *anthracites* in the older systems; bituminous *coals* in the carboniferous, triassic, oolitic, and cretaceous systems; *lignites* in the tertiary; and *peats* in the current epoch;—all of these products being merely vegetable masses in different stages of mineralisation and metamorphism. The available coals of Britain are chiefly of carboniferous age; but many excellent coal-fields in America, in India, the Indian Archipelago, and other countries, belong to the oolitic and chalk periods; while graphites and anthracites may belong to any period according to the metamorphism or debituminisation to which they have been subjected. Indeed, as our geological surveys are extended, it will yet be found that coals are products of all periods—differing, it is true, in the nature of the successive vegetable developments which contributed to their formation, and in the degrees of mineralisation they may have undergone, but essentially composed of the same inflammable elements.

Like other rocks, common bituminous coal presents many varieties; and these, according to their structure, texture, and qualities, have received various names,—as *caking coal*, which is soft and "tender" in the mass, like that of Newcastle, and swells and cakes together in burning; *splint* or *slate coal*, which is hard and slaty in texture, and burns free and open; *cannel* or *parrot*, which is compact and jet-like in texture, burns open with a clear candle-like flame, and, from its composition, is largely used in the manufacture of gas; and *coarse*, *foliated*, or *cubic coal*, which is more or less soft, breaks up in large masses, and contains, in general, a considerable percentage of earthy impurities. Besides these there is, of course, every gradation,—coals so pure as to leave only two or three per cent of ash; others so mixed as to yield from ten to thirty per cent; and many so impure as to be unfit for fuel, and so to pass into the category of *bituminous shales*.

As the bituminous coals differ in their composition and texture, so as *fuels* they differ in their fitness for certain purposes; hence such commercial terms as *steam coal*, *furnace coal*, *household coal*, *gas coal*, *coking coal*, *and oil coal*. Those suited for raising steam are usually hard, burn open, and give a strong white heat;

those suited for blast furnaces are free from sulphur and other impurities; a good household is that which burns with a cheerful flame and leaves comparatively little ash; gas coals are those which yield a large amount of dry incondensable gas; coking coal such as yield on smothered combustion a hard crystalline coke; and oil coals those which yield condensable gases at a low red heat for the manufacture of paraffin and other oils. There is no class of mineral substances so varied as the coals, differing not only in their structure and texture, but in their chemical composition, and in their special fitness for certain industrial purposes. The following analyses from the report of Sir H. de la Beche and Dr Lyon Playfair on "Coals suited for the Steam Navy" (Mem. Geo. Surv., vol ii.) exhibit the composition of several British varieties:—

Name of Place.	Sp. gravity.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.
SOUTH WALES:—							
Ebbw Vale,	1.27	89.78	5.15	2.16	1.02	0.39	1.50
Merthyr,	1.30	90.12	4.33	1.00	0.85	2.02	1.68
Plymouth Work,	1.35	88.49	4.00	0.46	0.84	3.82	2.39
Resolven,	1.32	79.33	4.75	1.38	5.07	in ash	9.41
Neath Abbey,	1.31	89.04	5.05	1.07	1.60	...	3.55
Llangennech,	1.31	85.46	4.20	1.07	0.29	2.44	6.54
Pontypool,	1.32	80.70	5.66	1.35	2.39	4.38	5.52
NEWCASTLE:—							
Willington,	...	86.81	4.96	1.05	0.88	5.22	6.48
Wallsend,	1.28	83.47	6.68	1.42	0.06	8.17	0.20
Hedley's Hartley,	1.31	80.26	5.28	1.16	1.78	2.40	9.12
Carr's Hartley,	1.25	79.83	5.11	1.17	0.82	7.86	5.21
Brownhill,	1.25	80.03	5.08	0.98	0.78	9.91	3.22
DERBYSHIRE:—							
Elsecar,	1.29	81.93	4.85	1.27	10.91	8.58	2.46
Park Gate,	1.31	80.07	4.92	2.15	1.11	9.95	1.80
Butterley,	1.30	80.41	4.65	1.59	0.86	11.26	1.23
Staveley,	1.27	79.85	4.84	1.23	0.72	10.96	2.40
LANCASHIRE—							
Inch Hall,	1.27	82.61	5.86	1.76	0.80	7.44	1.53
Pemberton,	1.34	80.78	6.23	1.30	1.82	7.53	2.34
Rushy Park,	1.28	77.76	5.23	1.32	1.01	8.99	5.69
Wigan Cannel,	1.23	79.23	6.08	1.18	1.43	7.24	4.84
Balcarres, 5 feet,	1.26	74.21	5.03	0.77	2.09	8.69	9.21
Moss Hall,	1.27	77.50	5.84	0.98	1.36	12.16	3.16
SCOTCH—							
Dunfermline, W.	1.20	76.09	5.22	1.41	1.51	5.05	10.70
Dalkeith,	1.31	76.94	5.20	trace	0.38	14.37	3.10
Eglinton,	1.25	80.08	6.50	1.55	1.38	8.05	2.44
Grangemouth,	1.29	79.85	5.28	1.35	1.42	8.58	3.52

Anthracite or Non-bituminous Coal.

Anthracite may be defined as a species of coal wholly, or almost wholly, deprived of its bitumen or volatile ingredients. It may be regarded as a natural coke or charcoal, formed by subterranean or chemical heat. Ordinary bituminiferous coal is often found converted into a kind of coke by the contact of igneous rocks; and in this way some anthracites may have originated, though the majority seem to be the result of that slow change or metamorphism which all rock-masses undergo in the course of ages. As a mineral, anthracite occurs massive and amorphous, has a subconchoidal fracture, less or more of a metallic lustre, of a greyish-black or iron colour, streak unaltered, conducts electricity perfectly, and burns with a very weak or no flame. It varies greatly in composition, though good American sorts generally yield about 90 carbon, 3 hydrogen, and 5 ashes, and the remainder oxygen and nitrogen. Submitted to the microscope, either in thin slices or in a state of ash, many varieties exhibit the vegetable structure, and leave no doubt as to the vegetable origin of all. Though not so generally convenient for fuel as ordinary coal—requiring more care in kindling, and a strong draught when kindled—it is rapidly rising in importance for the manufacture of the metals, for steam-raising, and even for household purposes, the United States consuming annually about 8 million tons.

Anthracite, or at least anthracitic coals, are not uncommon in some of the Welsh and Scottish coal-fields. It occurs in Switzerland, France, and Germany; and is especially abundant in the United States, as in Rhode Island, Massachusetts, and above all in Pennsylvania, where it seems to be an altered portion of the common bituminous coal of that region. The following analyses exhibit its ordinary composition:—

Sp. grav.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Ash.	Coke per cent.	Evap. power.
1.375	91.44	0.21	0.21	2.58	0.79	1.52	93	9.46
...	90.58	3.60	2.85	3.81	...	1.72	...	...
1.700	88.00	2.84	0.46	2.00	0.66	1.80	90	8.50
1.810	83.00	3.00	0.50	1.88	...	2.00	79	...

Or, taking some of the more esteemed varieties found Wales, France, and the United States, we have:—

	Carbon.	Volatile matter.	Ashes.
WALES:—			
Neath Abbey, ...	91.08	5.01	4.00
Swansea, ...	89.00	7.50	3.50
Ystalyfera, ...	92.46	6.04	1.50
Cwm Neath, ...	93.12	5.22	1.50
FRANCE:—			
Cote d'Or, ...	82.60	8.60	8.80
Mais Saize, ...	83.30	7.50	8.50
PENNSYLVANIA:—			
Beaver Meadow, . . .	92.30	6.42	1.28
Shenoweth Vein, . . .	94.10	1.40	4.50
Black-spring Gap, . .	80.57	7.15	3.28
Nealey's Tunnel, . . .	89.20	5.40	5.40
MASSACHUSETTS:—			
Mansfield Mine, . . .	97.00	—	3.00
RHODE ISLAND:—			
Portsmouth Mine, . .	85.84	10.50	3.66

Besides the larger and purer sorts of anthracite employed in steam-raising and metallurgy, there are soft, earthy, and pulverulent varieties known as *culm*, *bastard stone-coal*, *lambskin*, &c., which are used for lime-burning and other inferior purposes, or mixed with clay and formed into balls as a cheap household fuel.

The preceding fossil fuels—whether peat, lignite, bituminous coal, or anthracite—are all of vegetable origin, and only differ in the degree of mineralisation to which they have been respectively subjected. This is most convincingly seen from their chemical analyses, which exhibit the gradual loss of the gaseous elements, and the increase of fixed carbon in the passage of wood into peat, of peat into lignite, of lignite into coal, and of coal into anthracite and graphite. Thus:—

(At 212°)	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Inorganic Ash.
Wood, . .	48.94	6.10	35.45	...	...
Peat, . .	56.66	5.9	18.33	2.4	1.6
Lignite, . .	56.70	3.7	13.27	1.0	1.13
Coal, . .	70.92	2.6	1.8	0.2	3.15
Anthracite, .	74.94	1.4	0.3	trace	1.7
Graphite, .	90.98	...	...	...	1.7

According to M. Fremy the following are the degrees of alteration of woody tissue: 1. *Turf and Peat.*—Characterised by the presence of ulmic acid, and also by the woody fibres or the cellules of the medullary rays, which may be purified or extracted in notable quantities by means of nitric acid or hypochlorites, in which they are insoluble. 2. *Fossil Wood* or *Woody Lignite.*—This, like the preceding, is partially soluble in alkalies, but its alteration is more advanced, for it is nearly wholly dissolved by nitric acid and hypochlorites. 3. *Compact* or *Perfect Lignite.*—This substance is characterised by its complete solubility in hypochlorites and in nitric acid. Alkaline solutions do not in general act on perfect lignites. Reagents in this variety show a passage of the organic matter into coal. 4. *Coal.*—Insoluble in alkaline solutions and hypochlorites. 5. *Anthracite.*—An approximation to graphite; resists the reagents which act on the above-mentioned combustibles, and is only acted on by nitric acid with extreme slowness.

Coke.

Coke, or carbonised coal, which is now largely used as a fuel for metallurgical purposes, may be regarded as an artificial anthracite. It is extensively prepared in the north of England from the smaller dross of the coking-coal of that district, and when well burnt from carefully cleaned material, consists of from 85 to 92 carbon, 3 to 5 ash, and 5 to 10 hydroscopic moisture. The amount of coke obtained from different coals varies very widely, some yielding upwards of 80 per cent, and others less than 50; but both amount and quality depend greatly upon the mode of treatment. The main purposes to be subserved by the manufacture of coke are—the concentration of the carbon so as to yield a more intense heat than coal; to get rid of unpleasant vapours and odours; to prevent caking and produce free burning in the furnace; and to get quit of as much as possible of the sulphur which may be contained in the pyrites of the coal. It is prepared in ovens, kilns, and retorts, but almost exclusively in ovens, hundreds of which are now utilising thousands of tons of dross and culm, which thirty years ago were consumed at the pithead as worthless, or never brought to bank.

There are various constructions of oven (French, German, and English), and various methods of cleaning and washing the raw material, the main object being to produce a hard, uniform, and compact coke, as free from sulphur and earthy impurities as possible. In some ovens the gases and vapours evolved during the combustion of the coal escape unused; in some they are collected and used as fuel for coking the coal, &c.; and in others they are condensed, collected, and utilised for the preparation of ammoniacal salts. Like anthracite, coke is ignited with difficulty, requires for kindling a strong red heat, and a steady blast or draught to insure continuous burning. The preparation of coke is annually on the increase, especially for iron and steel manufacture; and one has only to observe the thousands of truck-loads which daily pass along the Durham railways to be convinced that it has now become one of the staple industries of the country. The amount carried from Durham to Cleveland and Barrow-in-Furness is of itself sufficient to prove the magnitude and importance of this variety of fuel.

Petroleum—Crude Oil—Coal-Gas, &c.

Native petroleum, the crude oil obtained from the distillation of bituminous shales, and coal-gas, have recently been the subjects of experiment to see how far they could be regulated and rendered available as heating materials. The experiments have hitherto been somewhat unsatisfactory when conducted on the large scale; but this has arisen more from the nature of the appliances than from the character of the materials employed. The theoretical evaporative power of petroleum, paraffin-oil, and coal-gas, far exceeds that of coal or anthracite; and if proper appliances could be invented and the materials produced at available prices, there seems no reason why substances so concentrated and unattended by refuse should not be employed, even on the largest scale. In the mean time, for small steam-boilers, for lamps, grates, stoves, and similar domestic purposes, oils and gases are coming more and more into use as cheap and effective fuels.

Patent or Artificial Fuels.

Under this name a great many compounds (most of them patented) have recently been brought before the public, and especially since the increased price of ordinary pit-coal. The bases of most of these fuels are coal-screenings, dust or dross, with various admixtures of coal-tar, clay-liquor, or pulped peat, to give them coherence and consistence. During the last and early in the current century, similar attempts were made to utilise coal-screenings, slack, and dust, by semi-fusing or caking the material and pressing it into moulds; but these attempts failed, partly from the expensive nature of the processes, and partly from the difficulty of igniting the blocks which had been largely deprived of their bitumen. Now, the raw material is simply mixed with some pulpy or tenacious substance to give it coherence, and compressed into blocks of convenient dimensions. In some instances the coal or coke waste is washed before being used; but in all, the material is granulated or reduced to fragments, incorporated with the liquor or pulp, and then pressed into blocks or briquettes of greater consistency than either coke or coal. From their shape these briquettes can be stored away in small space on board ship; and for domestic use afford a cleanly and cheerful fuel.

As yet the consumption of these artificial fuels has not been on a large scale in Britain, but on the Continent several of them (Peras, Parisian Coal, Charbon Briquettes, &c.) are in considerable demand at about two-thirds the price of ordinary household coal. The amount of patent fuel prepared in Britain during the year 1872 was about 230,000 tons, of which not fewer than 207,241 were exported to foreign countries. Of these fuels, Wylam's, Barker's, Bell's, &c., are well spoken of, and may, under the continued high price of coals, come more largely into use. In America, the artificial fuel of Capt. Hays (an admixture of anthracite dust, clay-pulp, and coal-tar) is highly commended, and can be produced at little more than half the price of the anthracite itself. The following are analyses of some of these artificial fuels:—

	Sp. grav.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Coke.
Wylam's, . .	1.10	79.91	5.69	1.68	1.25	6.69	4.94	65.8
Bell's, . .	1.14	87.88	5.22	0.81	0.71	0.42	4.96	71.7
Warlich's . .	1.15	90.02	5.56	trace	1.62	in ash	2.91	85.1
Barker's, . .	1.28	92.00	*	...	1.05	...	4.00	87.5
Livingstone's, .	1.18	85.07	4.13	...	1.45	2.03	4.52	...
Lyon's, . .	1.13	86.36	4.56	...	1.29	2.07	4.66	...

* Volatile matters, 6.70.

II.—LIGHT-PRODUCERS.

The conversion of wood, vegetable and animal oils, fats, wax, gums, and resins into inflammable gases, is the usual and primitive mode of supplying artificial light; but as man gathers in large communities and requires more brilliant and abundant illumination for his cities, workshops, and public buildings, the primitive sources become insufficient, and, as in the case of fuels, he has to have recourse to the mineral kingdom. From this he derives certain hydrocarbons — naphtha, petroleum, asphalt, bituminous shales, and coals; and from these, by chemical and mechanical appliances, he obtains the most copious and brilliant illuminating materials. Naturally the hydrocarbons are very volatile and unstable, and thus, on exposure to the air, pass into each other—limpid naphtha into petroleum, petroleum into mineral pitch or bitumen, and bitumen on further exposure into asphalt. Without much scientific error they may be described under the following heads:—

Gas and Naphtha Springs.

In the working of coals and lignites, and occasionally in boring in carboniferous, lignitiferous, and saliferous districts, discharges of carburetted hydrogen are met with, and those in some instances have been collected and lighted. In the neighbourhood of Fredonia, State of New York, a gas-spring from bituminous limestone is said to yield about 800 cubic feet in twelve hours, and this is collected and used for lighting the locality. According to Fouqué, it is an admixture of marsh gas (CH_4) and hydride of ethyl (C_2H_6). The salt-mine of Szlatina, in Hungary, is also said to be lighted by gas exuded from its beds of bituminous marl-clay; and in China, according to the Rev. Mr Imbert, gas springs from the salt-bearing beds of Szu Tchouan are collected and carried in bamboo tubes both for the purposes of lighting and heating. In our own coal-fields (as at Killingworth, Jarrow, and Usworth, near Newcastle) blowers of gas are sometimes persistent for years, though not, so far as we are aware, turned to any useful account. Generally speaking, however, such issues are uncertain, and after a few months' or years' escape, get exhausted, and disappear. Gas-springs occur also in volcanic and convulsed tracts, but are usually too varied in their composition and too uncertain in their discharge to be used economically.

Naphtha, which is a limpid, volatile, and highly inflammable variety of bitumen, is found exuding from rocks and soils in volcanic countries, and also in tracts where coals and lignites seem to be undergoing a slow natural process of distillation. One of the finest and purest varieties is that obtained from Baku and Scamachia on the western shores of the Caspian, where it rises from calcareous rocks in the state of an odorous inflammable vapour, or is collected in the liquid state by sinking shallow wells. Naturally it is of a yellowish colour, but may be rendered colourless by distillation. Its specific gravity is about .75; it boils at 160°, and appears to be a pure hydrocarbon, consisting of 86 carbon and 14 hydrogen. Most of the naphtha of commerce is obtained from the distillation of coal-tar, or directly from coals and bituminous shales. Owing to its volatile nature, it is somewhat dangerous as a lighting oil, and requires great care in its manipulation.

Petroleum and Oil-Wells.

Petroleum, or rock-oil, so called from its oozing out from certain strata like oil, is usually of a dark yellowish-brown colour, more or less limpid, according to external temperature, and consists of 88 carbon and 12 hydrogen. It occurs in various formations, chiefly in connection with fields of coal and lignite, and appears to arise from the decomposition or distillation of the strata by slow subterranean heat. In general, it comes to the surface associated with water; hence the "oil-wells" of America, Canada, Trinidad, Persia, Burmah, and other countries, which are now largely worked for distillation and rectification into illuminating oils, naphtha, and other similar products. Many millions of gallons are annually procured from the preceding districts; and when properly rectified, and burned in suitably constructed lamps, the paraffin-oils afford at once a safe, brilliant, and economical light. "A good petroleum oil (Dingl. polyt. J., ccxi. 76) should be colourless or light yellow; its smell should not be unpleasant; its specific gravity at 15° should not exceed 0.804, and should not be under 0.795. When shaken with a mixture of equal volumes of sulphuric acid and water, it should impart a pale yellow colour to the acid, and itself become less coloured; and finally, heated to 34°, it should not burn when a light is applied."

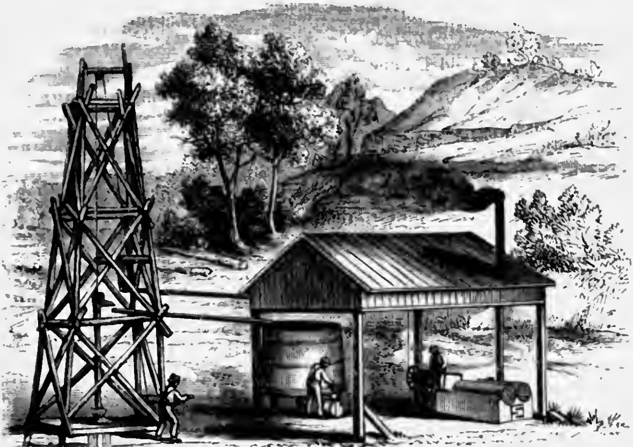
While petroleum occurs most abundantly in carboniferous and lignitiferous formations, it is found also in strata of all ages, from the Silurian upwards. The oil-wells of Canada flow from Silurian and Devonian rocks; those of the United States from Devonian and carboniferous; those of Trinidad from tertiary lignites; those of the Caspian and Persia from tertiary shales and limestones; and those of Rangoon from tertiary and post-tertiary clays and lignites. Indeed, mineral oil seems to be a product of all ages; and while the greater portion undoubtedly arises from the slow decomposition of vegetable matter, some of it may also be due to the decomposition of animal remains—fishes, shell-fish, crustacea (the trilobitic shales of Canada), and the minuter forms of life—which enter largely into the composition of many shales, limestones, and other strata. Abich has suggested that bitumen may be a *primitive compound*, engendered in the interior of the earth, like carbonic acid and nitrogen, the real origin of which is also unknown; but in the present state of our knowledge, the decomposition of organic (vegetable and animal) substances offers the most satisfactory solution.

In many instances the petroleum merely oozes or trickles out from the crevices of rocks; in others it oozes through clays and sands, and can be collected in shallow wells: in some cases, it comes up with springs of water, and floats on their surface; in others, as in North America, when the oil is "struck," it bursts forth from the bore-hole in conjunction with water with great force, as if it had been pent up in subterranean reservoirs; and not unfrequently in such wells its flow is intermittent and irregular. "The average depth" (says Dr Gesner, writing in 1861) "at which oil is obtained, has not yet far exceeded 250 feet.* Deeper sinkings may hereafter be found profitable. Carburetted hydrogen gas frequently escapes from the pipe, when it is first let down into the earth, and sometimes salt water rises with the oil. So great is the discharge of the petroleum in some instances, that sufficient vessels cannot be obtained for its reception, and it runs in oily streams over the surface. Some springs yield 200 barrels a-day; and a reservoir near Tideout, Erie county, Pennsylvania, when first struck, discharged 300 barrels. Accurate records have not been kept of all the strata penetrated; but they appear to consist chiefly of limestone, sandstone, and shale." We may add that at the present moment (1874) several springs are said to be running 500 barrels a-day; hence the unequal and unprofitable competition between the British shale-oil manufacturer and the American importer.

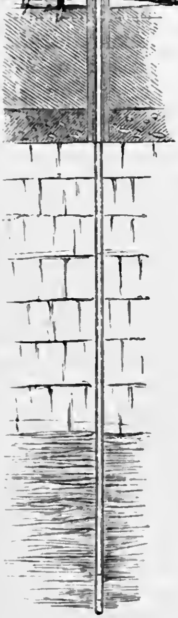
In whichever way the supply may be obtained, the trade in mineral oil has, during the last fourteen years (since 1859), assumed most gigantic proportions, and has become a new source of industry and wealth, not only in America and Canada, but in Trinidad, Italy, Spain, Switzerland, Germany, Turkey, Russia, Persia, and Burmah. Indeed, the occurrence of petroleum may be said to be world-wide, though few regions can vie with those of the Caspian, Rangoon, California, Canada, and the United States, where the oil-region includes a vast tract of country (computed at 63,000 square miles) running parallel with the Alleghany Mountains, and extending from Lake Ontario on the north, to the valley of the Kanawha, in Virginia.

* In Canada, many borings have been carried down to 500 feet, and occasionally without striking oil. When this happens, the bore is said to be a "dry hole;" and it is not unusual to send down an "earthquake shell," which, on explosion, so shatters the surrounding rock as to let in the oil from any veins or fissures that may lie within the sphere of its action.

The natural distillation of bitumen is a slow and gradual process, and may go on for ages, or in other words, till the



American Oil-Well (after Gesner).



vegetable masses producing it be thoroughly debituminised. The petroleum well of St Catherine's, near Edinburgh, arising from lower carboniferous shales, is mentioned early in the fifteenth century, and it still yields a small but regular amount of dark-brown bitumen, which floats as a scum on the slowly issuing water. Oil-wells, like many of the North American, which gush forth with great violence at first tapping, gradually become weaker, and often cease altogether. In such cases, what nature has been distilling and accumulating under pressure for ages, is rapidly discharged from the bore-holes, and the future supply is thus limited to the amount which nature annually distils. If the bituminiferous rocks be still undergoing metamorphism, a certain amount of petroleum may be looked for; but if the metamorphism has become complete, no further supply can be obtained. In either case the oil-supply of America, gigantic as it is, must by-and-by diminish, and all the more rapidly, the more extensively and energetically the area is tapped and drawn from. On an average, one hundred barrels of crude or natural petroleum yield about seventy-five of refined oil.

Solid Bitumens—Pitch, Asphalt, &c.

Bitumen, in its purest and most fluid state constitutes *naphtha* (86 carbon, 14 hydrogen); when of the consistence of oil, it is known as *petroleum* (1 to 8 per cent of nitrogen, oxygen, and ashes); in its next state of inspissation it is called *maltha*, or slaggy mineral pitch; then *elaterite*, or elastic bitumen; and ultimately, on further exposure to the air, it becomes indurated into *asphalt*, which varies considerably in purity—some specimens yielding from 8 to 14 per cent of oxygen and nitrogen, and from 4 to 6 of inorganic ashes. Besides mineral pitch and asphalt, there are other viscid and solid hydrocarbons, as elaterite, hatchetine, ozokerite, &c.; but with the exception of maltha, asphalt, and ozokerite, none of them appear in such quantities as to be of commercial importance. Available accumulations of pitch and asphalt are found in Trinidad, Barbadoes, Cuba, Canada, Virginia, Texas, France, Switzerland, Turkey, Persia, and India—sometimes in solid exudations, as in Trinidad, Texas, and Virginia, and in other cases in combination with gravels, sandstones, and limestones. "The celebrated pitch-lake of Trinidad, says Dr Gesner, is upwards of three miles in circumference, and forms the head of La Brae harbour. At the time of my visit, the bitumen, of the consistence of thin mortar, was flowing out from the side of a hill, and making its way outwards over more compact layers towards the sea. As the semi-solid and sulphureous mineral advances and is exposed to the atmosphere, it becomes more solid; but ever continues to advance and encroach upon the water of the harbour. The surface of the bitumen is occupied by small ponds of water, clear and transparent, in which there are several kinds of fishes. The sea, near the shore, sends up considerable quantities of naphtha from submarine springs, and the water is covered by an iridescent film of oil. In the cliffs along the shores there are strata of lignite, in which it has been supposed by some the bitumen and naphtha have their origin."

Whatever their origin and mode of occurrence, these bitumens require conversion either into oils or gases before being available for lighting purposes, and several ingenious processes are in use for such conversion. The mineral fats and tallows are rarely in abundance sufficient for economic uses; but where, like the ozokerites of Galicia and Bohemia, they occur in considerable quantities, they are usually distilled, and converted into paraffin-oil for lamps, and into solid paraffin for the manufacture of candles. The Galician ozokerite is said to contain about 25 per cent of solid paraffin, while the Scottish oil-shales ordinarily yield not more than 2 per cent. Other substances fitted for the production of oils have more recently come into notice, such as the "turbite" of Brazil, the "white coal" of Australia, and the "Waitata shale" of New Zealand, all of which seem to be recent clayey deposits largely impregnated with bitumen.

Albertite or Albert-Coal.

Another bituminous mineral, known as *Albertite* or *Albert-Coal*, from its occurrence at Hillsboro', Albert County, New Brunswick, is also of importance as an abundant light-producer. At Hillsboro' it appears as an injected vein, situated almost vertically in the earth, and from one to sixteen feet in thickness. It is associated with rocks highly charged with bitumen, and has neither roof, floor, nor other accompaniments which distinguish seams or beds of true coal. As a mineral, it is black and brilliant as jet, breaks with a fine conchoidal fracture, and does not soil the fingers. It melts and drops in the flame of a candle, and dissolves in naphtha and other solvents, forming a varnish. It has all the essentials of an asphalt, and according to Gesner consists of carbon, 85.40; hydrogen, 9.200; nitrogen, 3.06; sulphur, a trace; oxygen, 2.22; and ash, 0.12. On an average it yields 110 gallons of crude oil per ton, of which 70 per cent may be made into a brilliant lamp-oil.

This mineral has also been discovered in veins near the junction of the Old Red Sandstone and Metamorphic Schists of Sutherlandshire, in Scotland; but the veins rarely exceeding one or two inches in thickness, render it commercially unavailable. It is of very fine quality, however, being even more compact and lustrous than the Hillsboro' variety.

Peat.

It has also been attempted to employ peat, which occurs in inexhaustible supplies, as a light-producer. Good varieties of Irish peat are said to have yielded to the Irish Peat Company 3 lb. of paraffin, 1 gallon of lamp-oil, and 2 gallons of lubricating oil per ton. In Sir James Matheson's work at the Lews, 100 tons of peat give, it is said, about 7 per cent of tar, which yielded, on an average, a weekly produce of 749 gallons of illuminating oil. When prices were at 2s. a gallon, this gave a handsome profit; but petroleum has not for years brought half the sum, hence the discontinuance of the oil-manufacture, and the application of the tar to ship-yard purposes. So long, indeed, as the richer petroleums, bituminous shales, and oil-coals, can be had in abundance, it seems impossible to utilise peat in this direction.

Bituminous Shales.

In many geological formations—tertiary, cretaceous, oolitic, triassic, and carboniferous—there occur dark coaly-looking beds, generally known as *bituminous* or *bituminiferous shales.* Some of these approach almost to the character of coals, while others are merely dark-coloured argillaceous strata. They are all evidently old estuarine and marine muds, and differ in aspect and quality according to the amount of vegetable matter that enters into their composition. Geologically, they occur interstratified with the sandstones, limestones, fire-clays, coals, and ironstones of their respective formations, and vary in thickness and quality like the other strata, some beds being wholly available for the retort, others only partially so, and some very thick beds having one or more layers of superior richness. They are mined like ordinary coals, but, from their tough flaggy character and unequal thickness, require a somewhat special manipulation.

Some of the wealden and oolitic shales are of fair quality, and might be distilled for certain purposes—fuel and gas-making—but not, according to past manufacturing experiences, for illuminating oils.* It is chiefly those of the carboniferous system that since 1858 have been brought into use for the distillation of paraffin and paraffin-oils—crude or lubricating oil, rectified or light oil, solid paraffin, mineral spirits, and ammonia, being among the products obtained during their distillation and rectification. Bituminous shales occur in most of our British coal-fields; but hitherto it has been mainly those in the lower coal-measures of Linlithgow, Lanark, Ayrshire, Fife, and Mid-Lothian, that have been largely raised for this species of manufacture. Indeed, the mining and distillation of

* According to Dr Hoffman, the Kimmeridge shale yields to analysis :—

Mineral matter,	23.5
Carbon,	19.5
Light oil,	2.3
Heavy oil, containing 1.9 per cent paraffin,	36.7
Gas, water, ammonia, &c.,	18.0
	100.0

shales have created quite a revolution in the industry and aspect of some districts like Linlithgowshire; and estates which sixteen years ago brought only a few hundreds per annum to their proprietors now bring as many thousands, and hamlets of a few houses are now large and busy towns. All this has arisen since the introduction of Young's process for the distillation of coals and shales at a low red heat, whereby condensable gases are given off, and these subsequently reduced to crude oil, and the crude oils rectified into light paraffin-oil—solid paraffin, ammonia, mineral spirits, &c., being among the usual products of rectification and treatment. Few branches of industry have had such a marvellous and rapid rise as that of the production of shale-oils; and as the supply of the raw material is practically unlimited, and the pressure on gas-coal becomes more and more severe, we may still look forward to its further extension and improvement not only for the manufacture of paraffin-oil and paraffin-candles, but for the production of crude oils for conversion into dry gas for the lighting of workshops, factories, and country mansions.

Many of the shales now used yield from 18 to 80 gallons of crude oil per ton, a superior shale being characterised by its lightness, toughness, or "boardiness" as the miners term it, and by its brown streak. The following are analyses of some of the better known oil-yielding substances, as given by Dr Gesner in his 'Treatise on Coal, Petroleum, and other Distilled Oils,' and by other authorities:—

Locality.	Volatile matters.	Coke.	Gallons of crude oil per ton.
Torbane Mineral, . .	70.10	29.90	120
Lesmahago Cannel, . .	51.	49.	96
Leeswood Green Cannel, .	...	12.	90
Kimmeridge Shale, .	...	...	11½
Wigan Cannel, . .	44.	56.	74
Derbyshire Cannel, . .	48.36	53.	82
Poole Shale, . . .	42.	58.	50
Newcastle Coal, . .	35.	65.	48
Albertite, N. Bk., . .	61.30	30.65	110
Stellarite, Nova Scotia, .	65.56	25.23	100
Hartley Cannel, N.S.W., .	...	...	140
Asphalt Rock, . . .	43.	57.	64
Pictou Shale, N.S. . .	27.	73.	47
Breckenridge Coal, U.S., .	61.30	30.65	130
Arkansas Bitumen, . .	60.	60.	64
Canada Petroleum, . .	70.	30.	118
Virginian " . .	60.	40.	170
West Lothian Shales, .	...	...	25-45

Cannel Coals—Gas-Coals.

However useful and well adapted for many purposes the naphthas, petroleums, paraffins, and paraffin-oils may be, there is no lighting substance as yet known so convenient, so easily distributed, so eminently under control, and withal so brilliant, as common illuminating coal-gas. Compare the gas-jets of our streets, shops, and factories with the whale-oil lamps of fifty years ago, and it will at once be admitted that few inventions have been so useful and successful as the manufacture and distribution of this familiar illuminator. Under proper treatment any variety of bituminous coal will yield an illuminating gas, and a great proportion of our towns derive their supplies from this source. Of course, bituminous coals vary much in their quality; and while some, like the best Newcastle, will yield from 9000 to 9500 cubic feet per ton, others of a harder and drier nature will yield little more than half that amount. Again, some are freer from sulphide of iron and other impurities, and require less purification; others, after distillation, leave a firm and available coke; while many that yield a fair percentage of gas leave but a soft and worthless residue.* In the choice of a coal the gas-manufacturer has to take these and other circumstances into consideration, and it is greatly owing to his skill in selection and treatment whether a gas-work will yield a satisfactory or unsatisfactory return to its shareholders. Indeed, eminent as many of our gas-engineers undoubtedly are, there is still much to be learned in the matter of retorts, the nature of coals, the temperature of distillation, the subsequent processes of purification, and the utilisation of by-products.

But while ordinary bituminous coals are used in many, perhaps in the majority of gas-works, the "cannels," "parrots," or, as they are often termed, "gas-coals," produce, on the whole, not only a larger amount, but a superior quality of illuminating material. These cannels, like other coals, vary in appearance and quality; but, generally speaking, they are compact and jet-like in texture, brittle, break with a conchoidal fracture, are more or less lustrous, and do not soil the fingers when handled. They occur most abundantly in the Lancashire, Yorkshire, North Wales, and Scotch coal-fields; and are said to be called "cannels" from the candle-like flame they emit—and "parrots," by the Scotch miners, from the sparkling and crackling way in which they fly off in splinters when first thrown on the fire. Sometimes they occur in independent seams, but not unfrequently they form the upper portion of a splint coal, or even of a bed of blackband ironstone. Geologically, they seem to have arisen from a more thorough maceration of the vegetable mass, and under such conditions

* In some of the towns of Bohemia, where gas is made from lignite, a small proportion of ordinary coal is added, and this improves the coke without deteriorating the quality of the gas.

as permitted of a more equable bituminisation than ordinary coal. Their maceration is proved by the remains of shells and fishes (teeth, fin-spines, bones, and coprolites) which many of them imbed; and further, by the fact that they sometimes pass into coaly blackbands, and, *vice versa*, coaly blackbands into cannels.

While eminently gas-producers of the finest quality, the main objection to these coals by the gas-manufacturer is that they yield an inferior coke, and often no coke in the proper sense of the term, but a soft pulverulent residue of carbon and clay. Before the introduction of coal-gas these cannels were all but rejected, but since then they have gradually risen in demand; and what fifty years ago was scarcely worth 5s. a ton are now selling at 25s. and 30s., and even at higher figures. Several of these cannels—those of Wigan in Lancashire, Wellsgreen in Flintshire, Lesmahagow in Lanarkshire, and Wemyss and Capeldrae in Fife—have a high reputation as gas-producers, though none of these can compete in cubic feet per ton with the brown "boardy" cannel of Boghead, Bathville, and Torbanehill in Linlithgowshire, which is now all but exhausted, and in 1873 brought as much as £4 per ton for paraffin purposes. As a general rule, however, the larger the amount of gas the more worthless the coke; hence the objection of the gas-manufacturers to these rich cannels, and hence also the common practice of mixing them with poorer and better coking varieties. The following tabulation exhibits some of the better known cannels, and their average yield of gas per ton:—

Boghead or Torbane Mineral,	14,880 cubic feet per ton.
Methil or Pirnie, Fifeshire,	13,500 ,, ,,
Overtown, Lanark,	13,000 ,, ,,
Capeldrae, Fifeshire,	12,500 ,, ,,
Rocksoles, Lanark,	11,900 ,, ,,
Kirkness, Kinross-shire,	11,800 ,, ,,
Lesmahagow, Lanark,	11,680 ,, ,,
Adamhill, Ayrshire,	11,600 ,, ,,
Rigside, Lanark,	11,500 ,, ,,
Wigan, Lancashire,	11,500 ,, ,,
Wellsgreen, Flintshire,	11,400 ,, ,,
Wemyss, Fifeshire,	11,000 ,, ,,
Arniston, Mid-Lothian,	10,800 ,, ,,
Skatrig, Lanark,	10,400 ,, ,,
Lochgelly, Fifeshire,	9,500 ,, ,,

Such are the Heat and Light Producers obtained from the crust of the earth. They are all of vegetable origin, and differ in structure, texture, and composition, partly according to the conditions under which they were accumulated, but chiefly according to their age and the amount of mineralisation they have undergone. As we have already shown, there is a gradual passage from existing vegetable growths to peat, from peat to lignite, from lignite to coal, and from coal to anthracite. It is thus that the coal family presents so many varieties, and that these varieties, in the distillation or metamorphism they have undergone or are still undergoing, produce so many hydrocarbons both in the gaseous, the liquid, and solid conditions. They occur in every formation, but it is chiefly in the older systems that they acquire their greatest thickness, compactness, and regularity. Many coal-fields are no doubt unknown, many are being worked, and many are wellnigh exhausted; and considering the rapidly increasing consumption * in an age so thoroughly mechanical as the present, every care should be taken not only to utilise these fossil fuels and light-producers by the most economic methods, but to see that they are extracted from the crust to the utmost extent compatible with surface amenity and the safety of the miner.—See Chapter VIII. on "Mine Engineering."

The subjoined table, from Hunt's 'Mineral Statistics,' shows the amount of coal raised during the year 1872 from the various coal-fields of England, Scotland, and Ireland:—

	Tons.
North Durham, Northumberland, and Cumberland,	13,010,000
South Durham,	17,395,000
Yorkshire, Derbyshire, Nottinghamshire, Warwickshire, Leicestershire,	10,657,100
South Staffordshire and Worcestershire,	10,550,000
North Staffordshire, Cheshire, Shropshire,	6,327,188
Lancashire, North and East,	9,363,236
West Lancashire and North Wales,	9,000,000
Gloucestershire, Monmouthshire, Somersetshire,	7,000,000
South Wales,	10,131,720
Scotland, East,	9,046,814
Scotland, West,	6,336,795
Ireland,	103,463
Total produce of the United Kingdom,	123,497,316

With this enormous and gradually increasing output, the question naturally arises—and it is a most momentous one—

* Some idea of this increasing consumption may be formed from the fact that in Great Britain the coals raised in 1860 amounted to 80 millions of tons; in 1868 to 104 millions; in 1869 to 108 millions; in 1870 to 113 millions; and in 1872 to 123 millions.

How long will it be before the coal-fields of Britain become exhausted? This is a difficult problem to solve, and one which involves so many considerations, that it is impossible to arrive at more than a mere approximation. In the first place, the extent of our coal-fields is not exactly ascertained, as much may exist beneath the younger and overlying formations; secondly, more skilful modes of working may extract and bring to bank a much larger percentage; thirdly, new methods may utilise much that has hitherto been regarded as waste and worthless; fourthly, as the price increases, the thinner and inferior seams not now worked will be extracted; fifthly, with increased prices more economic modes of consumption will be devised; sixthly, compressed peat and cheap artificial fuels will tend to lessen the demand for high-priced coals; and lastly, for many minor purposes where coals are now employed, recourse will again be had to water and wind power, while engineering skill will utilise in the ebb and flow of the tides a titanic force at present all but overlooked and neglected. But with all these checks and auxiliaries there will still be a continuous demand for furnaces, forges, factories, steam-engines, steam-ships, railways, and domestic fires; and this demand upon a limited supply must sooner or later bring it to an end. Four or five hundred years at most and Britain must cease to be a coal-producing country; and with that cessation, the mechanical arts and industries for which she now stands unrivalled will pass away to other regions where sources of heat and light are at once the most attainable and the most abundant.

Works which may be consulted.

Report of the British Coal Commission, 1871; Hull's 'Coal-Fields of Great Britain;' Taylor's 'History and Statistics of Coal;' Wagner's 'Handbook of Chemical Technology;' Knapp's 'Chemical Technology,' vol. i.; Gesner's 'Treatise on Coal, Petroleum, and other Distilled Oils.'

X.

GEOLOGY AND THE FICTILE ARTS.

THE manufacture of Earthenware and Glass in all their qualities, forms, and varieties, is the object of the Fictile Arts. From substances the most common and familiar—from the clays and sands which are scattered in superficial abundance around us—the potter and glass-worker, by skilful admixture, manipulation, and treatment, can produce the most gorgeous articles of utility and ornament. Few substances are more dissimilar than the sands of the sea-shore and the most transparent crystal; few things more unlike than the produce of the clay-pit and a service of semi-translucent porcelain: and yet, in either case, the one is but a scientific metamorphism of the other. Whether in the preparation of earthenware or of glass, almost all the substances are obtained from the mineral kingdom—the admixtures, colours, pigments, glazes, and enamels. Few triumphs of art are more decided than those of the potter and glass-worker; few branches of industry can boast of fabricating from substances apparently so worthless such useful and beautiful productions. Without entering into details of the technical means by which the Fictile Arts have achieved their success, we shall here restrict ourselves to a brief account of the mineral substances employed in their various processes and manipulations. And first of—

I.—THE CLAYS WE FABRICATE.

All the clays are essentially hydrous silicates of alumina, more or less mingled with mineral impurities, and coloured by the presence of metallic oxides and organic matter. Generally speaking, they are soft, sectile, and plastic, and emit, when breathed upon, a peculiar odour, known as the clayey or argillaceous. The majority are superficial deposits, occurring in estuaries, desiccated lake-sites, river-valleys, and upraised sea-beds, or scattered over the surface as drifts or boulder-clays. They are also found in tertiary formations sufficiently soft and plastic for the purposes of the potter and brick-maker; but in the older formations, with the exception of some beds in the lias and oolite, they become more compact, and pass into the texture and consistency of shales and clay-slates. As sedimentary deposits, resulting from the waste and decomposition of pre-existing rocks, they occur in various states of purity and plasticity—some being pure, unctuous, tenacious, or *long* clays as they are termed—and others impure, meagre, and *short*, or deficient in tenacity. Whatever their natural characters, they are all improved by being dug in summer, laid out in heaps of moderate thickness, and exposed to the action of air and frost, during which they undergo a kind of fermentation or internal decomposition. This ripening or tempering, as the workmen term it, greatly improves their quality, and is no doubt the result partly of chemical change, as the decomposition of lime, pyrites, &c., and partly of mere mechanical disintegration. Besides this mellowing, most of them have to undergo various processes of washing, crushing, pugging, and admixture, according to the fabric for which they are intended—a clay fit for a common brick being unfitted for a fire brick, and a clay suited for common or brown earthenware being altogether unsuitable for porcelain or china.

Pure clay (silicate of alumina) is refractory—that is, capable of resisting intense heat; and one essential requisite in a good clay is, that it should not contain iron oxide, lime, or other alkaline earth in such proportions as to render it in any degree fusible. According to the experiments of E. Richters (1868), the refractory qualities of clay are least influenced by magnesia, more so by lime, still more by oxide of iron, and most of all by potash. The clays of commerce may be intelligibly described according to their uses, beginning with the finer and more valuable varieties.

Kaolin or China-Clay.

The finest *porcelain* or *china clays* are generally known by the name of *Kaolin*, a Chinese word (*Kau-ling*, high ridge) having reference to the locality from which the richest supplies were obtained. Kaolin arises from the decomposition of felspar in soft disintegrating granitic, gneissose, and porphyritic rocks—the granites rich in soda-felspar yielding it in greatest abundance. It is found in beds and masses along the stream-courses which descend from hills composed of these decomposing rocks—the richest and purest deposits occurring in the low grounds, and naturally farthest from the sources of disintegration. The larger fragments having been left in the higher reaches of the stream, the low-valley clays are often wonderfully fine, though, generally speaking, they have to be subjected to repeated levigations to free them from particles of quartz, mica, undecomposed felspar, and similar impurities. When freed from these impurities, which may amount to from 5 to 30 per cent of their bulk, the best varieties are of a white or whitish-grey colour, soft, and rather meagre to the touch when dry, and plastic when wet. Their composition is somewhat variable; but 45 silica, 40 alumina, and 15 water, may be taken as an available average. The most important characters in a china-clay are colour, plasticity, and hardening under heat; and to correct or improve these qualities, various admixtures and modes of treatment are resorted to by different manufacturers, but these belong to the technology of the potter's art rather than to the lithological description of the geologist.

In Britain the main supplies of kaolin are obtained from Devonshire and Cornwall, where it is found in the low grounds in considerable purity, or is prepared artificially by washing the decomposed rock in such a way that the material passes through a succession of tanks—the cruder and heavier particles falling first, and the finer being carried farthest forward. After settling, the water is run off, the clayey sediment dried, consolidated, and cut up into blocks for the potteries. As much as 10,000 tons of the finer, and three times as much of the commoner kinds, are said to be annually made use of in the Staffordshire potteries. China-clay of excellent quality is also found in Bavaria, Prussia, Saxony, and Bohemia; in Hungary; in France (Limoges); at various localities in the United States, and abundantly in China, where it is usually ground up with *pe-tun-tze*, a quartzose felspathic rock, to give the ware greater hardness and vitreous translucency.

In general, the kaolin or china-clay is a product of natural decomposition; but at Belleek, Co. Fermanagh, it is obtained (Hull's 'Building and Ornamental Stones') by calcining the red orthoclase granite of the district. After calcination the felspar becomes white, and the colouring iron which has separated during the process in a metallic state is abstracted by magnets from the powdered and milky clay. And here it may be remarked, that while china-clay is the fundamental ingredient in all the porcelains or finer clay-wares, numerous mineral admixtures (silica from calcined flints, felspar from Cornish-stone or soft, decomposing granite, chalk, gypsum, &c.), are employed, according as the ware has to be hard or soft, dense or porous, glazed or unglazed. Indeed there are few things more perplexing than the varieties of china-ware, which seem to graduate in every degree from glass on the one hand to common earthenware on the other.

Pipe-Clays.

Pipe-clay, employed in the manufacture of tobacco-pipes, is another variety of fine plastic clay, differing little from china-clay except in an excess of silica—54 silica, 32 alumina, and 12 water, with traces of iron oxide, lime, and magnesia, being an average composition. The less of iron and earthy impurities, the whiter the clay; and where a yellow tinge appears, the firing is continued longer to discharge the colouring material. Pipe-clays are found in Cornwall, Devon, and Dorset; and much of the finer pottery-clays, with artificial silicious admixture, are also employed in the manufacture. The glazed tips are produced by dipping in a solution of soap, wax, and lime-water. The following are analyses of two dry specimens of Dorset pipe-clay—the former a light-coloured, and the latter a dark-coloured, variety:—

Silica,	65.49	72.23
Alumina,	21.28	23.25
Iron oxide,	1.26	2.54
Alkaline earths,	7.25	1.78
Sulphate of lime,	4.72	trace
	100.00	99.80

Pottery-Clays.

Potter's clay, or that employed in the fabrication of ordinary earthenware, varies very much in composition and quality, according to the kind and quality of the pottery. Some sorts, for the manufacture of coarse ware, differ little from brick and tile clays; others, for finer vessels, approach in quality to the porcelain and china clays. They are widely scattered over the earth's surface, and there are few localities where they do not occur in various degrees of purity, and of all colours—yellow, brown, reddish-brown, blue, and grey. The essential properties of a pottery-clay are—plasticity, sufficient freedom from iron and alkaline earths to resist heat without fusing or overfiring, and requisite colours. For the most part they are subjected to ripening, grinding, washing, and admixture (often with china-clay for the finer wares), and scarcely any two present the some composition—analyses in technological works giving from 44 to 58 of silica, 24 to 38 alumina, 1 to 7 iron oxide, 10 to 15 water, with traces of lime and magnesia.

Pottery-clays are of various origin as well as quality, some being fine laminated silts of the glacial period, others old estuary deposits; some river-valley accumulations—and others, again, re-formations from the waste and wash of the boulder-clay. They are all more or less superficial, having seldom any thickness of earthy or gravelly covering; and are dug from shallow openings (clay-pits), either to be ground or kneaded for immediate use, or to undergo, in the open air, a certain period of disintegration and ripening. It is needless to mention that, according to the nature of the ware to be fabricated, these clays are all submitted to processes of admixture and tempering—each manufacturer adopting, from experience, his own modes of treatment. For strong ware—jars, carboys, India ale bottles, and the like—the Devonshire clays are usually tempered with fine white silicious sand, often obtained by crushing the white sandstones of the coal-formation.

It need not be added that it is owing partly to admixture and treatment of the raw material, partly to glazing and colouring, partly to artistic design, and partly also to the whims of fashion, that certain wares become the rage of a period, and bring prices altogether disproportioned to their real industrial value.

The digging, mining, and preparing of the *finer* clays for pottery and porcelain purposes constitute an important branch of British industry. According to Hunt's 'Mineral Statistics,' there were, in 1872, 106 clay-works in Cornwall, 14 in Devonshire, and 5 in Dorset, besides others of less repute for ordinary earthenware in different parts of the country. The quality of clay—fine and fire—raised during that year was estimated at 1,200,000 tons, and its value at £450,000.

Brick-Clays.

Brick and *tile clays*, or those fitted for the fabrication of those coarser articles, are the most widely diffused—few districts in Britain being devoid of clay-beds fitted for the manufacture of ordinary building-bricks, roofing-tiles, drain-pipes, and other kindred fabrics. The thickest and most extensive beds are the so-called "brick-clays" of the glacial or immediately post-glacial period, and which are generally fine in texture, and red, blue, yellow, or grey, according to the rock-formations from which they have been derived, or with which they are associated; but abundant supplies can also be obtained from estuary silts, from the clays of the tertiary system, and occasionally from the outcrops of the argillaceous beds of the older systems. "Brick-clays of the common kind" (we quote Professor Ansted's 'Applications of Geology to the Arts and Manufactures') "consist of a coarse and irregular admixture of silicate of alumina—which we may regard as pure clay—with sand, lime, iron, carbon, mineral alkalies, and a host of impurities for the most part accidental. The admixture with sand is essential; and the proportions of free sand in the clay, as well as the actual composition of the clay as a silicate of alumina, admit of great variety. The clay must, indeed, be free from large stones; but the admixture of a proportion of silica-sand, which results in a combination that contains as much as 90 per cent of silica, is not at all incompatible with the formation of an excellent brick.

"The number of common or stock bricks annually manufactured and used in England must greatly exceed one thousand million; and to supply this demand, brick-pits have been opened in the neighbourhood of every town in which dressed stone is more expensive than brick. Generally, a sensible quantity of iron, lime, potash, or soda would be an unfavourable sign in a brick-clay; for too much of any of these substances would cause the brick to run into glass when left in the kiln to burn. By this burning process the clay loses some of its properties—amongst others, the capacity of mixing with water and its plasticity. It becomes permanently hard, not softening in water, although it absorbs it readily. Bricks resist weathering if the brick-earth be of good quality; and if iron has been originally present in the clay, it is converted into peroxide, and changes the dull brown of the clay into a bright red. To make an even and average brick, the material must be freed from small pebbles and grit as much as possible. It is also ground up with some care into a uniform mass and mixed with water, after which it is left to dry before being made up. In preparing it for use, it must be mixed with coarse sharp sand; and besides sand, the ashes of coal are very useful in this stage of the manufacture. If tempered or exposed for some time to the weather, clay is always improved, and makes better bricks or tiles. In a good brick-clay there should not be more than 2 per cent of lime or potash." These remarks must be received as referring to fair average bricks and brick-clays; for in the neighbourhood of many of our large manufacturing towns any sort of surface rubbish, provided it has plasticity enough to cohere, is worked into bricks, which, when turned out of the clamp, are, for the most part, so rent, blistered, and twisted, as to be fit only for buildings of the cheapest and most worthless description.

The manufacture of building-bricks, fire-bricks, roofing-tiles, floor-tiles, and drain-pipes, is now conducted in Britain upon the most gigantic scale—whole towns being reared and roofed by the one, and hundreds of miles of drainage most efficiently accomplished by the other. To meet the demand, which mere hand-making could never have supplied, numerous machines have been invented, by which the rough clay is at once cut up, crushed, pugged, discharged, and fashioned into bricks or tiles ready for the clamp or kiln, and this at the rate of 30,000 per day!

Fire-Clays.

As the *fire-clays* will be noticed in Chapter XII., on "Refractory or Fire-resisting Substances," we need here only remark that they derive their name from their highly refractory or infusible nature—a property they possess from their containing little or no lime, protoxide of iron, or alkaline earths, that would cause them to yield to intense temperatures. Unlike the other clays, which are mainly superficial deposits, the fire-clays are obtained from the coal-formation, where they occur in beds from one to five feet in thickness, and for the most part as the floors or "under-clays" of coal-seams. Being more expensive to raise and manipulate than ordinary clays, they are chiefly employed in the fabrication of fire-bricks, furnace-linings, grate-backs, oven-soles, gas-retorts, coke-ovens, crucibles, and other objects, which have to endure exceedingly high and long-continued temperatures.

Terra Cottas.

The *terra cottas* or "baked earths" of the Italians, are merely unglazed wares—vases, bricks, tiles, mouldings, and other architectural ornaments—prepared from the finest fire-clays. Extreme care is bestowed on the selection and manipulation of the raw material—the object being to secure a substance that will contract equally, and so avoid all warping or distortion in the finished article. Italy and France have long enjoyed the supremacy in *terra cottas;* but recently Staffordshire and Lanark have produced shafts, vases, statuettes, and the like, of unrivalled symmetry and elegance.

Silicious Earths.

Infusorial and *microphytal earths*—that is, light mealy deposits composed of the silicious shields of infusoria and the frustules of diatoms—have also been employed in the manufacture of "floating bricks," or bricks so light as to float on water. Such bricks were known to the ancients, who were ignorant, however, of the nature of the substance of which they were composed. Fabroni, in 1791, is said to have been the first who detected the nature of this "fossil flour," and succeeded, by mingling it with a paste of lime and clay, in producing bricks which not only floated on water, but which were indestructible by fire. As these bricks are only one-sixth the weight of ordinary bricks, and unaffected by the strongest heat of a porcelain oven, it has been suggested to use them as fire-proofs on board ship. The powder-magazines, the cooking-galleys, the hearth of the steam-engine, the flues, and the spirit-room, can all be made of these bricks, and the chances of fire reduced, without sensibly diminishing the floating power of the vessel. These silicious earths—microphytal and microzoal—are by no means rare; the "polishing slate" of Bilin, the "mountain meal" of Sweden and Tuscany, and the "Richmond earth" of Virginia, being examples on a large scale, and most of them fitted for this species of manufacture.

Meerschaum.

Meerschaum (Ger., sea-froth), so called from its lightness and white colour, is a hydrous silicate of magnesia, consisting of 60 silica, 28 magnesia, and 12 water. It occurs among the serpentinous rocks of several countries; but that used in commerce comes chiefly from Greece and Asia Minor, where it is found in stratified earthy or alluvial deposits, arising apparently from the decomposition and waste of the carbonate in the older rocks. When first dug it is soft, has a soapy feel like most magnesian minerals, and forms a lather like soap. Being capable of forming a paste with water, it is sometimes spoken of as "plastic magnesia"—the commoner sorts being employed in the manufacture of porcelain, and the finer (after treatment in various solutions) in the making of tobacco-pipes, for which its absorbent texture is peculiarly adapted, taking in the oily matter of the weed, and acquiring thereby those warm tints so much admired by smoking connoisseurs. All, however, is not gold that glitters, for we learn from Wagner's 'Technology' that hardened gypsum, treated with stearic acid or with paraffin, and polished, much resembles meerschaum, and is used for it in the manufacture of cheap pipes—the resemblance being increased by a colouring solution of gamboge and dragon's blood to impart the much-coveted tints.

II.—THE SANDS WE VITRIFY.

All the glasses, whether crystal, crown, mirror, window, or bottle, are but amorphous compounds of various silicates obtained by a process of melting. Silicates of soda, potash, lime, baryta, strontia, magnesia, and alumina, with oxides of lead, bismuth, zinc, iron, and manganese, are the main ingredients in the different varieties ; and these substances, it is superfluous to observe, are all obtained directly or indirectly from the crust of the earth. *Plate-glass* or *crystal*, for example, is a silicate of potash and lime ; *window-glass*, a silicate of soda and lime ; *flint-glass*, a silicate of potash and lead, occasionally with bismuth and borax for optical purposes and for artificial gems ; and *bottle-glass*, a silicate of alumina and lime (sometimes magnesia instead of lime), with oxides of iron and manganese. The great object in these varieties is to obtain different degrees of fusibility, hardness, toughness, and transparency, and these are secured by changes in composition, as well as by methods of treatment.

We have said that all the substances employed in the manufacture of glass are obtained from the mineral kingdom ; and it may render the matter more obvious (geologically speaking) by taking the ingredients *seriatim*, and noting the part they play as detailed in works on Technology :—

1. Beginning with silica, which lies at the foundation of the manufacture, we may observe that, for very pure glass, crushed quartz or well-washed "silver sand" is necessary; but for other sorts clean sharp sand or pulverised flint-stones will suffice. For bottle-glass the sands of the sea-shore are often preferred, as the lime, clay, and other admixtures they contain increases their fusibility. Sands of great purity and whiteness are often found inland as drifts from the sandstones of the coal-formation ; "silver sands" of fine quality, and so called from their silvery whiteness, are often brought from the coasts of Holland ; and soft quartzose sandstones like those of Fife might be crushed and used with advantage. Where the sands contain impurities, they have occasionally to be washed and bleached to free them from iron, lime, clay, and other earthy ingredients. Indeed the great difficulty is to obtain a pure white quartzose sand ; for though millions of tons are scattered over the British Islands, it is rarely found free from colouring matter and earthy admixtures.

2. The next substance to be noticed is borax, which is some-

times used as a substitute for a portion of the silica. It increases the fusibility of the glass, and renders it more susceptible of a high polish. It is employed either as borax or as boro-calcite, which is imported in large quantities from the salinas of Peru, under the name of borate of lime or *Tiza*.

3. Potash and soda are used in a variety of forms—carbonate, nitrate, and sulphate—and generally, in the crude state, as described in Chapter XIV., on "Salts and Saline Earths."

4. The earths employed in glass-manufacture are lime (generally chalk), either raw or burnt, carbonate of strontia and carbonate of baryta; and for semi-opaque glass, fluor-spar and aluminate of soda.

5. The metallic oxides are chiefly those of lead, to impart weight, transparency and polish; of tin, to produce opacity; of copper, to impart a green colour; of bismuth, to secure transparency; and so on of others.

6. As chemical agents for the discharging of colour or glass-clearing, oxide of manganese, arsenious acid, nitrate of potash, nitrate of soda, and minium or red-lead, are the principal ingredients employed; and these, like the substances which enter into the composition of the mass, are all mineral products coming under the cognisance of the geologist.

7. Besides the mere fabrication of the glass—its melting, shaping, and colouring—several sorts require to be cut, polished, or obscured; and for these purposes sandstones, sands, emery, oxides of iron and tin, &c., are usually employed, all, like the constituents of the fabric itself, obtained from the mineral kingdom.

Thus one of the most beautiful and useful fabrics ever invented by man depends at once for its composition, its colour, transparency, and other qualities, upon the mineral and metallic products of the rocky crust; and whether we regard the amount or variety produced—the opaque bottle, the transparent window-pane, the shining mirror, the sparkling crystal, the coloured ornament, or the pellucid lens of the optician—there is perhaps no mastery of art over the crude materials of nature so decided and triumphant as that of the glass-manufacturer.

Besides the sands we vitrify or convert into glass, there are, as already noticed under "Geology and Architecture," large quantities used in the preparation of mortars, concretes, and cements, a considerable amount of the finer and more cohesive varieties for the moulding of metals, and a fair portion of the cleaner and sharper sorts for cutting and polishing by the marble, slate, and granite worker, by the lapidary, and by the worker in metals. These varieties, however, will be more appropriately described under the sections to which they respectively belong. Among the moulding sands, esteemed for the high face and finish they give to castings, may be noticed that of Mansfield, Notts, which (according to the Jermyn Street Catalogue) is not only largely used at home, but exported in considerable quantities to the Continent. It consists, according to Mr Haywood, of—

Silicates,	Silica,	84.00
	Alumina,	9.40
	Potash,	0.54
	Soda,	0.10
Iron peroxide,		4.00
Manganese,		trace
Phosphate of iron,		0.01
Sulphur and carbon of lime,		0.05
Free alumina,		0.40
Chloride of sodium,		trace
Moisture and organic matter,		1.30
		99.80

III.—GLAZES, ENAMELS, COLOURS.

Like the substances composing the main body of earthenware and glass, the glazes, enamels, and colours with which they are ornamented, are also procured directly or indirectly from the mineral kingdom. The preparation of these glazes and colours is strictly a matter of chemistry, and belongs to Technology; and we notice them in this place merely to show how extensive and intimate the relations of Geology are to the Arts and Manufactures.

With the exception of *biscuit-ware* used for statuettes, &c., under the names of "Parian" and "Carrara," all other kinds of porcelain and earthenware are glazed or enamelled; and these glazes are usually of four kinds: 1. Earth or clay glazings for hard porcelain, which are transparent, and are formed by solutions of silica, alumina, and alkalies—that is, by admixtures of quartz, kaolin, lime or gypsum, and broken porcelain. They readily become fluid, and melt about the same temperature as that at which the vessels are baked. 2. Lead-glazes which contain lead, are transparent, and generally melt at the same temperature at which the articles are fixed. 3. Enamel or opaque glazes, which may be white or coloured. They contain oxide of tin as well as oxide of lead, melt easily, and are employed to cover the unequal colour of the under fabric. 4.

Lustres which are chiefly earth and alkali glazes—such as the common salt-glaze, and the glazes containing metallic oxides used to imitate gold and silver. These glazes and enamels are put on before firing, either by immersing the article in a thin solution of the material, or by watering or pouring it over the article; by dusting the freshly formed and still damp surface of the vessel with a powder of the material; or by placing the material in the oven along with the articles, where it volatilises and combines with the silica of the ware, forming a film of glass as in the case of common salt-glazing.

As with the glazing so with the painting, gilding, silvering, and bronzing of earthenware, all the materials employed are strictly mineral and metallic. The preparation of the colours and the laying of them on are matters of chemistry and technology, but we may here briefly indicate the tints obtained from the oxides, chromates, and chlorides made use of. Thus—

Oxide of iron, for red, brown, violet, yellow, and sepia.
,, manganese, for violet, brown, and black.
,, copper, for green and red.
,, chromium, for green.
,, cobalt, for blue and black.
,, iridium, for black.
,, uranium, for orange and black.
,, titanium, for yellow.
,, antimony, for yellow.
Chromate of iron, for brown.
,, lead, for yellow.
,, barium, for yellow.
Chloride of silver, for red.
,, platinum, for platinising.
,, gold, for purple and rose-red.

In gilding, silvering, and platinising, the metal is laid on in solution, and after being burnt in, is either left flat or made bright by burnishing with agate tools.

As with earthenware, so with glass; the materials for ornamenting it—cutting, colouring, staining, painting, &c.—are all products of the mineral kingdom, and, as such, come within the sphere of geology. The substances for cutting and obscuring will be noticed in the next chapter on "Cutting and Grinding Materials;" the colours employed in staining and painting are much the same as those used for colouring porcelain and earthenware—namely, the oxides, chlorides, sulphides, and chromates of the metals,—copper, cobalt, manganese, iron, uranium, titanium, antimony, silver, and gold, being those most frequently in request.

The preparation and colouring of glass for the production of "artificial gems" might be noticed under this head, but will come more appropriately under the Chapter on "Gems and Precious Stones," when the student shall have become acquainted with the nature of the substances intended to be imitated. In the mean time, however, it may be observed that all the factitious gems are merely varieties of glass, rendered denser, clearer, and more brilliant by special admixtures, and coloured by metallic oxides to imitate as nearly as possible the tints of the natural productions.

From what has been sketched in the preceding pages—and it is merely a sketch in outline of a vast and varied subject—the student will perceive that all the varieties of glass and earthenware, their composition, fusing, firing, and ornamentation, are wholly dependent upon the mineral kingdom. The sands and clays, the alkaline earths, the salts, the metallic oxides, as well as the fuel required for their preparation, are all obtained from the rocky crust. Comparing the beauty and elegance of the finished products, tender and fragile though they be, with the raw materials from which they are derived, it is impossible not to accord to the manufacture of glass and porcelain a very high place among the arts and industries of modern civilisation. The raw materials with which we have here mainly to deal occur in widespread abundance; and while it is the business of the chemist and technologist to experiment and apply, it is equally the duty of the geologist to search for and determine the nature (quality, abundance, and accessibility) of new sources of supply. Splendid as are the achievements of the Fictile Arts, it were vanity to suppose that, with all the appliances of modern science, there is nothing higher to be accomplished, nor a wider and cheaper diffusion of their elegancies to be attained. To promote this advancement, the geologist will best contribute his mite by studying the nature of the raw materials employed, and by noting, when in the field, whatever he considers superior in quality, or whatever can be more readily and cheaply obtained.

Works which may be consulted.

Wagner's 'Handbook of Chemical Technology,' Crooke's edition; Knapp's 'Chemical Technology,' vol. ii.; Ure's 'Dictionary of Arts and Manufactures,' Hunt's edition; Watt's 'Dictionary of Chemistry.'

XI.

GRINDING, WHETTING, AND POLISHING MATERIALS.

Little progress can be made in the Arts and Manufactures without appropriate tools and instruments, and especially without what are termed "edge-tools." These, generally fashioned of the finest and best-tempered steel, cannot be furnished with the requisite cutting edge without some process of grinding, whetting, and polishing. Be it axe or adze, sword or spear, plane or chisel, knife or scissors, lancet or needle, each requires to be ground and set for its special work; and the materials for this purpose are, one and all of them, derived from the mineral kingdom. Again, in the Arts and Manufactures, a great deal of crushing, grinding, and pulping of various substances is necessary—food-stuffs, chemicals, paper-pulps, clays, mortars, and cements—and hence a great variety of millstones and crushing-stones, according to the difficulty or delicacy of the operation to be accomplished. Further, for utility as well as ornament, much polishing and burnishing is needed, alike of mineral and metal, and the most efficient implements for these purposes are in like manner obtained from the crust of the earth. Grinding, whetting, and polishing materials have been requisite at every stage of human civilisation, and are especially so in an age of mechanical appliances like the present. The rude savage who polished his stone hatchet, the ancient warrior who whetted his bronze spear-head, and the modern cutler who puts the keenest edge on the knife of the surgical operator, have all had recourse to the same mineral source for their materials. The old prehistoric man who crushed his nuts and grain, or pounded the pigment wherewith to bedaub himself, the miller of the nineteenth century who produces the finest flour-meal, and the chemist who reduces his admixtures to the most inpalpable pulp, have all called to their aid much the same rocks and minerals. It is to the lithological nature of these grinders, whetters, polishers, crushers, and pulpers, that we devote the present chapter.

I.—MILLSTONES.

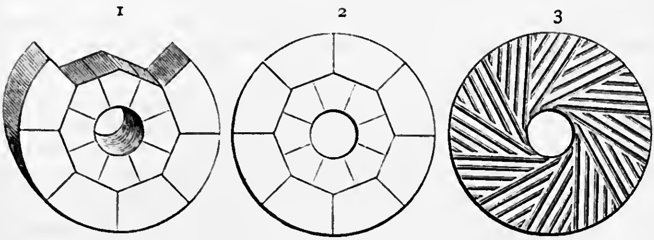
Grits.

In the olden times, the ordinary millstones—that is, stones for the reduction of grains and seeds into meals—were chosen from the harder, tougher, and more *silicious sandstones.* Wherever a good tough grit with a keen-cutting surface could be obtained, such grits were raised, dressed, and centred for the meal, flour, and barley mill. The grits of the Silurian, Old Red Sandstone, and Carboniferous systems (millstone grit) were those most highly prized; some varieties being brought from great distances, and owing to the then limited means of transport, often at considerable expense. The great object was to obtain a milling surface with a keen "burr," and yet of sufficient hardness and toughness as not to give off any appreciable amount of sandy particles to the meal. In course of time the best of such millstones become smooth in surface, and had again and again to be taken out and re-dressed with delicate pick-points so as to renew their burr. At that time—sixty and seventy years ago—wind and water mills, on a small scale, were very numerous; and such millstones as we have spoken of were in great request; but now, like other branches of industry, meal, flour, and barley mills have become gigantic factories, and the heavier work to be done has called into use harder and more durable materials.

Burrs.

One of the keenest and most durable of materials, whether for making meal and flour, or for the trituration of cements, manures, pigments, and other chemicals, is *burrstone*, a porous silicious rock from the tertiary formations of Europe and America. These burrstones are of various colours, whitish, yellowish, and reddish brown, are almost pure silica, with just sufficient calcareous matter to give them the requisite toughness, are slightly porous or vesicular from the decay of imbedded shells and other minuter organisms, and are of fresh-water origin. Those used in Britain are generally obtained from the tertiary deposits of France (Seine et Marne) from whence they are brought in blocks of a foot or more square, to be dressed, built up, and clamped or hooped for millstones of varying dimensions. The dressing, fitting, and building up of these blocks requires much skill and labour, as the jointings of the separate pieces should be scarcely perceptible, and the whole surface rendered true and even. As burrstone is expensive, the requisite weight and thickness is usually obtained by a backing of concrete, made up of the chippings, which for these purposes answers perfectly well.

These burrstones are now largely employed for all kinds of trituration and milling, not only in meal and flour mills, but in cement-works, potteries, chemical works, and other similar factories. In course of time they wear smooth like other stones, and their "burr" has to be renewed by a tedious process of



1. In process of building; 2. Completed; 3. Finished, with grooved milling surface.

pick-dressing, though recently diamond points have been applied with great success, and saving of time and money. As the majority of burrstones vary from 6 to 6.7 in hardness, while that of the bort or black diamond is about 10, the influence of the latter on the former is readily perceptible, while it is free from the dangerous "fire" which accompanies the use of steel.

Quartzites.

Besides grits and burrstones, *quartzites* and *close-grained lavas* have been used for milling—the whiter quartzites of the metamorphic rocks (Norway, Banffshire, and Argyleshire) answering well for certain pottery purposes, and the lavas—the old tertiary lavas of the Rhine, for example—being employed for the trituration and intimate admixture of chemicals which would act upon many other rocks.

II.—GRINDSTONES.

Sandstones and Grits.

In an age so eminently mechanical as the present, a great deal depends upon the use of tools of the keenest edge and of the surest adjustments. For the shaping and setting of these tools, grindstones of various sizes and texture are required, and these are obtained from the sandstones and grits of all formations. What is requisite in a good grindstone are uniformity of texture, keenness of bite for the purpose in view, freedom from cracks and flaws, and sufficient toughness or consistency to hold together during the rapid revolution to which it may be occasionally subjected. The Newcastle grindstones, said to be known all over the world, are obtained from the thick-bedded sandstones of the coal-measures (Gosforth, Kenton, Eighton Banks, &c.); and such strata as have uniformity of texture, keenness of bite, and sufficient solidity, are those generally chosen. Stones from a foot to six feet in diameter are raised from these beds, and are extensively used for the grinding or reduction of edge-tools employed by joiners, carpenters, engineers, and kindred professions.

Besides the Newcastle grindstones, those of Bilston in Staffordshire, of Wickersley and Haderley near Sheffield, and of Congleton in Yorkshire, have a good reputation—presenting different degrees of grain, toughness, and density. For more rapid reduction of metallic surfaces, stones of coarser grain, of large dimensions, are obtained from the Carboniferous grits and sandstones of Yorkshire and Derbyshire; but as many of these grits want coherence and toughness, they require careful selection to prevent accidents from their breaking up under centrifugal force when in rapid revolution. For cutlers' and smaller wheels—that is, for the finer description of edge-tools—useful stones are selected, not only from the coal-measures (Wickersley), but from the Upper Old Red, Oolite, and Greensand—and in these, fineness and uniformity of grain are the qualities most esteemed.

Besides the natural grindstones, stones of every texture, from the Derby grit to the Devonshire batt, are now manufactured by Ransome's patent process (see Chap. VI.), and, so far as experience has gone, answer well the various purposes for which they are intended. The solid emery wheels prepared by the same process, and noticed in another section, seem to be the perfection of grinding and cutting materials.

For glass-cutting, stones of a close keen texture are preferred, and these are generally selected by experienced hands from the blocks in sandstone quarries of various formations. A useful wheel is obtained from the more homogeneous beds of Craigleith near Edinburgh, Kenton near Newcastle, and from the Gannister beds of Yorkshire.

III.—CRUSHING AND PULPING WHEELS.

Besides millstones and grindstones, in the proper sense of these terms, there are employed in the Arts and Manufactures a great many stone-wheels, often of great size and weight, for crushing and triturating purposes. Crushers of great weight are occasionally made of iron; but where iron would be objectionable or expensive, wheels of granite, quartzite, sandstone, gritstone, and granular lava, are usually adopted for crushing, pulverising, and pulping. For the reduction of clays, cements, and the like, any hard, tough, and heavy stone, naked or shod with iron, will do; but where the imparting of colour would be objectionable, quartzites, and similar silicious stones, are most suitable.* For pulverising, either in the dry or wet way, a great deal depends upon the nature of the floor or bed over which the wheel is run, and few floors exceed in durability one of neatly-jointed and solidly-laid blocks of quartzite.

For pulping purposes, such as the reduction of fibrous materials for the making of tissue-paper, wheels of soft fine-grained sandstones are often employed—the object being to secure a granular surface throughout the process, and to avoid such stones as would wear hard and smooth. Stones of this kind are imported from Wirtemberg in Germany; but wheels of equal, if not superior quality, have been recently obtained from the soft, thick-bedded sandstones of the lower coal-measures, near St Andrews in Fifeshire. According to the Messrs Patterson, millstone builders, Newcastle, the Fife stone is as suitable in every way as the German, while it can be obtained at little more than half the cost. The softer and finer in the grain, the better are these sandstones adapted for this species of fibre-pulping.

IV.—POLISHING AND CUTTING MATERIALS.

In the sawing, cutting, and polishing of marbles, granites, serpentines, jaspers, gems, and other stones, as well as in the reduction and polishing of metallic surfaces, a great many mineral substances are in use—some of keen bite and burr, and open texture, others of gentle burr, and of close impalpable texture and fineness. In stone-polishing—marble, for ex-

* We take no notice of the many strong and efficient iron-machines which have recently come into use for crushing ores, stones, slags, coals, shales, sands, &c. These belong to mechanical engineering.

ample—it is usual to employ several substances having different textures or "grits," as the workmen term them—beginning with some sharp-grained sandstone as first grit, some silicious slate as a second, snakestone or Water-of-Ayr-stone as a third, and then to finish off with the finest emery-flour or putty-powder. Among the numerous polishers in use may be noted quartz-sands, tripoli, Bath-brick, rotten-stone, pumice, crocus, emery, and diamond-dust. We take no notice of revolving discs, and other appliances made of iron, though recently some ingenious machines (like that of Adams) have been invented, by which the face of one stone, with the aid of sand and water, is rubbed against the face of another till both are rapidly reduced to a smooth, true, and uniform surface.

Sands.

Quartz-sands of sharp grain, clean and well washed, are largely used for the sawing and cutting of stone blocks and slabs (sandstones, marbles, serpentines, and granites), and do their work cheaply and efficiently, though somewhat slowly compared with some other substances. They are also employed for reducing and giving the first polish to ornamental stones, and not unfrequently for the reduction of metallic surfaces. For these purposes they are found abundantly in surface-drifts, in river-reaches, and along certain portions of the sea-shore, but generally require washing to remove clayey and earthy debris. Quartz-sands of this nature, whether used in blocks as grits, loose in grains as sand, or fixed on flexible surfaces as sand-paper, are among the cheapest and most efficient of cutters and polishers. In some instances silicious grits are crushed to afford a keener and sharper material than natural sands, whose particles are all less or more rounded by attrition. The scrubbers or *holystones* cut, squared, and sold by the gross in Newcastle, are obtained from the sharper-grained sandstones of Hepburn, Kenton, and other quarries in the neighbourhood.

Tripoli.

Tripoli, so called from its being originally brought from Tripoli in Africa, is a fine earthy silica, generally massive, soft, light, and friable, and of various colours—greyish-white, yellow, and yellowish-red. It is found in many countries—Italy, Bohemia, Germany, France, and in the United States of America; and seems, in some instances, to be a microphytal or infusorial earth, composed of the silicious shields of diatoms, and the like; in others, to be derived, like rotten-stone, from the decomposition of silicious limestones; and occasionally from the alteration of argillaceous shales by combustion. When reduced to powder, it is used for polishing metals, marbles, glass-lenses, and other hard substances. Much of the so-called "Tripoli" is simply finely prepared rotten-stone.

A recent form of diatomaceous or microphytal earth, under the German name of *Keiselghur* (flint-froth), from its soft and spongy texture, is also used as a polishing material, and further, as the absorbent of nitro-glycerine in the preparation of the explosive *dynamite.* Like the *bergh-mahl* (mountain-meal) of the Swedes, it is a fine mealy form of silica, and gives a viscous or semi-solid body to the dynamite, which thereby becomes more convenient and safer for use than the liquid nitro-glycerine.

Rotten-stone.

Rotten-stone, largely used in a state of powder for polishing brass, silver, Britannia metal, glass, &c., is a soft and friable silicio-aluminous compound, resulting from the decomposition of impure limestones by the percolation of carbonated waters. Most of the rotten-stone of commerce is derived, like that of Derbyshire, from the decomposition of silicious limestones—the lime being decomposed, and the silica and alumina left as a light earthy mass of a greyish or reddish brown colour. It is found in many limestone districts, and for the softer metals forms a cheap and efficient polisher. A Derbyshire grey-coloured specimen yielded to Mr Richard Phillips 86 alumina, 4 silica, and 10 carbon; another specimen, of a yellow colour, from Derbyshire, consisted, according to Professor Johnston, of 83 alumina, 9 silica, 3 iron, and 5 carbon; and a reddish-brown variety from Gilmerton, near Edinburgh, analysed by Connel, gave 82 alumina, 13 silica, and 5 iron. A good rotten-stone should be light, of very fine grain, and meagre to the feel—so light, indeed, as almost to float on water.

Crocus.

Closely allied to the rotten-stones are the *polishing-pastes* of commerce. These consist of various admixtures—the oxides of the metals (*crocus*), *reddle*, or the native peroxide of iron, prepared putty-powder or oxide of tin, pulverised pumice and rotten-stone, the silicious mud (levigated and dried) arising from the cutting and polishing of whetstones, stone-cutters' waste levigated and sharpened with emery-flour and various other compositions, the ingredients of which are known only to their manufacturers. The common *crocus* of commerce is a sesquioxide of iron, and makes a cheap and efficient polisher.

Bath-brick.

The substance known as *Bath-brick*, and so extensively used for cleaning and polishing metal goods and utensils, is manufactured at Bridgewater, from a tidal deposit of fine silicious silt, deposited in the river Parret in Somersetshire, at the junction of the fresh and salt water. "The peculiar properties of this material," says Professor Ansted, "are probably owing to the silicious cases of infusorial animalcules destroyed by the salt tidal water where it meets the fresh water of the river." Deposits of similar silicious muds are formed in other tidal rivers, and might be utilised as polishers where sufficiently free from earthy and vegetable matter. Some years ago a greyish mealy bed was dug from the flats of the Clyde, near Hamilton, and introduced as a "rotten-stone," but met with indifferent success.

Pumice.

Pumice, which is largely used both in its natural and powdered state as a scrubber and polisher, is a light, spongy lava, so porous, vesicular, and fibrous, as sometimes to float in water. It receives its name from its froth-like and scum-like appearance. Lat. *spuma*, froth; Ital. *pumice.* It is usually of a whitish-grey colour, with a sub-pearly, silky lustre; and, according to Klaproth, consists of 77 silica, 17 alumina, with varying proportions of soda, potash, peroxide of iron, and water. Its hardness is about 5 of Mohs' scale, and specific gravity from 1.5 to 2. It is found in almost all volcanic districts, and appears to be an ejectment which, becoming cooled in its passage through the air, retains the porous spongy texture it originally possessed, from the presence and permeation of gaseous vapours. Good qualities from the Lipari Islands sell at from £7 to £10 a ton, and are employed in the polishing of wood, stones, metal, glass, and ivory—and, in a powdered state, for preparing the surface of parchment.

Emery.

Emery (from Cape *Emeri*, in the island of Naxos, where it occurs in abundance), is a massive, nearly opaque, greyish-black, or indigo-coloured variety of rhombohedral corundum, consisting chiefly of alumina, with peroxide of iron, silica, and lime. It is brought chiefly from Ephesus in Asia Minor, from Naxos and other of the Greek islands, but is found also in

Saxony, Spain, Jersey, Massachusetts, and Greenland. It is usually associated with the older crystalline rocks, such as granular limestones, gneiss, mica-schists, and talc-schists, but occurs also in rolled masses and detached blocks. "The emery generally used in this country," says Mr Bristow, "is found in the island of Naxos, where it occurs in large blocks, imbedded in a red soil, and sometimes in whole marble. These blocks are so abundant, that, notwithstanding the immense quantities carried off, it is not yet requisite to quarry the rock itself. This substance is of so much value in the arts, that an English merchant found it advantageous to obtain a monopoly of it from the Greek Government; in consequence of which its price in this country has been greatly advanced, and at one time was as high as £30 per ton." At present a large proportion of the emery used both in England and America is obtained from near Ephesus, and shipped at Smyrna.

In its preparation the original blocks are first broken with heavy hammers, then crushed with steel-headed stampers driven by steam-power, and afterwards passed through various sieves, which assort it into different degrees of fineness (about twenty, it is said), such as "flour," "corn," "grinding-emery," &c. Much of it is used in the manufacture of *emery-paper* and *emery-cloth*, in both of which articles it is often largely adulterated with triturated iron-slag, garnet-rock, and other hard substances. Indeed, the so-called *red emery* is merely the massive garnet-rock of Norway, stamped, crushed, and reduced to powder—suitable enough for certain purposes, but inferior in hardness, and consequently in abrasive power, to the real emery. In this sifted and prepared state it is extensively employed in grinding and polishing by plate-glass manufacturers, by lapidaries, by marble and granite cutters, and by all the workers in metals.

Of recent years it has been formed into solid grinding-wheels and cutting-discs either by the silicate of lime process of Mr Ransome (see Chap. VI.), or by the Tanite process of America. In either case the emery particles are cemented into solid discs of unrivalled cutting power—their efficiency depending partly on the hardness of the mineral, and partly on the speed at which they are driven—their toughness and compactness permitting them to be driven at a rate which would be destructive to any natural stones. In hardness it varies from 7 to 9; in specific gravity from 3.95 to 4.5; and in abrasive power (sapphire being 100) from 45 to 57. The following are analyses by J. Lawrence Smith :—

	Alumina.	Iron.	Lime.	Silica.	Water.
Kulah, . .	63.50	33.25	0.92	1.61	1.90
Samos, . .	70.10	22.21	0.62	4.00	2.10
Naxos, . .	68.53	24.10	0.86	3.10	4.72
Nicari, . .	75.12	13.06	0.72	6.88	3.10
Massach, . .	74.22	19.31	......	5.48	......

Diamond.

Diamond, in addition to its value as a precious stone, is employed for engraving and cutting glass; in splinters, for drilling; and, reduced to powder, for polishing and cutting other gems. Its specific gravity is about 3.5, and its hardness 10; and being thus the hardest of minerals, all other mineral substances must yield to its cutting and abrasive powers. Diamond-powder being worth £50 per ounce, it is too expensive to be used alone, and is therefore generally mixed with emery, and applied to the wheel with oil. Chemically, diamond is carbon or charcoal in its pure and crystallised form; geologically, nothing is known of its origin and formation. For its mode of occurrence in India, Brazil, Australia, the Urals, California, and Cape Colony, the reader is referred to the section on "Gems and Precious Stones;" and under this head it may be enough to mention that it is only the smaller, the flawed, and the inferior in colour, that are reduced to powder for cutting and polishing purposes. These inferior sorts are usually known as *Bort* or *Boort* and *Carbonado*, being greyish-white, or even of darker colours, and occurring in irregular, twisted-looking, and mammillary fragments. We have already alluded to the use of diamond-points in the dressing of burr millstones; more recently they have been employed as a drill for rock-boring (Beaumont's Diamond Drill); and our American friends are now experimenting with diamond saws—that is, blades of iron armed with diamonds—for the sawing or cutting up of rock-blocks, a process at present tediously accomplished by iron and quartz-sand.

V.—WHETSTONES AND HONES.

For whetting or sharpening the smaller edge-tools and implements, a great variety of stones are in use; and in the majority of these, quartz or silica, in coarser or finer states of dissemination, is the reducing material. From fine-grained sandstones to the most intimate admixture of impalpable silica, batts, ragstones, whetstones, and hones, are in constant requisition, some being used dry, some with water, and others with oil. It is very difficult to arrange these whetstones into anything like scientific order, partly because the same material is found in several formations, and partly because the same substance receives different names in different localities. Beginning with the more common and coarser-grained, we may notice them in the following order :—

Batts.

Batts or *Sandstones* of keen grain and toughish consistency are found in many districts, and are used as whetters for scythes, mowers, hedge-bills, knives, and other similar implements not requiring a smooth or delicate edge. The Devonshire batts, from the greensands of the Blackdown Hills—the Yorkshire, from the millstone grit and Gannister beds of the coal-formation—and the Lomond, from the lower carboniferous sandstones of Fifeshire,—have good reputations; but suitable sandstones might be found in many other places if skilled hands would only commence the industry. A good batt should have a keen bite, be equal in texture, and not be apt to "glaze" or wear too smooth in the surface. They are cut of all sizes, from five to fifteen inches, and fashioned in all forms—square, cylindrical, spindle-shaped, and oblong.

Ragstones.

What are known as Norway, Russian, and Scotch *Ragstones*, are merely tough and highly silicious portions of mica-schist, often with a slight twist in the long direction. They are obtained from the metamorphic or crystalline schists, have a keen severe bite, and are well adapted for rapid reduction. They are generally sold in their natural state, or with very little dressing, and can be used dry, with water, or with oil. The Russian sorts are usually softer and more micaceous than the Scotch and Norwegian.

Hones.

Hones, or *Oilstones*, as they are generally termed by the workmen using them, are obtained from the varieties of the metamorphic schists and slates which are sufficiently compact, and in which the particles of quartz are extremely minute and regularly disseminated, so as to give them a uniform consistence. Among the varieties most prized are the *Turkey Oilstones*, obtained from the interior of Asia Minor, of a yellowish or bluish colour, of very close grain, often flawed and cracked, and therefore rather brittle, and requiring to be backed with slate or set in wood; the *German razor-hone* or *Novaculite*, from the slate-hills in the neighbourhood of Ratisbon, of keener bite and tougher texture; the *Arkansas Oilstone*, from North America (largely prepared at Keswick), consisting of a very fine white amorphous silica, of excellent bite, but rather brittle and expensive;* the *Welsh Slate* or *Oilstone*, a tough, fine-grained, silicious slate, but of rather unequal texture; the *Charley Forest Oilstone*, a strong and serviceable whetstone, from Leicestershire; and the *Water-of-Ayr* or *Snake stone*, apparently an altered shale of greyish mottled colour, rather soft in texture, and chiefly used for polishing copper-plates and the mouldings of ornamental marbles. As the name implies, most of these whetters are used with oil, and are chiefly employed in giving the last or finished edge to the finer-cutting tools and implements. Many of them being rare and expensive (from three to five shillings per pound), they are used in small blocks, and backed with slate or set in wooden frames, to give them the necessary strength and solidity.

VI.—BURNISHERS.

Though tools of hard-tempered and highly-polished steel are mostly used for metal-burnishing, other burnishers for foils (gold-leaf, silver-leaf, and the like) are obtained from the mineral kingdom. These are chiefly agates, bloodstones, carnelians, and jaspers—all hard, tough, and compact varieties of silica, obtained from geodes and veins in the amygdaloid and other igneous rocks; but as these substances are likewise used as gems and ornamental stones, their geological history will be treated more fully under the section "Gems and Precious Stones," to which the reader is referred. Burnishers of highly-tempered steel are also largely used; but for certain purposes, agates and carnelians, though much more expensive, are always preferred.

All the substances noticed in the preceding sections, whether millstones, grindstones, whetstones, or polishers, are of infinite use in the Arts and Manufactures, their utility depend-

* An analysis of this whetstone, by C. E. Waite, shows that it consists of—

Silica,	99.635
Alumina,	0.113
Magnesia,	0.087
Soda,	0.165
Potash and iron,	traces
	100.000

ing upon their hardness as compared with that of the substances to which they are applied. The majority of rocks, wrought metals, glass, and the like, do not exceed 5 in hardness; while the silicas, emeries, and diamonds range from 7 to 10, and are thus capable of cutting, abrading, and polishing the softer materials. The rapidity with which the abrading substance is applied has also a certain effect; and in this way even diamond itself can be cut and polished by its own powder. Considering the necessity for edge-tools of high temper—for smooth surfaces to diminish friction in machinery, for true forms to increase the power of optical glasses, and for polish and lustre to produce ornamental effect—these substances are of great value in the arts; and any addition, geologically speaking, that can be made to their number and efficiency, will be hailed as a boon. The whole matter is a question of hardness, of abundance, and facility of application; and the field geologist can have little difficulty in determining qualities in any new mineral that may be discovered in the course of his surveys. Important as may be the collecting of facts, they are shorn of half their significance when not made to administer to the requirements of society and civilisation.

XII.

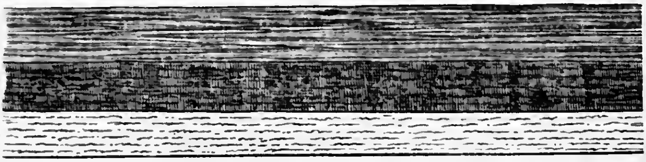
REFRACTORY OR FIRE-RESISTING SUBSTANCES.

In a country like Britain, where so much fire is required not only for domestic purposes—cooking, baking, brewing, &c.—but for manufacturing processes carried on in furnaces, kilns, retorts, crucibles, and the like, substances capable of withstanding intense heat will always be prized and sought after. We cannot proceed a step in the reduction of the metals, in smelting glass, in baking pottery, or in distilling gas, for example, without fire-resisting materials, and these, one and all of them, are obtained from the mineral kingdom. Some of these, as potstone and asbestos, have been known from early times; others, as fire-clay and graphite, have come largely into use chiefly within the current century. They may be arranged into two sections: those, like the graphites and fire-clays, which require manipulation, purification, and admixture; and those, like the potstones and firestones, which are obtained directly from the crust of the earth.

I.—PREPARED SUBSTANCES.

Fire-Clay.

One of the most abundant and most easily manipulated of refractory substances is *Fire-clay*—a term applied to any clay capable of resisting a great heat without slagging or vitrifying. This property arises from the absence of any alkaline earths—lime, soda, or potash—that would yield or act as a flux. Fire-clays abound in the coal-measures of Great Britain, and most frequently as the floor or under-stratum of seams of coal,—*a*, in the accompanying sketch, representing the *roof* of shale, *b* the seam of coal, and *c* the *floor* or *under-clay*. About the beginning of the century there were only two or three fire-clay works in the country, but now there are dozens of them, situated chiefly in Worcestershire, Staffordshire, Durham, Northumberland, Lanarkshire, and Mid-Lothian. Those of Stourbridge in Worcestershire, Blaydon on the Tyne, Garnkirk, Percetown, Hillhead, &c., in Lanarkshire, and Lilly-hill in Fife, are large and well-known factories. Stourbridge clay



is said to consist of from 60 to 66 silica, 25 to 31 alumina, and 2 to 6 oxide of iron, the remainder being water, traces of alkalies and carbonaceous matter. Indeed, most of the fire-clays contain remains and impressions of plants, but this does not interfere with their quality, as the carbon burns out in firing; the small percentage of iron present tends only to give to the manufactured material a richer and warmer colour. Like other sedimentary beds, the fire-clays are by no means uniform over extensive areas; the Stourbridge seam varies considerably in composition, so do the Lanarkshire beds, and those of Newcastle are still more irregular and capricious. The following are analyses of a few of the better-known British fire-clays: *a*, Stourbridge (C. Tookey); *b*, Staffordshire (T. H. Henry); *c*, Newcastle-on-Tyne (T. Richardson); *d*, Newcastle-on-Tyne (H. Taylor); *e*, Glasgow (J. Brown); *f*, Dowlais, South Wales (E. Riley):—

	a	*b*	*c*	*d*	*e*	*f*
Silica,	63.30	51.80	51.10	55.30	66.10	67.12
Alumina,	23.30	30.40	31.35	27.75	22.54	21.18
Potash,	...	...	...	2.19	...	2.02
Soda,	...	trace	...	0.44	...	...
Lime,	0.73	...	1.48	0.67	1.42	0.32
Magnesia,	...	0.50	1.54	0.75	trace	0.84
Iron oxide,	1.80	4.14	4.63	2.01	5.34	1.85
Water, combined,	...	...	...	...	3.14	4.82
Water, hygroscopic,	10.30	13.11	10.47	10.53	...	1.39
Organic matter,	...	...	...	...	...	0.90
	99.43	99.95	100.57	99.64	98.54	100.44

The fire-clays are raised by the same shaft as the coal, unless when their outcrop comes to the surface, and then they are obtained by open workings. They usually vary from one to four or five feet in thickness, and occasionally the thicker beds contain a band or bands of stone. A good fire-clay should have a uniform texture, a somewhat greasy feel, and be free from any of the alkaline earths. When properly ground, pugged, and mellowed, it is fit to be worked into any form and to be baked without showing either crack or distortion. The following account of the manufacture at Stourbridge, from Lieut. Grover's Report on Fire-clay Goods in the International Exhibition of 1871, shows well the method and process of treatment: "The clay is first exposed in spoil heaps over as large an area as can be secured, for from three to eighteen months, according to the state of the weather. The action of frost, as with ordinary brick-earth, is of great service in disintegrating the compact tough lumps of clay, and in dry weather the clay is frequently watered. In very wet weather three months' exposure will suffice for its proper mellowing or ripening, and it ultimately slacks and falls to pieces. After sufficient weathering, the clay is ground in circular pans by heavy stone-rollers shod with iron rims. Being ground, the clay is carried on an endless band to a 'riddle' of about 4 or 6 mesh to an inch for fire-bricks, 6 or 10 for fine cement-clay, and 12 or 14 mesh for glass-house pot-clay—the larger-sized mesh being used for the sifting of the clay in wet weather. The large particles that will not pass through the riddle are carried back on an endless band to the pan, and there reground. As a general rule, it is only for very large fire-brick lumps, that reground pots, crucibles, or bricks—locally termed 'grogg'—are added to the clay before grinding; and fire-cement clay is always ground pure. After passing through the riddle, the clay is tempered or brought to a proper degree of plasticity by the addition of water. It is then thoroughly stirred and kneaded in a circular iron pug-mill, by revolving knives projecting from a circular shaft driven by steam-power. The clay is forced down by the obliquity of the rotating knives, and streams slowly from a hole near the bottom, whence, being cut by wires into the proper forms, it travels on in an endless band to the moulding-sheds. The bricks are then moulded by hand in the usual manner, and dried at a temperature of 60 or 70 degrees in sheds heated by flues. In fine weather, however, the sun's heat is made to economise fuel. The bricks are burned in circular-domed kilns or cupolas, locally termed 'ovens,' where they remain from eight to fourteen days under gradually increasing temperature, which amounts to white heat for three or four days. They usually require seven days to cool down — the heat being gradually withdrawn as it was gradually raised."

The uses to which fire-clay is applied are very varied, and extensive as varied—fire-bricks, linings for furnaces, grate-backs, soles for ovens, chimney-flues, gas-retorts, coke-ovens, crucibles, glass smelting-pots, safes, garden-borders, vases, statuettes, and the like, being among the more abundant manufactures. Many of these are of great beauty and symmetry, and all but indestructible by fire; while sewage-pipes, when thoroughly glazed and carefully laid, afford by far the best material for the purpose which modern science has invented. Indeed, so far as experience goes, there is nothing so durable, so clean and sweet, or so easily flushed as well-made, well-glazed, fire-clay pipes; and thus, for sanitary uses, they stand unrivalled. The old-fashioned, square, stone-built drain required a large amount of water to flush it, decayed in course of time, leaked, and became a refuge to rats: the pipe-drain (circular or elliptical) is flushed by a mere trickle of water, endures for generations, and gives no harbour to vermin. In some manufactures (crucibles, furnace-linings, and the like) the clay is mixed with small and varying proportions of graphite, coke-powder, quartz-sand, and metallic oxides, according to the purpose in view, and occasionally an admixture of "cement" or "grogg" (old fabrics reduced to powder) is found to be of advantage.

We have no statistics of the quantity of fire-clay annually raised in Britain; but considering the number of works in Staffordshire (about twenty), in Durham, in Lanark, and other places, it must amount to many thousand tons, and is still on the increase. According to Hunt's 'Mineral Statistics,' the quantity of clay, *fine* and *fire*, raised in Britain during the year 1872, was estimated at 1,200,000 tons — value, £450,000; and of this the fire-clays must constitute no inconsiderable amount.

Silicious Sands.

The celebrated Dinas bricks of Glamorganshire may be regarded more as artificial standstones than as bricks in the ordinary sense of the term. They are fabricated from material obtained from the vale of Neath, and, according to Dr Siemens, are the only substances practically available on a large scale, which he has found, capable of resisting the intense heat (4000° Fahr.) of steel-smelting furnaces. Analyses show them to consist of silica, 95.98; alumina, 1.20; lime, 2.15; magnesia, 0.24; iron oxide, 0.48; and manganous oxide, traces. They are imitated in Germany (Wagner's Technology) by an admixture of pure quartz-sand and 1 per cent of lime.

Fossil-Flour.

Another fire-resisting substance obtained from the earth, and occasionally fabricated into bricks, is "*Fossil-flour*," a mealy, silicious deposit consisting of the myriad-shields of infusoria, or the frustules of diatoms. Mingled with a paste of clay or lime, as has been shown by Fabroni in Italy and Fouret in France, this substance can be fashioned into bricks so light as to float in water, and therefore well adapted for fire-proof purposes on board ship without sensibly increasing the weight of the vessel. Having been already noticed under "Fictile Arts" (Chapter X.), the reader is referred to that section for further details.

Graphite.

Graphite (so called from its use in writing-pencils, and known also as *plumbago* or *black-lead* from its appearance, though lead does not enter into its composition) is another refractory substance, now largely used in the manufacture of crucibles. It consists almost wholly of carbon—there being present in some specimens a small percentage of mechanically admixed iron oxide, with occasional traces of silica. It occurs chiefly in the primary or metamorphic rocks, in nests and stratiform masses, and is found abundantly in many countries—United States, Canada, Scandinavia, Germany, Urals, Siberia, &c.—in various degrees of purity and texture. In our own country unimportant nests occur in the gneisses of the Scottish Highlands, and in trap-altered portions of the coal-formation; but a very fine and valuable variety is found at Borrowdale in Cumberland, running in vein-like form through trap-rocks which intersect the clay-slates of that locality. This vein has not been worked for years, but when mined yielded some choice blocks for the manufacturer of drawing-pencils.

Commercially, graphite is used for making writing-pencils, for polishing, and other purposes to be noticed under other heads: here we advert only to its use in the fabrication of crucibles for metal smelters and refiners. For this purpose the graphite is finely ground, and two parts intimately mixed with one part of best fire-clay, and then moulded into the requisite size and form. This composition bears a high heat and sudden changes of temperature, and forms a clean, smooth-surfaced, and profitable crucible. For some purposes coke and old crucibles reduced to a fine powder are added to the admixture—each maker preferring some composition of his own. Thus, the Berlin crucible consists of 8 parts in bulk of fire-clay and cement, 5 of coke, and 4 of graphite; the Passau, of 56 fire-clay, 34 carbon, 8 iron oxide, and 2 magnesia; the Hessian, of fire-clay containing a little iron oxide and silicious sand; the Cornish, of the best Poole or Stourbridge clay, ground pots, and sand; and the Birmingham glass-pots, of the best Stourbridge or Monmouth clay. Fire-clay suitable for crucibles—"pot-clay" as it is termed—is by no means abundant, and brings a high price, that in the Stourbridge seam selling at five times the price of the ordinary material.

Alum, &c.

Among fire-resisting substances may be noticed the alum of commerce, the nature and preparation of which is described in Chapter XIV. Steeped in a solution of this salt, cloth, paper, and wood become almost incombustible—at least do not ignite so readily, and when ignited, burn away slowly and with difficulty. "If alum and common salt," says Jackson ('Minerals and their Uses'), "are reduced to an impalpable powder, and mixed with spirits of wine, and several coats of this be laid upon the skin of the hand, a red-hot iron may be held without inconvenience. This is, in fact, the secret of the human salamanders, or incombustible jugglers, fire-eaters, &c." As a check to the inflammability of light dresses worn by ladies, the solution of alum might be more extensively and advantageously employed.

Other solutions have been recommended by chemists, such as magnesium sulphate and borax, ammonium sulphate and gypsum, and sodium tungstate—all of which lessen the inflammability of fabrics, by enveloping their fibres with a thin coating, which prevents the escape of inflammable gases.

II.—NATURAL SUBSTANCES.

Firestones.

Any stone that stands heat for a considerable time without perceptible injury is entitled to the designation of a *Firestone.* The term, however, is usually applied to certain sandstones of the greensand, oolitic, and coal formations employed in the construction of ovens, glass-furnaces, and similar erections subjected to high and oftentimes to intermittent temperatures. The upper greensand of Kent and Surrey (Reigate) yields a stone of this description which was at one time much prized; some of the soft yellow sandstones of the Tyne (Walker and Bellingham) have also been employed in furnace-structures; and the sandstone of Craigenbank, near Borrowstounness, has been shipped to St Petersburg for furnaces, ovens, and similar purposes. Such sandstones, however, are now all but superseded by fire-clay fabrics. The firestone of Nevada, U.S., is described as a light, porous, silicious rock, having a specific gravity of 1.49, capable of being sawn into blocks of any form, and able to resist intense and intermittent temperatures.

Leckstones.

Another stone occasionally employed in oven and furnace structures, but especially as oven-soles, is obtained from the traps of the coal-formation. The *Leckstones*, as they are called, are open, granular varieties of trap (old ash-beds), and when carefully selected and dressed, stand well the alternations of heating and cooling. We have seen them quarried in Fife and Linlithgow, but the cheaper and handier slabs of fire-clay have driven them, we believe, entirely out of the market.

Potstone.

Potstone, the *lapis ollaris* of the ancients, and so called from its use, is a soft magnesian or talcose rock, of a greenish-grey or leek-green colour, sectile, and capable of being fashioned into pots, vases, and other articles. Mineralogically, it is an uncertain admixture of talc, chlorite, asbestos, and the like, occurring in beds among the serpentines and crystalline rocks of various countries: in other words, coarse granular varieties of steatite or soapstone. Like most magnesian minerals, it is little affected by heat, and was early fashioned into pots and pipkins—pipkins, which had the property not only of being unaffected by changes of heat and cold, but of communicating no bad taste or quality to the food, and of being thoroughly cleaned by being heated red-hot. It is now seldom used for this purpose save in northern Italy and the Grisons; but slabs of steatite are employed in Norway, Sweden, and America for furnaces, stove-linings, and ovens. It is also fashioned into gas-burners, which possess the property of not corroding, nor becoming clogged up, as is frequently the case with those made of metal. The Corsicans, it is said, use a fibrous variety, or asbestos (for both are nearly allied silicates of magnesia), in the fabrication of pots or pipkins, by mixing it with clay, and thereby obtaining a lighter and more durable vessel than could be obtained from the use of clay alone.

Some talc-slates and gneisses also offer great resistance to high temperatures, and are occasionally employed in the construction of reverberatory and other furnaces. Indeed, most silicio-magnesian rocks are endowed with this property, besides being readily cut and fashioned into any required form.

Asbestos.

Asbestos and *Amianthus* are the names applied by mineralogists to fine fibrous varieties of tremolite, actinolite, and other members of the hornblende family. They are all essentially silicates of magnesia, with a little lime, and traces of alumina, iron, manganese, and water. The fibres—often readily separable, elastic, and flexible—were used by the ancients in the manufacture of an incombustible cloth for the funeral pile; hence the name *asbestos*, inconsumable; and hence also *amianthus*, unsoilable, because the fabric when passed through the fire came out clean and unaltered. There are many varieties, and these receive their names from their appearance and quality—as *rock-wood*, *rock-cork*, *mountain-leather*, *fossil-paper*, *fossil-flax*, &c. In rock-wood, the fibres are long, parallel, curved, and compact; in rock-cork they have a felted texture, and so light as to swim on water; in mountain-leather, they form flat flexible pieces; and in fossil-flax they are so loose and silky that Dolomieu, when in Corsica, used it for packing his other minerals. Asbestos thus passes from the silky flexibility of amianthus to a degree of rigidity and compactness which admits of receiving a polish. It occurs among the metamorphic rocks of many countries, and especially in connection with serpentine, which it traverses in irregular veins, varying from half an inch to two or even three feet in thickness—the fibres being transverse to the cheeks of the vein.

As a refractory or fire-resisting substance, it has been put to many uses: by the ancients, in the manufacture of incombustible fabrics, for funeral-pyre sheets, and for table-napkins; and in modern times, for incombustible lamp-wicks, for filling gas-grates—the fibres remaining red-hot without being consumed—for making fire-proof safes, and occasionally for manufacturing indestructible paper. Recently it has been employed on a large and important scale in the manufacture of "packing" for steam-pistons, and of "paper-board" for the junction of steam-pipes, and the like. For these purposes it is obtained in large supplies from Italy, Corsica, the Tyrol, &c., in Europe, and from Massachusetts in America. The variety employed at the Asbestos Steam-packing Company's factory in Glasgow is obtained, we believe, from the north of Italy and Corsica, and is of a lamellar-fibrous texture, varying from three to twenty or more inches in length. Being exceedingly tough, it is first broken into pieces by sledge-hammer, then passed through corrugated rollers to soften it, next put through a teasing-machine and reduced to flossy fibres, and ultimately passed through a mill which slightly twists it into strands, enclosing these at the same time in a sheathing of pack-thread to give them greater consistency. In this state it is ready for the mechanical engineer, and is reported to stand longer than any other material yet employed as steam-packing. The paper-board is felted into sheets of various dimensions, whose thickness varies from that of a sheet of writing-paper to that of the heaviest pasteboard, and makes one of the handiest substitutes for lutings that has ever been adopted.

The substances noticed in the preceding pages are of vital importance to the Arts and Manufactures. They are essential in all our smelting and refining furnaces ; in our grates, hearths, flues, and chimneys ; in our gas and oil distilleries ; in our baking, pottery, and glass ovens ; and, in fact, wherever intense or long-continued heat has to be resisted. One of their main recommendations is that they are all abundant, easily obtained, and readily manipulated. Their supply is equal to any demand, and there is practically no limit to the forms or modes in which they can be applied. Considering their cheapness and abundance, and the frequency of destructive fires in factories and warehouses, it seems culpable that they are not more extensively employed as floorings, partitions, linings, and even roofings—their lightness, and the exactitude with which they can be shaped and fitted together, rendering them nearly as convenient as wood, without its liability to combustion.

XIII.

PIGMENTS, DYES, AND DETERGENTS.

The substances noticed under the present head are intimately connected with the Arts and Manufactures, both in the way of utility and ornament. The pigments when well prepared and carefully applied, are the best preservations of wooden and metallic structures; the dyes give beauty and colouring to fabrics otherwise tame and uninviting; and the detergents are essential to cleanliness and health. It is true that pigments, dyes, and detergents are obtained from the vegetable and animal as well as from the mineral kingdom; but those from the latter have a brilliancy, permanence, and abundance which do not belong to those of the former. These substances early attracted the attention of mankind—the savage smearing his body with ochre, daubing his robe with reddle, or washing himself with magnesian clay, seeking, only in a ruder way, the same effect as the man of civilisation and refinement by his most costly colours and detergents. Few of these substances can be applied in their natural state; most of them have to undergo treatment and preparation; and some of them can only be obtained in perfection by intricate chemical processes and manipulation. It is more, however, with the raw materials that we have here to deal—their mineral characters and geological positions—the processes by which they are brought to their finished state being altogether technological.

I.—PIGMENTS.

"By paints," says Wagner, in his 'Handbook of Chemical Technology, "we understand substances which, as a rule, are insoluble in water, and are mixed with either weak glue solution, being then termed water-colours, or with linseed-oil, called oil-paints. To these pigments belong white-lead, red-lead, ultramarine, Berlin blue, vermilion, chrome-yellow, bone-black, &c. The ordinary water-colours are insoluble in water, being finely suspended therein by the aid of gum, white of egg, &c. The pastel pigments used for drawing are made up of various colouring matters mixed with pipe-clay, soap, and gum-tragacanth mucilage, and moulded into cylindrical sticks."

Mineral Pigments.

Among the most common and abundant of these pigments or colouring matters are the hydrated oxides of iron, known as ochres, boles, reddles, and the like. Strictly speaking, *ochre* (Gr. *ochros*, yellow) is a hydrated peroxide of iron, consisting of about 80 of the hydrate and 20 of water; but it is very rarely found pure, being often, in fact, clay coloured yellow by hydrate of iron, though a fair ochre should not contain less than 15 or 20 per cent of the hydrate. Naturally it varies from pale yellow to a deep orange or brown; but the manufactured article is usually toned to any shade by treatment and admixture. It occurs in all formations; much of that used in Britain being obtained from the coal-formation, where it appears as a product of decomposition. *Bole* (Gr. *bolos*, a clod) is the term usually applied to friable clayey earths coloured by the peroxide of iron, and varying from yellow to yellowish-red and reddish-brown. The term is rather an indefinite one, and loosely applied; but a useful variety may consist of about 32 silica, 28 alumina, 21 iron peroxide, and 17 water. A variety from Cape di Bove yielded to C. von Hauer 45.64 silica, 29.33 alumina, 8.88 iron peroxide, magnesia a trace, and water 14.72; while another from New Holland gave 38.22 silica, 31.00 alumina, 11.00 iron peroxide, traces of lime and magnesia, and 18.81 water. Bole occurs in irregular beds and disseminated masses in various formations, some of the finest sorts (Sinopian earth) being procured from Italy and Asia Minor. The better-known varieties are the *Armenian*, of a bright red colour; the *Sinopian*, of a deeper red; the *Bohemian*, of a yellow red; the *Blois*, of a pale yellow; the *French*, of a pale red; the *Lemnian*, of a yellowish red; and the *Silesian*, of a similar but brighter hue. *Reddle*, which is merely a corruption of red-clay, is another of these argillaceous hydrated peroxides of iron, usually of a deep red, and, in fact, a decomposed hæmatite. It occurs abundantly in England, France, and Germany, and usually in the hæmatite-yielding districts of the carboniferous limestone, as Cumberland, north Lancashire, Somerset, and Devon.

All these substances are prepared for the colour-merchant by grinding, washing, and drying; and the desired shade of colour is obtained by admixture.

Another closely allied colouring material is *Umber*, which presents various shades of brown, and which occurs either naturally in veins or beds, or is prepared artificially from various admixtures. The "umber" proper of the mineralogist is a soft earthy combination of the peroxides of iron and manganese, with minor proportions of silica, alumina, and water—48 iron peroxide, 20 manganese peroxide, 13 silica, 5 alumina, and 14 water. It is usually found in veins in the crystalline schists, and appears to be a product of decomposition. Commercially it is obtained from the island of Cyprus, Anglesea, Isle of Man, Forest of Dean, and other localities. Much of the umber of the colourman, however, is merely an ochraceous admixture; and that from Cologne is said to be only brown lignite finely pulverised.

Some idea of the value of these ochres and umbers may be formed from the fact that in 1872 upwards of 3300 tons (worth £8240) were raised from Anglesea, Devon, Cornwall, and the Isle of Man.

Whiting, or *Spanish White*, one of our most common but useful colouring matters, is obtained from the softest and purest white chalks by grinding and elutriation. It is extensively used as a whitewash; and occasionally, when carefully and delicately prepared, as a cheap white paint. A serviceable *whitewash* for external walls, and one possessing disinfecting properties, is obtained by diluting quicklime—the purer and whiter the limestone, the more brilliant the whitewash. *Coloured washes* and rubbing bricks for external use have usually a basis of whiting or clay, the basis being obtained from ochre, reddle, bluestone, or other cheap material.

Ultramarine (literally "beyond the seas," from its being brought from China and Further Asia), so highly esteemed for the extreme beauty, softness, and durability of its fine azure-blue, was originally prepared from the *lapis lazuli*. This mineral, which occurs in the old crystalline schists and limestones (see Chapter on "Precious Stones"), is rather rare, and after treatment yields only a small percentage of the colouring matter; hence the former high price of the pigment. From analyses of the stone, which consists of 45.40 silica, 31.67 alumina, 9.09 soda, 5.89 sulphuric acid, 3.52 lime, 0.86 iron, 0.42 chlorine, and 0.12 water, Gmelin, in 1822, was led to attempt its artificial production. His experiments were successful; but not till many years after was ultramarine produced on a commercial scale, though now as much as 180,000 cwt. are annually manufactured in Europe, at a mere fraction of the price of the natural product.

The artificial pigment can be made to rival the natural in beauty and softness, at the same time that it admits of a greater variety of shades and tonings. It is manufactured principally in Germany and France, and consists of definite proportions of kaolin or silicate of alumina, calcined sulphate of soda, calcined soda (sulphuret of sodium is a by-product of the manufacture), sulphur, and pulverised charcoal or pit-coal—other ingredients, as gypsum, baryta, &c., being added to tone the colour to special requirements. Different manufacturers adopt different methods and proportions; but the following may be taken as an example of the composition of the artificial pigment: 46.60 silica, 23.30 alumina, 3.83 sulphuric acid, 21.48 soda, 1.06 iron peroxide, with traces of lime, sulphur, and magnesia. Ultramarine is largely employed as a paint, as a pigment for paper-hangings, in calico-printing, for colouring printing-ink, for the bluing of linen, and for imparting blue tints to various fabrics; and is said to be rapidly superseding smalt, litmus, and Berlin blue.

Metallic Pigments.

A great many pigments are prepared from the metals—lead, zinc, copper, cobalt, chromium, arsenic, iron, manganese, mercury, &c.; but as the processes are purely technological, they belong to chemistry rather than geology. The metals, no doubt, belong to the mineral kingdom, and will be treated in other Chapter (XVIII.); but all the reductions, manipulations, and admixtures by which they are converted into colours of unrivalled brilliancy and durability, are matters that lie beyond the domain of the geologist. In illustration, however, of their importance as colour-producers, we may adduce a few examples: From *lead* we obtained massicot or the yellow oxide, litharge, red-lead, and white-lead; from *chromium* and *lead*, chrome-yellow, chrome-orange, and chrome-green; from *cobalt*, smalt or cobalt-blue, cobalt-ultramarine, cobalt-green, and cobalt-bronze; from *zinc*, zinc-white; from *copper*, Brunswick green, mineral green, emerald green, Bremen green and blue, and the like; from *mercury*, vermilion; from *gold*, purple of Cassius; from *antimony*, orange, Neapolitan yellow, and vermilion-red; from *arsenic*, realgar and orpiment; and from iron and manganese, various tints of black, red, brown, and yellow. Indeed it is from the metals that we obtain the majority of our most brilliant and durable pigments; and chemistry is every year inventing new methods and producing new colours—the art of the colour-manufacturer being at once one of the most subtle and successful.

The subject, perhaps, may be rendered more obvious by tabulating the colours and the mineral and metallic sources from which they are derived:—

White pigments, from lead, zinc, heavy-spar or sulphate of baryta, chalk, and admixtures.

Yellow pigments, from antimony, lead, arsenic, chromium, chalk, and admixtures.

Orange pigments, from ochre, chromium, lead, chalk, and admixtures.

Brown pigments, from umber, Terra di Sienna, manganese, and admixtures.

Red pigments, from ochre, bole, reddle, chrome, mercury, arsenic, lead, and admixtures.

Black pigments, from iron, manganese, asphalt, coal-tar, and admixtures.

Blue pigments, from cobalt, copper, iron, lapis lazuli, potash, soda, and admixtures.

Purple pigments, from gold and tin, and from admixtures.

Green pigments, from copper, chrome, arsenic, potash, and admixtures.

Intermediate shades, like compound colours, are all obtained by skilful admixture—the produce, in fact, of the chemist and technologist.

Pastel Pigments.

As already mentioned, pastel pigments for writing, drawing, and marking, consist of colouring matters worked up with pipe-clay, steatite, soap, and various gums, to give them body and consistency. Writing and drawing pencils, drawing-chalks, lithographic chalks, and the like, belong to this class of materials. Some of them, like the common black-lead pencils, consist of native mineral substances; others, like the coloured crayons, are manufactured admixtures. Their preparation is wholly technical; we only allude to the minerals which enter into their composition.

Formerly, *black-lead pencils* were sawn from the finer varieties of graphite, like that of Borrowdale in Cumberland; but now the great majority of those in ordinary use are manufactured from graphite finely triturated, and then compressed into blocks in imitation of the native mineral—the various shades of B, BB, HB, &c., being brought out by admixture and treatment. The Borrowdale mine having been closed for many years, the Keswick pencils, like others in the market, are now chiefly made from the manufactured material. For the composition, modes of occurrence, and other characteristics of graphite, which is found in the metamorphic rocks of many countries, the reader is referred to Chapter XII.

Coloured Crayons or Drawing-Chalks.—Red, blue, and other tints are chiefly made of fine pastes of pipe-clay, china-clay, or steatite, intimately mixed with earthy or metallic pigments. Some of these so-called chalks, however, are natural products, such as *Red chalk*, a clay or reddle containing from 15 to 20 per cent of iron peroxide; *Brown chalk*, a fine variety of umber; *Black chalk*, a variety of carbonaceous drawing-slate; and *French chalk*, a variety of steatite or soapstone.

Lithography.

While speaking of chalks and crayons, we may appropriately advert to the limestones fitted for the purposes of *Lithography*, and which also come under the domain of Economic Geology. Though attempts have been made to utilise some of our own liassic and oolitic limestones, the slabs of the best quality are still obtained from the quarries of Solenhofen, near Munich, where the art of lithography had its birth. There, and throughout Pappenheim, on both sides of the Danube, lithographic slabs of all sizes and qualities can be obtained from the flaggy oolites. Good serviceable stones have usually a yellow or bluish-grey colour, are compact and uniform in texture, and free from veins, flaws, and spots, that would interfere with the delicate lines of the lithographer. The quarrying, dressing, and polishing of lithographic slabs for home use, and their exportation to all parts of the world, has of late years become an important branch of industry in Upper Germany.

Varnishes.

Closely related to the pigments are the *varnishes*—compounds which are spread over the surface of any body to give it a shining, transparent, and hard coat, capable, more or less, of resisting the action of air and moisture. The great majority of the varnishes employed by cabinetmakers, japanners, tanners, and others, are solutions of gums, resins, and wax in alcohol, turpentine, oils, and the like, and consequently lie beyond the domain of Geology. A few, however, are prepared from amber and asphalt—the former forming a very hard and durable varnish, the latter being the main ingredient in most of the black or Japan varnishes.

II.—DYES.

"Dyeing," says Wagner, "is distinguished from painting by the fact that the pigments are fixed to the animal and vegetable textile fabrics according to certain physico-chemical principles, and are not, as in painting, simply fixed by adhesion to the surface, although painters and artists occasionally use the same pigments. Printing consists in the duplication of coloured patterns, and is a very important part of dyeing. In the art of dyeing, some colouring matters are applied by immersing the tissue to be coloured in the decoction or solution of the pigment. Some substances are applied to the surface of the woven fabric by the intervention of what is termed a 'mordant,' which secures the adhesion, fixing, and permanency of the colours."

The great majority of *dyes* and *dye-stuffs* are obtained from the vegetable kingdom; some from the animal; and, till recently, only a few from the mineral. Though these are chiefly of organic origin, the "mordants," or substances employed in *fixing* or *striking* their colours, whether in woollen, silk, cotton, or linen, are all, or nearly all, of inorganic origin—such as acetates of iron, lead, and alumina, sulphates of iron and alumina, aluminate of soda, and alum. In this way the art of dyeing comes within the range of Economic Geology. Of recent years, however, the relationship has become more intimate, and by the researches of modern chemistry we now derive from the inorganic world a variety of dyes of unsurpassed beauty and brilliancy. Strange as it may seem, these are chiefly obtained from coal-tar—a dark, dingy, and uninviting by-product of our gas-works. Chemically treated, by a number of ingenious processes this substance yields the aniline or coal-tar colours of commerce—fuchsin, magenta, aniline blue and violet, Manchester yellow, aniline orange and aniline brown, coralline, alizarine, Magdala red, and aniline black. Few triumphs of chemistry have been more marvellous than the production of these beautiful colours—no substances so unlike as a mass of pitchy coal-tar, and the brilliant flush of roseine, mauve, and magenta.

III.—DETERGENTS.

Fuller's Earth.

One of the best-known and abundant of mineral detergents is *fuller's earth* or *fuller's clay*, so called from its being employed in the fulling of woollens. In composition it is somewhat varied; but all the varieties are soft, unctuous, hydrous silicates of alumina—that of Reigate, from the greensand of Surrey, consisting of 53 silica, 11 alumina, 24 water, and 9 iron oxide, with traces of magnesia and lime. Good fuller's earth is usually massive, opaque, soft, dull, with a greasy feel and an earthy fracture; scarcely adheres to the tongue; and when placed in water, falls down to an impalpable powder without forming a paste with it. It occurs abundantly in the oolitic and cretaceous systems of England, in beds from one to several feet in thickness, and of a greenish or greyish-green colour. So important at one time was this earth to the woollen manufacture of England, that its exportation was prohibited by Act of Parliament. Its place is now mainly supplied by soap and other chemical detergents, though considerable quantities are said to be still dug and prepared for the fuller in Surrey, Gloucestershire, and Bedfordshire. Besides being used by the fuller, under the names of fuller's earth, Walker's earth or walkerite, and smectite (Gr. *smectes*, a cleaner) it is also employed in paper-making, and as an addition to artificial ultramarine.

Nowadays the principal detergents, whether employed in woollen, silk, cotton, linen, or leather manufacture, are of chemical preparation—soaps, leys of soda and potash, chlorine, chloride of lime, &c.—and as far as the limes, alkaline salts, and soluble silica (which enters into the composition of some soaps), are concerned, come under the cognisance of Geology. The operations of washing, bleaching, and tanning are all more or less facilitated by preparations obtained wholly, or in part, from the mineral kingdom. The same may be said of sugar-refining, in which lime, gypsum, and baryta are now successfully employed, not only in producing a purer article, but in facilitating the operation.

As explained in the preceding pages, most of the pigments, several of the dyes, and many of the detergents, are obtained either directly or indirectly from the mineral kingdom, and in this way come within the scope of Economic Geology. The elaboration of these substances belongs more especially to chemistry; but to the working geologist is left the discovery of the raw materials, their modes of occurrence, abundance, and the facility with which they can be procured. Many of them have long been known; but some are the results of recent research, and hold out the hope that others may yet reward the skill and industry of the diligent inquirer. The earth is a vast storehouse of mineral and metallic wealth, only awaiting the requirements of man, and the skill to utilise them ; and the geologist best performs his function, when in conjunction with the chemist and technologist, he is ever on the watch for new products and more advantageous appliances. Numerous, beautiful, and useful as our pigments, dyes, and detergents undoubtedly are, it cannot for a moment be supposed that we have either exhausted the field of their variety, or the sources from which they are derived. The artificial preparation of ultramarine, and the discovery of the coal-tar or aniline colours, are apposite cases in illustration, and hold out the incentive alike to chemist and geologist to persevere in their researches for results equally successful and satisfactory. The discovery of mineral substances has not been exhausted, any more than the limits of invention have been reached, by those who have gone before us.

Works which may be consulted.

Wagner's 'Handbook of Chemical Technology'—Crooke's Edition ; Ure's 'Dictionary of Arts and Manufactures'—Hunt's Revision ; Knapp's 'Chemical Technology'—vol. ii. ; Watt's 'Dictionary of Chemistry.'

XIV.

SALTS AND SALINE EARTHS.

By the Salts and Saline Earths we mean those substances which, like rock-salt, natron, and nitre, are obtained from the rocky crust, either in a crystallised state comparatively pure, or so associated with earthy matters as to require chemical processes of extraction and purification. These substances play important parts in the arts and industries—in domestic economy, in medicine, agriculture, bleaching, dyeing, glass-making, powder-making, glazing, enamelling, and various other processes. Some, like rock-salt, occur in stratiform masses; some are obtained by the evaporation of saline waters; and others, again, are found commingled with sand, gravel, and earthy debris, in the sites of desiccated lakes, deserted sea-lagoons, and old upraised sea-beaches. Many of these salts are *hydrous*, —that is, they contain a definite proportion of water of crystalisation; others are destitute of water, and are dry or *anhydrous* salts. Some attract moisture when exposed to the air, and are said to be *deliquescent;* others suffer their water to escape, and become opaque and pulverulent, and are said to be *efflorescent.* They are all more or less soluble in cold water, and much more easily so in boiling water—forming brines and saturated solutions. Whatever their characteristics, they are easily treated, and many of them are produced on the large scale by artificial processes.

I.—SALTS OF SODA.

Foremost among these, both in point of bulk and importance, is *Rock-salt,* common salt, or chloride of sodium, 60.4 chlorine and 39.6 sodium. This mineral occurs as an efflorescence in most of the salt-deserts of the world, in old sea-reaches, and on the shores of salt-lakes. It is thrown up in solution by saline springs, and forms a principal ingredient in the waters of the ocean. It is also found as a rock-mass in several formations, often in a state of considerable purity, but more frequently coloured by iron oxides and commingled with earthy impurities. In its purest state it may consist of 98 or 99 of chloride of sodium, with traces of chloride of magnesium, sulphate of lime, chloride of calcium, and insoluble matter — the rock-salt of Chester yielding to Henry 98.3 chloride of sodium, 0.05 chloride of magnesium, 0.65 sulphate of lime, and 1 of insoluble ingredients. In its impure condition it may contain from a sixth to even a half of earthy admixtures. Pure chloride of sodium is not liable to deliquesce, but it rapidly attracts moisture from the air when it contains chlorides of magnesium and calcium.

In the British Isles the great repository of rock-salt is the Trias, or Upper New Red Sandstone (Cheshire, Middlesborough, Antrim); but deposits of equal magnitude are found in connection with oolitic strata, as in the Salzburg Alps—with cretaceous greensands, as at Cordova in Spain—with chalk and tertiary rocks in the Valley of Cardona in the district of the Pyrenees—with tertiary marls, as in Sicily and at Wielitscka in Poland; and salt or brine springs are known to issue from carboniferous and older strata. It is thus a product of all epochs, and must have been formed either by the gradual and long-continued desiccation of limited areas of salt water alternately cut off and placed in communication with the ocean, or by precipitation from saturated solutions, brought about, perhaps, by the evaporating power of volcanic or other thermal agency.

The Cheshire deposits of rock-salt, which may be taken as a typical illustration, lie along the line of the valley of the Weaver, in small patches, about Northwich. There are two main beds lying beneath 120 feet of coloured marls, sands, and irregular bands of salt and gypsum, in which no traces of animal or vegetable fossils occur. The upper bed of salt is 75 feet thick; it is separated from the lower one by 30 feet of coloured marls, sands, and salt-bands, similar to the general cover: and the lower bed of salt is above 100 feet thick, but has nowhere been perforated. They extend in an irregular oval area, about a mile and a half in length by three-quarters of a mile in breadth. The salt in these deposits is in some portions pure and transparent, and in others of a dirty reddish hue, and mixed to the amount of half its bulk with earthy impurities. It is not stratified nor laminated, but divided into vertical prisms of various forms and magnitudes, sometimes more than a yard in diameter—the outer sides of these rude crystallisations being generally pure and transparent.

Rock-salt is seldom sufficiently pure to be crushed for direct use, but has to undergo lixiviation and preparation. Occasionally it is more economical to pump the brine from old mines and salt-springs and evaporate, than to raise the solid mineral. Indeed, the sands which alternate with the marls and salt-beds are saturated with brine, and in several localities are the chief sources from which the salt is obtained. The preparation of salt from sea-water (bay-salt), at one time so largely carried on in Britain, is now little if at all resorted to, and where practised is often facilitated by the addition of rock-salt to the natural brine. In tropical and sub-tropical countries, however, a large amount is still prepared, partly by natural and partly by artificial evaporation. The great centres of the salt industry in Britain are Cheshire and Worcester—the mines of the former, and the brine-pits of the latter, not only supplying almost the whole of the home consumption, but exporting annually nearly 800,000 tons (747,803 in 1872) to all parts of the world, at a value of £592,100! In 1872, the total quantity of salt returned as made in the United Kingdom, amounted to 1,309,497 tons. In 1873, the amount of rock-salt and salt produced in Cheshire was 1,013,497 tons; in Worcestershire, 276,000 tons; and in Ireland, 20,000 tons—quantities which show at a glance the extent and importance of this branch of mineral industry.

The uses of salt in the arts and manufactures are at once numerous and important. Passing over its value as a condiment and antiseptic in domestic economy, it is largely employed in agriculture and the manufacture of artificial manures, in the glazing of pottery and earthenware, in the preparation of soda, chlorine, and sal-ammoniac, in tanning, and in many metallurgical processes.

Natron (Lat. *natrium*, soda), or hydrated carbonate of soda, is an abundant natural product, consisting of about 19 soda, 27 carbonic acid, and 54 water. It occurs in solution in the waters of many springs and salt-lakes (Germany, Egypt, Central Asia, &c.); as a crystallised incrustation on the beds of dried-up lakes, in deserted river-courses (Central Asia, Colombia, &c.); and in numerous salinas or upheaved sea-reaches (South America); as a pulverulent efflorescence on the ground, as in the plain of Debreczin in Hungary; and as a product of decomposition in many lavas and other volcanic rocks. In general it is found mingled with sand, clay, and other impurities, from which it requires to be dissolved and evaporated to recover it in the crude crystallised form. At one time it was largely, and is still to some extent, prepared from the ashes (kelp, barilla) of certain sea-plants; but now the bulk of the soda of commerce is obtained by chemical processes from common salt, and minor portions, we believe, from cryolite, bauxite, and during the conversion of the nitrate of soda into the nitrate of potash for the manufacture of gunpowder. The amount of soda (caustic, carbonate, and bicarbonate) annually produced in Britain is said to exceed 400,000 tons.

This salt is employed in bleaching, washing, dyeing, in the manufacture of soap and glass, and for numerous industrial purposes.

Trona (Arabic), or the native sesquicarbonate of soda, is found in similar situations, and employed for similar purposes as the preceding salt. It consists of about 37 soda, 38 carbonic acid, 2.5 sulphate of soda, and 22.5 water.

Nitratine is the mineralogical term for nitrate of soda, which consists of 36.6 soda and 63.4 nitric acid. This salt, like the carbonates, occurs in many situations, but most abundantly in the *salinas* or desert saline tracts of South America. These salinas have been already noticed under Chapter III., and for their extent and richness are among the most wonderful repositories of saline ingredients in the world. Nitrate of soda is largely used as a manure, and is employed in the arts as a substitute for nitre; but it is unfitted for gunpowder from its tendency to deliquesce.

Glauber-salt (after Glauber, a German chemist) is the sulphate of soda—the *sal mirabile* of the older chemists, consisting of soda 19.3, sulphuric acid 24.8, and water 55.9. It occurs chiefly as an efflorescence in quarries and on old walls, as in the salt-mines of Austria, Spain, and other countries; it is deposited in great abundance from the hot springs at Carlsbad, and is found in many other mineral waters; and is likewise procured from salt-springs, and forms a crust or efflorescence on the borders of salt-lakes in Central Asia, Egypt, Southern Russia, the United States, and other regions. Glauber-salt is usually of a greyish or yellowish white colour, has a cooling and then a bitter saline taste, and is extremely efflorescent. It is used in medicine.

Glauberite, a nearly allied salt, and so called from its containing a large amount of Glauber-salt, is a sulphate of soda and lime—51 sulphate of soda and 49 sulphate of lime; or sulphuric acid 57.5, lime 20.1, and soda 22.4.

Borax (Arab.), or *Borate of Soda* (boracic acid 36.5, soda 16.3, and water 47), is found associated with rock-salt in loose crystals among sands and clays on the shores of certain salt-lakes in Tibet and Nepaul, in Ceylon, South America, and California. Many springs also yield borax in small quantities, and according to G. E. Moore, the waters of Borax Lake in California contain 535 grains of crystallised borax to the gallon. In its crude or impure state it is known as *tincal*, and from this the pure borax of commerce is derived by several chemical processes. It is also made in large quantities from the boracic acid of the Tuscan lagoons. These lagoons occupy a large extent of surface, and consist of numerous fumeroles and springs in a violent state of ebullition. The vapours contain boracic acid, and by making these pass through reservoirs of water they impregnate the water with the acid. This impregnated water is then evaporated in leaden reservoirs by the heat of the vapours themselves, and leaves the acid in a state of crystallisation. By various processes the crystallised acid is combined with carbonate of soda (in the proportion of 38 of the former to 45 of the latter) to produce the borax of commerce.

Boracic acid is also contained in the mineral *Hayescine*, known as boro-calcite or borate of lime (50 boracic acid, 18 lime, and 35 water), which occurs in incrustations near the Tuscan lagoons, and largely in the salinas of South America, where it is found as soft rounded nodules, from the size cf a hazel-nut to that of a potato, having when broken up a silky, fibrous, radiated structure, of a snow-white colour. In this crude state it is imported into Britain under the native name of *Tiza*.

Borax has a sweetish taste, affects vegetable colours like an alkali, effloresces and becomes opaque in a dry atmosphere, melts at a heat a little above that of boiling water, and gives out its water of crystallisation, forming a dry spongy mass known as calcined borax.

Industrially, borax forms the most valuable re-agent for blowpipe purposes; it is used in the preparation of fine glass and artificial gems, in enamelling, in soldering, as a flux in several metallurgical operations, and as an ingredient in certain varnishes, in toilet soaps, and in cosmetics. The non-metallic element *Boron*, which is a dark greenish-brown powder, tasteless, and inodorous, is obtained by chemical treatment from boracic acid.

Another rare and important salt of soda is *Cryolite* (Gr. *kryos*, ice; *lithos*, stone), a double fluoride of sodium and aluminium, consisting of 13.10 aluminium, 33.27 sodium, and 53.63 fluorine. Hitherto it has been brought only from West Greenland, where it occurs with other minerals in gneiss in a vein about 80 feet thick, massive, and of lamellar structure. There are two varieties—a snow white and a rusty yellow, and both are used as commercial ores of aluminium.

II.—SALTS OF POTASH.

The most important of the potash salts is the nitrate known as *nitre* (*Nitria* in Egypt) or *saltpetre* (*petra*, a rock), from its occurring so frequently in connection with loose shingly soils. It consists of 46.6 potash and 53.4 nitric acid. "It is," says Brande, 'Dict. of Science,' "spontaneously generated in the soil, and crystallises upon its surface in several parts of the world, especially in India, whence nearly the whole of the nitre used in Britain is derived. It has occasionally been produced artificially in *nitre-beds*, formed of a mixture of calcareous soil and animal matter. In these nitrate of lime is slowly formed, which is extracted by lixiviation, and carbonate of potash added to the solution, which by double decomposition gives rise to the formation of nitrate of potash and carbonate of lime—the latter is precipitated, the former remains in solution, and is obtained in crystals by evaporation." Nitre crystallises in six-sided prisms, is soluble in four parts of cold water, and in less than its weight of boiling water. It has a cooling taste, is antiseptic, and is not altered by exposure. At 616° it fuses, deflagrates vividly on burning coals, and detonates with combustible substances.

"Nitre," says Dana, "requires for its formation dry air and long periods without rain; hence its frequency in India, Persia, Egypt, Algeria, and Spain. The potash comes mainly from the debris of felspathic rocks in the soil, and the oxidation of the nitrogen of the air is promoted by organic matters; hence the nitre is generally associated with nitrogenous decomposed organic substances."

The potash salts obtained from superficial deposits, from kelp, sea-water, &c., are now inconsiderable compared with what are obtained by chemical processes from the natural deposits of Stassfurt in Germany. These deposits, which were discovered in 1851 and first worked in 1857, consist of a series of saliferous beds—*carnallite*, *kieserite*, *kainite*, *poly-*

halite, common salt, &c.—in bands of various thickness and purity, and all rich in salts of potash, soda, magnesia, and lime, These beds form a very complex series in the salt-formation of Germany, and are evidently the results of marine evaporation and deposition. F. Bischoff divides them vertically into *four* regions, corresponding, he observes, to the natural order of origin from an evaporating saline,—viz., 1, or lower, the *anhydrite* region; 2, the *polyhalite;* 3, the *kieserite;* and 4, the *carnallite.* The kieserite is in beds from 9 to 12 inches thick, alternating wtih common salt. The whole deposit is about 190 feet thick, and has the following mean percentage composition: Common salt (chloride of sodium), 65; kieserite (sulphate of magnesia), 17; carnallite (double chloride of potassium and magnesium), 13; hydrated chloride of magnesium, 3; and anhydrite (sulphate of lime) 2 = 100. Similar compounds are found in the saliferous system of Kalutz in Hungary, and at the salt-mines of Maman in Persia.

Nitre is largely employed in the arts—in glass-making, in medicine as a diuretic, in metallurgy as an antiseptic, and for producing nitric acid; but especially, and most extensively, in the manufacture of gunpowder, lucifer-matches, detonating powder, and the like.

III.—SALTS OF MAGNESIA.

The most abundant and best known of the magnesian salts is the sulphate, consisting of 16.26 magnesia, 32.52 sulphuric acid, and 51.22 water. It is generally known as *Epsomite* or *Epsom salts*, from the springs of Epsom in Surrey, in whose waters it forms the most notable ingredient. It occurs, however, in many mineral waters (Seidlitz, Saidschutz, &c.), and as botryoidal masses and capillary efflorescences in old mines, veins, coal-workings, quarries, and caverns. It is a white lustrous salt, translucent and brittle, with a bitter saline taste. Though occurring abundantly in nature, the greater portion of the Epsom salts of commerce is manufactured either from the magnesian limestones of Durham and York, or from the white chalk-like carbonate of magnesia (*Magnesite*) imported from the Mediterranean, which is said to produce a finer and purer sample. The Magnesian limestones have been already noticed under Chapter V. Magnesite generally occurs in veins or in masses associated with serpentine, and consists of 51 magnesia, and 49 carbonic acid.

The salts of magnesia are used chiefly in medicine; and the earth itself in the preparation of the metal magnesium.

IV.—SALTS OF AMMONIA.

The principal salt under this group is *sal-ammoniac*, or the *muriate of ammonia*, consisting of chloride of ammonium 99.5, and sulphate of ammonia 0.5, and so called from the temple of Ammon in Egypt, where it was originally extracted from the soot obtained by burning camels' dung. It is now largely produced by the destructive distillation of organic bodies containing nitrogen, but occurs *native* in crusts, stalactites, and pulverulent masses, chiefly in rents and fissures near active volcanoes, in the vicinity of ignited coal-seams, and in the guano of the Chincha islands. It is of a greyish or yellowish white, according to impurities of iron, sulphur, &c.; has a saline pungent taste, is easily soluble in water, and volatilises without fusing. Sal-ammoniac is used in medicine, in dyeing, and in various metallurgic processes.

The *carbonate of ammonia* (ammonia 32.9, carbonic acid 32.9, and water 55.7), and the *sulphate of ammonia* (sulphuric acid 53.3, ammonia 34.7, and water 12), are salts occurring in a crude or native state—the former chiefly in connection with guano deposits, and the latter in the neighbourhood of volcanoes, and as a product of the combustion of coal and the manufacture of gas and paraffin-oils. The crude sulphate can be obtained in large quantities from the ammoniacal water of gas and oil works; in other words, from the distillation of bituminous shales, gas-coals, and peats—the latter yielding, according to Sir Robert Kane, about 25 lb. per ton. These salts are employed in the manufacture of sal-ammoniac, in the preparation of ammonia-alum, and, in their crude state, as stimulating manures. (Saline Manures, Chap. III.)

V.—SALTS OF ALUMINA.

What are known as *Alums* are double salts—that is, sulphates of alumina, with sulphates of potash, of soda, of ammonia, of magnesia, or of iron; hence spoken of as potash-alum, soda-alum, ammonia-alum, magnesia-alum, and iron or feather alum. They occur in nature on the surfaces and in the chinks and fissures of many rocks in minute snow-like crystals, or in feathery efflorescences, but never in commercially available masses. They are extracted by chemical processes, and the rocks containing them in notable proportion generally manifest their presence when exposed to air and moisture, by emitting whitish or yellowish-white efflorescences of the salts; and these, as well as the water which trickles from the rocks, are readily detected by their sweetish astringent taste—the taste peculiar to common alum.

Alum is manufactured from certain transition slates (Norway), from coal-shales (Renfrew and Lanark), from lias-shales (Yorkshire), lignite-shales (Germany), and from alum-stone in the volcanic formations of Sicily; hence such geological designations as *alum-slate*, *alum-shale*, *aluminite*, *alum-stone*, &c. For the extraction of the salts these aluminous earths are variously treated: some containing iron pyrites being merely exposed to the disintegrating effect of the air and moisture; others, void of pyrites, being roasted by the adding of brushwood or coal-slack, during which processes the sulphur of the pyrites becomes converted into sulphuric acid, and sulphate of alumina is formed, together with sulphate of iron. Whether the ustulation is produced by the spontaneous combustion of iron pyrites or by the addition of fuel, a slow continued heat is always most favourable to the reduction of the alum-shales. The salts are extracted by digestion in water—the iron sulphate is removed, and potash, soda, ammonia, &c., added to purified sulphate of alumina—the salts of alum being obtained by subsequent partial evaporation to saturation. Alum is also obtained by treating the Dorsetshire and other fine clays with sulphuric acid; but this is a process of technological rather than of geological interest. Common alum is soluble in from 16 to 20 times its own weight of cold water, and in slightly more than its own weight of boiling water.

Alum is used in medicine as an astringent, as an antiseptic, as a mordant in dyeing and calico-printing, in the manufacture of paper and leather, for rendering wood and cloth incombustible, and for various other purposes. The earliest centres of alum production in Britain were Whitby in Yorkshire, and Hurlett and Campsie near Glasgow; but more recently large quantities have been produced by the sulphuric-acid process at works near Manchester, Goole in Yorkshire, and other places. A few thousand tons are annually imported; but a larger amount is exported, the manufacture having of recent years assumed gigantic proportions.

The alum of commerce is principally an *ammonia-alum* (alumina 11.90, sulphuric acid 35.10, ammonia 3.89, and water 48.11); the *potash-alum*, which it has greatly superseded, consists of alumina 10.83, sulphuric acid 33.71, potass 9.95, and water 45.51; and *soda-alum*, of alumina 11.12, sulphuric acid 34.9, soda 6.8, and water 47.1. Aluminate of soda (alumina 48, soda 44, and chloride of sodium and Glauber-salt 8) is also prepared on a large scale as a useful form of soluble alumina, especially in dyeing and calico-printing.

Other salts of alumina are used in commerce—the acetate as a mordant in calico-printing, and the sulphate as a substitute for alum; but with the exception of the fact that the alumina is derived from the rocky crusts, their history and preparation have more of a chemical than of a geological interest.

VI.—METALLIC SALTS.

Under this head are comprehended such salts as the sulphates of iron, copper, and zinc, familiarly known as copperas or green vitriol, blue vitriol, and white vitriol. These salts occur sparingly in a crude or native state, but are prepared on a large scale for the arts and manufactures. They are extensively and variously employed, and are amongst the most important products of the manufacturing chemist.

The sulphate of iron, familiarly known as *copperas* or *green vitriol*, is a salt occurring in various shades of green and greenish yellow, lustrous and brittle, with a strong metallic or astringent taste. It consists of sulphuric acid 28.9, protoxide of iron 25.7, and water 45.4. It is generally produced by the decomposition of iron pyrites in shales and clays, and is found in many situations and formations, though on a limited scale. As an artificial product it is produced on a large scale by moistening the pyritous shales (sulphides of iron), which are found abundantly in the coal-measures (Renfrew and Lanark), &c.; exposing them to the air, when decomposition takes place, and the sulphide is converted into the sulphate of iron, which is subsequently dissolved and evaporated, to procure it in the crystallised state.

Copperas is a valuable salt, and is extensively employed in dyeing and tanning; in the manufacture of writing-ink, Prussian blue, sulphuric acid, and in various other arts and processes. It is soluble in 1.6 parts of cold, and 0.3 of boiling water.

Sulphate of copper or *blue vitriol*, mineralogically known as *chalcanthite*, *cyanose*, and *cyanosite*, (Gr. *kyanos*, dark blue), is a fine dark sky-blue salt, having a vitreous lustre, and strong metallic and nauseous taste. It consists of 32 sulphuric acid, 32 oxide of copper, and 36 water, and is found as a product of decomposition in copper-mines, copper-waste heaps, and in the water issuing from old workings. Though occurring in nature as a secondary production from copper pyrites, or from iron pyrites containing small quantities of copper, it is more frequently prepared artificially, either by the roasting and lixiviation of pyrites and other copper ores, by treating these and metallic copper (old sheathing, copper scraps, and refinery scales,) with sulphuric acid, or as a residuary product of metallurgic operations.

Sulphate of copper when refined is employed in dyeing operations, in calico-printing, as a pigment, in electrotyping, and in various other arts. It is soluble in three parts of cold and in a half part of boiling water.

Sulphate of zinc, *white vitriol*, or *Goslarite*, as it is mineralogically termed, is a salt of a greyish or greenish white, vitreous in lustre, astringent, metallic and nauseous in taste, and occurring in old zinc-mines in crystalline tufts, and in massive, botryoidal, and reniform incrustations. It consists of 28 oxide of zinc, 28 sulphuric acid, and 44 water, and is supposed to arise from the decomposition of sulphide of zinc. For industrial purposes, "the salt," according to Gmelin, "is prepared by roasting ores containing sulphide of zinc, afterwards exhausting them with water, and evaporating the solution to the crystallising point. By fusion in its own water of crystallisation, stirring in wooden troughs with wooden shovels till crystallisation takes place, and subsequent pressing in boxes, commercial zinc vitriol is made to assume the appearance of loaf-sugar."

White vitriol is extensively used in medicine and in dyeing.

VII.—BARYTES—STRONTIA.

Barytes or *Baryta* (Gr. *barys*, heavy) is one of the simple earths, of a whitish or greyish-white colour, deriving its name from its great specific gravity, which is about 4.2. As determined by Sir Humphry Davy in 1808, it is a protoxide of the metal *barium*. In nature, it occurs chiefly as a sulphate or carbonate, traversing the older rocks in veins from an inch to several feet in thickness, and familiarly known as *heavy spar*. The native sulphate or "cawk" consists of 65.63 baryta and 34.37 sulphuric acid; the carbonate, or "Witherite" (after Dr Withering), of 77.59 baryta and 22.41 carbonic acid. These salts of baryta occur abundantly in the British Islands, and are worked in Shropshire, Derbyshire, Northumberland, Cumberland, Montgomeryshire, Ayrshire, and till recently in Arran. According to Hunt's 'Mineral Statistics,' the quantity raised in 1872 amounted to 4650 tons sulphate and 4442 carbonate—in all, 9092 tons—having an estimated value of £7078. The sulphate is principally obtained from Derbyshire, and from Wetherton and Snailbeach in Shropshire; the carbonate from Fallowfield near Hexham and Settlingstones in Northumberland, and from Alston Moor in Cumberland; but available supplies occur in Devon, Cornwall, and other parts of the island.

The carbonate is employed in the manufacture of plate-glass, as a base for some of the more delicate colours, and in the refining of beet-root sugar; the whiter varieties of the sulphate, after being heated and thrown into water, are ground, and the heavy white powder used as an adulterant of white-lead. The nitrate is employed in the production of "green-fire" in pyrotechny.

Strontia, from the lead-mines of Strontian in Argyleshire, where it was first discovered, is another of the alkaline earths whose metallic base is *strontium*. It occurs either as a carbonate (*strontianite*) or as a sulphate (*celestite*, so called from its faint tinges of celestial blue). The carbonate is found chiefly at Strontian, the sulphate in the New Red marls of England. Both minerals are found in other countries; but, on the whole, strontian minerals are rare. As an earth, strontia is nearly as heavy as baryta; its reduced powder has an acrid burning taste, but not so corrosive as baryta; its compounds are harmless, while those of baryta are poisonous. The nitrate, which is chemically prepared from the sulphate, is employed in the manufacture of the "red-fire" of the pyrotechnist.

VIII.—SULPHUR.

The element *sulphur* occurs in nature as a greenish-yellow, brittle solid, crystalline in structure, and exhaling a peculiar odour when rubbed. It has a specific gravity of from 1.98 to 2.12; is insoluble in water, but dissolves in other liquids, as oil of turpentine, the fixed oils, and especially in the bisulphuret of carbon. It is a non-conductor of electricity, but acquires negative electricity by friction. It melts at the low temperature of 227°, takes fire at 518°, and burns with a bluish flame and most suffocating odour.

Sulphur occurs abundantly in a free state, chiefly in volcanic districts, where it appears in veins, amorphous masses, in drusy cavities, or mingled with clay and other earthy impurities—Sicily, Lipari Islands, Hungary, Iceland, Jamaica, Mexico, California, East India Islands, and indeed in almost every region of igneous activity. In some districts of California (Omaha) the earthy impurities rarely exceed 15 per cent, in Sicily they often amount to 35 per cent, while in Austria they generally exceed that proportion. Sulphur is also extensively diffused throughout the globe in combination with other substances, forming with the metals the numerous ores known as *sulphides*, and with the earths the rocks and minerals known as *sulphates*. It is largely diffused through the waters of the ocean in combination with soda, magnesia, &c., and is present in the structure both of plants and animals. It is extensively employed in the arts, for which it is obtained from volcanic districts in a crude state; from deposits such as those of Poland and Galicia, where it occurs as an ore in connection with clay; or from pyrites, in which it is in chemical union with iron, copper, zinc, or other metal.

The preparation of sulphur and sulphuric acid from the metallic sulphides is now an important branch of industrial chemistry; and as these sulphides appear in various conditions and admixtures, the discovery of such as can be used economically, or from which by-products (copper, &c.) can be recovered, should be a prime object on the part of the field geologist. The amount of sulphur ore annually brought into the Tyne from Spain, Germany, Norway, and other localities, cannot fall much short of 100,000 tons.

Large quantities of sulphur are consumed in the preparation of sulphuric acid, in the manufacture of gunpowder, in the making of matches and fireworks, in sulphuring vines against certain diseases, in vulcanising india-rubber and gutta-percha, in the preparation of certain cements, of ultramarine, and in medicine. It is further employed in the manufacture of sulphurous acid, sulphites and hyposulphites, sulphide of carbon, vermilion, mosaic gold or bisulphide of tin, and other metallic sulphurets.

The substances noticed in the preceding paragraphs are of vast and varied importance in the arts and industries—in domestic economy, in medicine, in agriculture, bleaching, dyeing, tanning, glass-making, powder-making, glazing, enamelling, and numerous other processes. Though seldom found in independent masses of any magnitude, they are widely diffused, and require not only geological knowledge to discover their associations, but chemical and mechanical skill to extract and prepare them for economic application. The majority of them are found as surface deposits in dry and arid regions, but others are intimately blended with the earths, and occur in strata in the older formations. But whether occurring in superficial salinas or as deep-seated beds,—whether occurring in native purity or in chemical combination,—their presence is readily recognised, and the observant geologist can have no difficulty in bringing them under the notice of the chemist and manufacturer. It is by observation of this kind that the geologist best fulfils his function; and every contribution he can make to the arts and manufactures is at once a triumph of science and a gain to society. Every surface efflorescence, however insignificant, every trickle of styptic water (and every issue of water should be tasted by the field geologist), every mealy disintegration of a rock, and even the presence of such plants as affect saline soils, should all be duly noted as indications of the mineral treasures below. Only a few scattered patches of the earth's crust have been sufficiently explored; the great bulk remains unknown, offering at once the strongest incentive to scientific research and the most sanguine expectation of industrial extension.

Works which may be consulted.

Wagner's 'Manual of Technology'—Crooke's Edition; Knapp's 'Chemical Technology;' Ure's 'Dictionary of the Arts and Manufactures'—Hunt's Edition; Watt's 'Dictionary of Chemistry.'

XV.

MINERAL AND THERMAL SPRINGS.

Closely related to the Salts and Saline Earths are those mineral and thermal springs whose waters enjoy a reputation for their therapeutic and soothing qualities. These waters are, indeed, but solutions of the salts, or of combinations of the salts already mentioned—incorporating, besides, various gases whose liberation on coming to the air gives to many of them their sparkle and piquancy. From the earliest times these waters have attracted the attention of mankind; their virtues sung, and their sources deified. Issuing from the earth and holding its substances in solution, they come directly under the cognisance of geology, both as regards their chemical composition and the rock-formations from which they flow; and under the notice of the economic geologist for the special medicinal and commercial value attached to their waters. To the theoretic geologist they are of special interest, as throwing light on the transformations that are taking place in the interior of the earth, as well as on the nature of the substances so transformed; and to the industrial geologist they present so many sources of wealth according to the attractiveness of their position and the nature of the ingredients they contain. In Europe and America thousands are annually drawn to them for health and recreation; their waters, in increasing quantities, are bottled and exported to every civilised country; and in several instances their essential salts are obtained by evaporation, and enter largely into the *materia medica* of modern practice.

These springs occur in all systems, from the metamorphic schists to the tertiary sands, and from the earliest granitic outbursts to the latest volcanic eruptions—being found most abundantly, perhaps, in the older rocks, and in and around former centres of vulcanicity. Wherever there are beds through which water can percolate, or rents and fissures through which it can arise, there it will exert its solvent influences, partly according to the solubility of the substances with which it comes in contact, partly according to the gases it contains, and partly according to its temperature—hot water, other things being equal, acting with greater energy than cold. In this way various salts of the earths and metals are brought to the surface—lime, magnesia, potass, soda, sulphur, silica, iron, &c.—sometimes singly and simply, and at others numerously and in very complex combinations, sometimes scarcely traceable in the issuing springs, and at others impregnating them almost to saturation. Surface or deep-seated, hot or cold, oozing as the merest trickle, or gushing forth in copious fountains, there is no absolutely pure water coming from the rocky crust; though only that is regarded as "mineral," whose nature manifests itself either to the taste, to the smell, by the bubbling escape of gases, or by its temperature.

Looking at springs from a geological point of view, they may be considered under two main heads, Mineral and Thermal—both holding mineral matter in solution, but the one set characterised by their lower, and the other by their higher temperatures. As already stated, all springs are impregnated less or more with mineral or metallic matters; but here we notice only those in which the proportions are notable; and as their temperatures are very varied, we here advert only to those considerably higher than the atmospheric mean of the districts in which they occur. A simple mineral spring may arise either from the solvent power of cold water, as above stated, or it may arise from the solvent energy of hot water at great depths, but which has become cool before reaching the surface; while thermal springs may arise directly from volcanic heat—from that increasing temperature which takes place at the rate of one degree for every 60 or 65 feet of descent into the crust—or from chemical interchange, which generally takes place with an evolution of heat more or less perceptible.

Springs of all temperatures up to the boiling-point, and sometimes beyond it, occur in most volcanic regions, and are evidently dependent on the fire-forces that are operating below. The hot springs of Iceland, of the Azores, Tuscany, the Yellowstone in North America, and New Zealand, are well-known examples on a large scale: but thousands less noticeable are to be met with in all active volcanic centres. Silica, lime, alumina, sulphur, borax, and various metallic salts, are deposited from their waters, while several gases and acid vapours are discharged from them as they come to the surface. The following, from M. de Fouqué's account of the hot springs of the Azores (Compt. Rend. lxxvi.), gives a fair idea of the nature and complexity of the waters arising from such centres of vulcanicity: "The valley of Furnas, in the eastern part of San Miguel, was disturbed about three centuries ago by volcanic eruptions, and the soil is now perforated by a number of geysers. The three largest and most active of these have received the name 'Caldeiras.' One of these only furnishes a continuous stream of water; another sends forth intermittent currents; while the third emits only water, vapour, and gas. Besides these boiling springs, there exist others which possess a temperature about 61° Fahr., and whose waters are ferruginous. The water of some is very alkaline and but slightly sulphurous; others are not in the least sulphurous: many contain a considerable amount of hydroferric carbonate and carbonic acid; and some, again, free sulphuric acid. These springs, especially those containing sulphuric acid, are used medicinally. All of them contain a large quantity of silica in solution—so large, indeed, that it is deposited at the mouth. Soda salts and free carbonic acid are present in large quantity; while iron, lime, and magnesia are comparatively scarce. Several of the springs contain traces of bromides, iodides, and fluorides; boracic acid and arsenic are not present."

But while thermal springs are most abundant, as might be expected, in volcanic districts, they are also to be found in other regions from which vulcanicity has long since departed, and even in sedimentary areas in which it is difficult to trace any connection with subterranean agencies. The Pyrenees, for example, abound in thermal waters, some exceeding 185°, and yet no igneous force has been operating there for ages. The waters of Bath (120°) and Buxton (82°) issue respectively from oolitic and carboniferous limestones, and are far removed from rocks of eruptive origin. There is little difficulty in assigning a sufficient cause for thermal waters when they occur in volcanic centres; but when issuing from old hill-ranges, or from sedimentary rocks, the difficulty is greatly increased, and we must fall back upon residual connections with old igneous foci, upon the gradually increasing temperature which is experienced as we descend into the crust, or upon chemical changes which are still going on among the deeper-seated strata. The problem is beset with many difficulties; and in the mean time geology must rest contented with indicating rather than with assigning a true and sufficient cause.

In another Chapter (VII.) reference has already been made to the stratigraphical relations of springs and subterranean waters, but here it may be recapitulated,—that they occur most frequently along lines of faults and fissures; that they appear in greatest numbers in broken and dislocated areas; that they break out at all heights, but most abundantly along the flanks of mountains and in abrupt valleys; that they are found most copiously at depths not exceeding 2500 feet; and that in well-defined basins they generally partake of the same mineral character. It must be remembered, however, that water-bearing beds containing different mineral constituents may occur at different depths in the same formation; and as a consequence chalybeate and sulphur, saline and earthy, and even cold and hot, may break forth within a few hundred yards of each other. In this way springs of varied character often appear in clusters —as, for example, at Homburg and our own Harrogate.

Springs, as already stated, arise from every formation; but those most abundantly charged with mineral salts are more frequent in sedimentary than in igneous rocks. In igneous masses, whether granite, greenstone, or lava, the mineral is more crystalline and compact, and less pervious to water; in sedimentary strata the particles are less crystalline and coherent, and therefore more pervious and accessible to the solvent power of the permeating fluid. Springs issuing from granites and greenstones are comparatively pure; those arising from sands, gravels, sandstones, limestones, shales, and ironstones, are all more or less impregnated with mineral and metallic matter. The soluble matters occurring in stratified formations, whether tertiary, secondary, or primary, are very numerous; hence the complex composition — carbonates, sulphates and chlorides of lime, magnesia, potass, soda, and iron, as well as silicic acid—of many of our mineral waters. No doubt, water issuing from limestones will be chiefly calcareous, from ironstones chalybeate, from rock-salt saline, and from volcanic tracts, if hot, chiefly silicious; but generally speaking, subterranean waters traverse many different beds, and during their percolation new combinations are brought about which render their ultimate composition very complex, and very difficult to be accounted for. There is, perhaps, no branch of chemistry so difficult as that of water-analysis; no problem in geology so perplexing as that relating to the origin of the salts and gases held in solution by mineral waters.

The following substances, some of them in very minute proportions, have been detected by spectrum analysis in the waters of Germany:—

Oxygen and ozone, nitrogen, chlorine, hydrogen, carburetted hydrogen, carbonic acid, ammonia; hydrosulphuric, hydrochloric, sulphuric, sulphurous, nitric, nitrous, phosphoric, antimonic, silicic, and boracic acids; calcium, sodium, potassium, bromine, iodine, fluorine, arsenic, sulphur, lithium, rubidium, cæsium, barium, strontium, magnesium, aluminium, manganese, iron, copper, lead, and zinc.

The really important constituents, however, according to Dr MacPherson ('Baths and Wells of Europe') are—carbonate and sulphate of soda, chloride of sodium, carbonate and sulphate of magnesia, carbonate and sulphate of lime, carbonate and sulphate of iron, sulphurets of sodium and of lime, bromine and iodine, carbonic acid and nitrogen. As these ingredients are evidently the result of decompositions and transformations taking place in the interior of the earth, one would naturally suppose that in course of time mineral springs would become feebler in composition and cooler in temperature—and so in course of ages they must. It is remarkable, however, that many celebrated by the ancients are still in equal favour, and, as far as observation has been recorded, flow as freely as ever, maintain the same temperatures, and discharge the same amount of saline constituents.

Owing to the variety and complexity of their substances, it is very difficult, in treating of mineral waters, to classify them in any simple and intelligible manner. To speak of them merely as calcareous, silicious, saline, and chalybeate, is too general; and to attempt any strictly chemical classification is, in the mean time, impossible. The following, according to the authority above quoted, is a popular French arrangement:—

1. Sulphur waters, . .	Sulphuret of soda. Sulphuret of lime.
2. Common salt waters, .	Chloride of sodium. Chloride of soda, bicarbonated. Chloride of soda, sulphuretted.
3. Bicarbonated waters, .	Carbonate of soda. Carbonate of lime. Mixed carbonates.
4. Sulphated waters, . .	Sulphate of soda. Sulphate of magnesia. Sulphate of lime. Mixed sulphates.
5. Iron waters, . . .	Bicarbonate of iron. Sulphate of iron, with manganese.

And the following is that usually adopted in Germany:—

1. Alkaline, ...	*a.* Simple carbonated. *b.* Alkaline. *c.* Alkali and common salt.
2. Glauber-salt,	
3. Iron, ...	*a.* Pure. *b.* Alkaline and saline. *c.* Earthy and saline.
4. Common salt, . . .	*a.* Simple. *b.* Concentrated. *c.* With bromine or iodine.
5. Epsom salt.	
6. Sulphur.	
7. Earthy and calcareous.	
8. Indifferent.	

After all, as the principal interest of mineral springs arises from their reputed medicinal virtues, that arrangement usually adopted by the Faculty, if not the most scientific, is perhaps the most appropriate; namely, Indifferent, Earthy, Sulphur, Saline, Alkaline, Purgative, and Chalybeate. To these may be added the Bituminous, which, though chiefly valued for their illuminating products (Chap. IX.), have long been employed as lubricants and plasters in certain external affections. Under these respective heads we may glance at some of the more celebrated, and in particular at those of our own islands.

Indifferent Waters.

Under this head are usually ranked such waters as contain a very small amount of mineral constituents—ranging, for instance, from 2 to 6 parts in the 10,000. So feeble, indeed, are many of them that they would have escaped notice, and been regarded as simple potable waters, had it not been for their temperature, which varies in the better known of Europe from 63° to 140° Fahr. Among the most notable of these waters are Gastein (3.4, 95°-118°), Pfeffers (2.9, 99.5°), Wilbad (5.7, 95°-101°), and Teplitz (6.7, 101°-120°), in Germany; Plombières (2.8, 66°-158°), Bains (3, 73°-120°), and Chaudefontaine (3, 94°), in France; Caldas de Oviedo (1.5, 108°) and Panticoza (1.9, 85°-95°) in Spain; and Buxton (3.2, 82°) and Matlock (68°) in our own country. The springs of Buxton and Matlock rise from the thick-bedded mountain limestone of Derbyshire—the former containing, according to Dr Lyon Playfair, about 20 grains of saline ingredients per imperial gallon; namely, carbonate of lime 7¾, carbonate of magnesia 4½, sulphate of lime, the chlorides of sodium and potassium, 2½ each: with fractional proportions of silex and iron oxide. Besides the solid contents, there are discharged, at the moment the water issues from its source, about 3.47 cubic inches of carbonic acid, and 206 cubic inches of nitrogen per gallon. Various theories have been advanced to account for the temperature and constituents of the Buxton waters; but none of them, in the mean time, have been received as satisfactory. Chemical changes are, no doubt, going on below, and something must be suffering oxidation; but what or where? is the problem that still awaits the solution of the chemical geologist.

Several of these *indifferent* springs are largely frequented during their respective seasons—their waters being used both for drinking and bathing. Their therapeutic virtues are variously extolled—dyspepsia, rheumatism, affections of the joints, gout, neuralgia, loss of power, and paralysis, being among the maladies on which they are said to have a beneficial effect. As the majority of them are situated in elevated and picturesque regions, perhaps the bracing air, change of scenery, and cheerful society, may not be the least of their hygienic recommendations.

Earthy Waters.

Earthy waters are those which hold in solution a considerable portion of the salts of lime, magnesia, alumina, and other earths. They differ from the indifferent springs chiefly in the larger amount of mineral ingredients, as well as in the higher temperature which seems necessary to dissolve and sustain these increased proportions. Their most abundant salts are carbonate and sulphate of lime, carbonate and chloride of magnesium, sulphate of soda and chloride of sodium, sulphate of potass, and sulphate of alumina. Their solid constituents vary from 10 to 44 parts in the 10,000; and their temperature from 80° to 160° and upwards. Among the most celebrated of these earthy waters are Lucca (26.3, 122°), San Giuliano (34.5, 105°), and Bormio (10.3, 104°), in Italy; Bagnères de Bigorres (28.4, 123°), Garsao (41°-48), St Amond and Contrexeville, in France; Leuk (18.6, 123°) and Baden (53.4, 124°) in Switzerland; Sacedon (85°), Alzola (87°), and Fitero (118°), in Spain; and Bath (20.2, 108°-120°) in our own country. The springs of Bath rise from the oolitic limestones of the district, and have, according to the analysis of Meek and Galloway, the following composition, viz.:—

Carbonate of lime,	8.820	grains.
Carbonate of magnesia,	0.329	,,
Carbonate of iron,	1.873	,,
Sulphate of lime,	80.052	,,
Sulphate of potass,	4.641	,,
Sulphate of soda,	19.229	,,
Chloride of sodium,	12.642	,,
Chloride of magnesia,	14.581	,,
Silicic acid,	2.982	,,
An imperial gallon containing	144.018	grains.

Therapeutically, these earthy waters are used much more for bathing than for drinking, though some of the weaker sorts are taken internally in limited quantities. Several of them have a high reputation for rheumatism, partial anchylosis of the joints, neuralgia, partial paralysis, uterine, nervous, and cutaneous affections; and are not only annually visited by thousands, but are bottled (Contrexeville, Pougas, &c.,) and exported in considerable quantities. Several of them have been known and used from the time of the Romans, and no doubt by the primitive inhabitants, in their own rude way, long before Rome and the Romans had existence.

Sulphur Waters.

Several of the waters noticed under the heads *Indifferent* and *Earthy* contain traces of sulphur; but only those emitting sulphurous odours or depositing sulphur from their stream are entitled to be ranked under the present section. They are weak solutions of sulphur in combination with alkalies, or of hydrosulphuric acid, and in all likelihood arise from the decomposition of sulphides in the rocky interior. They may be cold or hot—and the majority are undoubtedly thermal; but those occurring in the British Islands are exclusively cold. Their mineral constituents are very varied, ranging from 3 to 156 parts in 10,000, and of this the sulphur may vary from the merest trace to 4; while their temperatures range from cold and lukewarm up to 185°. Among the most celebrated of these are Barèges,* Cauterets, St Sauveur, Eaux-Bonnes, Eaux-Chaudes, Bagnères de Luchon, and Amélie de Bains, in the Pyrenees; St Honoré, Enghien, Pierrefonds, Challes, and Aix-le-Bains, in France; Santander, Archena, Carballo, and Caratraca, in Spain; Baden, Schinznach, Stachelberg, Gurnigel, and others, in Switzerland; Baden, Ofen, and Mehadia, in Austria; Aix-la-Chapelle and Weilbach in Germany; Acqui and Abano in Italy; Harrogate, Askern, Dinsdale, Gilsland, and Shap, in England; Llandridnod in Wales; Moffat and Strathpeffer in Scotland; and Lisdunvarna in Ireland. The following tabulation, from Dr MacPherson's 'Baths and Wells of Europe,' will give some idea of their composition and character:—

Cold Sulphur.				
	Sulphur.	Total contents.	Temperature.	Elevation.
Cambo,	.012	32.4	...	...
Gurnigel,	.015	19.3	...	3600
Weilbach,	.071	11.6	...	...
Uriage,	.150	141.	...	1425
Neundorf,	.326	27.6	...	...
Enghien,	.435	30.7	...	...
Harrogate,	.896	156.	...	300
Challes,	2.200	8.4	...	...
Warm Sulphur.				
Aix-les-Bains,	trace	28.8	108.5	765
Aix-la-Chapelle,	.039	21.	140.	520
Eaux-Chaudes,	.048	3.	96.8	2100
Amélie,	.095	2.7	147.	810
Eaux-Bonnes,	.096	6.	90.5	2400
S. Sauveur,	.097	2.5	109.	2525
Cauterets,	.135	1.8	134.	3254
Abano,	.154	65.9	185.	...
Barèges,	.176	2.1	113.	4100
Luchon,	.230	2.5	135.5	2000
Acqui,	.229	63.	167.	...
Schinznach,	.870	26.2	96.7	1060

* The glairy semi-organic substance, known as *Baregine*, was first detected in these waters, but has since been found in several of the hot Pyrennean springs. Its nature and origin are still imperfectly understood.

The sulphur wells of Britain (Harrogate, Askern, Dinsdale, Gilsland, Shap, Moffat, Strathpeffer, Llandridnod, and Lisdunvarna) are much frequented by invalids and pleasure-seekers, who have the advantage not only of the sulphur waters, but of the saline and chalybeate springs which occur in the neighbourhood. Sulphur, sulphate and carbonate of lime, chloride of sodium and sulphate of soda, carbonic acid, and sulphuretted hydrogen, are their chief constituents, though in general they have a very complex composition, as may be seen from Professor Hoffman's analyses of three of the Harrogate springs :—

	Old Well.	Montpellier W.	Hospital W.
Sulphate of lime,	.182	.594	51.660
Carbonate of lime,	12.365	24.182	25.560
Chloride of calcium,	81.735	61.910	...
Chloride of magnesium,	55.693	54.667	17.140
Carbonate of magnesia,	...	...	3.251
Chloride of potassium,	64.701	5.750	3.975
Carbonate of potasa,	...	...	...
Chloride of sodium,	866.180	803.093	369.014
Sulphide of sodium,	15.479	14.414	7.155
Carbonate of soda,	...	...	...
Silica,	.246	1.840	.525
Total grains per gallon,	1096.580	966.456	437.968

With traces of bromide and iodide of sodium, ammonia, carbonates of iron and manganese, and organic matter. The gases evolved are carbonic, carburetted hydrogen, sulphuretted hydrogen, and nitrogen—ranging from 20 to 40 cubic inches per gallon.

Employed both internally and externally, these sulphur or saline-sulphur waters have a high reputation both at home and on the Continent, are annually visited by thousands, and in some instances (Challes, near Chambery, &c.) bottled and exported. In local guide-books and medical works on mineral waters, their curative properties embrace a wide range of maladies—rheumatism, affections of the bones and joints, neuralgia, dyspepsia, hypochondriasis, chronic constipation, cutaneous disorders, scrofula and glandular enlargement, abdominal plethora, local congestions, and mucous catarrhs, being chiefly dwelt upon as yielding to their medicinal virtues. On the Continent many of these springs are situated in pretty and picturesque or in high and bracing situations, and afford ample opportunities for pleasant relaxation, often as beneficial as medicine; but at home, with the exception, perhaps, of Dinsdale, Gilsland, Moffat, and Strathpeffer, our saline-sulphur springs are situated in localities which have anything but genial or attractive surroundings.

Saline Waters.

In those waters usually designated *Salt* or *Saline*, common salt or chloride of sodium is the characteristic ingredient, and this is most frequently associated with chloride of calcium, carbonate of lime, and chloride of magnesium. A great many springs contain salt in small proportions; but only those in which it is distinctly perceptible to the taste are entitled to the designation of saline. They arise from all formations, from the Silurian to the Tertiary inclusive; but in England brine-springs proper are restricted to the Trias. Many of these are, no doubt, connected with deposits of rock-salt; but others, and perhaps the majority, derive their salinity from slow solution and chemical transformation. In some instances it has been attempted to trace them to infiltrations of sea-water; but, generally speaking, this is an untenable hypothesis, as they occur in Silurian, Old Red, and Carboniferous districts hundreds of miles from the sea and hundreds of feet above its level. They are found in every region of the globe, and have early attracted the attention of mankind, as well as of many of the lower animals that periodically frequent their sources either to drink or bathe in their waters, or to lick the saline muds that surround them. Therapeutically, some of the weaker sorts, and in which there are other salts, are used chiefly for drinking; others, which are also of mixed composition and thermal, are used both for drinking and bathing; while the more concentrated, whether hot or cold, are employed mainly for bathing. Closely connected with these springs are the *salt-lakes* which occur in various parts of the world—Africa, Central Asia, and North America—and which are fed either directly by salt-springs, or by streams that traverse tracts of saline sands and gravel. These lakes vary in size from mere pools to seas like Aral, thousands of square miles in area, and in salinity (according to the season of the year) from waters slightly brackish like those of the Caspian, to others intensely bitter like those of the Dead Sea, which contain fully 24 per cent of mineral ingredients. The following tabulation exhibits the character of some of the better known and more frequented salt-springs in Europe :—

Cold Salt-Springs.

	Salt.	Mineral contents.	Temp.	Car. acid.
Kronthal, ...	29.	38.3	...	36.
Niederbronn, . . .	30.8	46.2	...	...
Kissingen, ...	61.	85.2	...	31.9
Kreusnach, ...	95.5	112.2	...	...
Homburg, ...	102.	132.9	...	26.3
Soden, ...	148.9	166.1	...	16.7
Woodhall, ...	214.	279.	...	...
German Ocean,* . .	285.8	371.	...	...
Thermal Salt-Springs.				
Pozzuoli, ...	6.2	9.	113	...
Luxeuil, ...	7.7	11.6	123	...
Canstadt, ...	20.	45.5	75	18.2
Baden-Baden, . . .	23.1	27.2	155	...
Bourbonne, ...	57.7	74.7	149	...
Wiesbaden, ...	69.8	82.	156	10.3
La Porretta, . . .	83.4	90.	95	...
Nauheim, ...	165.4	235.	103	16.9
Monte Catini, . . .	180.8	221.3	88	...

* The following is the mean of several analyses of SEA-WATER by M. Regnault:—

Water, ...		. . . .	66.470
Saline Ingredients,	3.505,	Chloride of sodium, . .	2.700
		Chloride of magnesium, .	0.360
		Chloride of potassium, .	0.070
		Sulphate of lime, . .	0.140
		Sulphate of magnesia, .	0.230
		Carbonate of lime, . .	0.003
		Bromide of magnesium, .	0.002
Loss (including iodides, silica, &c.),		. . . . . .	0.25
			100.000

Besides common salt, most of these waters contain salts of lime, magnesia, soda, iron, iodine, and other ingredients. Many of the Continental springs (Kissingen, Homburg, Soden, Wiesbaden, Baden-Baden, Ischia, Monte Catini, &c.) have a high reputation and are much frequented; while their waters are bottled, and in some instances largely exported. In our own country we have such saline waters as those of Droitwich, Gloucester, Ashby de la Zouch, and Woodhall, in England; and Bridge of Allan, Pitcaithly, and Innerleithen, in Scotland —some of which are fairly frequented, partly for their waters and partly for their sheltered situations (Bridge of Allan and Gloucester); while the water of others (Woodhall), containing bromides and iodides, is further exported for drinking. The following is an analysis of the Woodhall waters as given in Dr Lee's 'Watering-Places of England:'—

Common salt, ...	189½ grains per pint.
Muriate of lime, ...	8⅓ ,, ,,
Muriate of magnesia, ...	1½ ,, ,,
Iodine, ...	½ ,, ,,
Bromine, ...	1⅛ ,, ,,
Nitrogen, ...	2½ cubic inches.
Carbonic acid, ...	2½ ,,

These saline waters, hot and cold, are administered internally and externally for a long list of diseases—scrofula, cutaneous affections, anæmia, dyspepsia, relaxed habit and general debility, various nervous affections, rheumatism, gout, and disorders often arising from intemperate and reckless living. How far they may be efficacious, or on what speciality their efficacy may depend, lies beyond our sphere; but viewed from an economic or industrial point, they are the means of annually circulating millions of money, and bringing wealth and activity to districts that would otherwise remain poor and unfrequented.

We have said nothing of the sea, which is the great centre and reservoir of all saline waters, nor of sea-bathing, which is of universal application as a bracer, healer, and restorer. The favourite resorts along our own shores are very numerous; and while it may be said that the eastern coasts are more bracing and the western more sheltered, and that some beaches are cleaner and safer than others, still it is simply fashion and caprice which make one place thronged and popular for a few seasons, and leave another, equally eligible for its waters, dull and deserted.

Alkaline Waters.

As might be expected, from their abundance and frequent combinations in the rock-masses of the crust, the alkaline earths are held largely in solution by the percolating and issuing waters. There is scarcely a spring that comes to the surface which does not contain one or other of their salts—carbonates, sulphates, phosphates, sulphides, and chlorides,—and this from formations of all ages, sedimentary and eruptive. These waters in which lime and magnesia prevail, have already been noticed under the head of *Earthy;* those in which soda and potass are the effective ingredients are regarded as the *Alkaline* proper. Lithia and strontia are occasionally present, but generally in very minute proportions, though great stress is laid by some practitioners even on the merest traces of these, and such substances as iodine, bromine, fluorine, and arsenic. France and Germany are rich in alkaline waters, cold and hot; Britain has none of importance. These Continental springs are not only frequented by thousands for drinking and bathing, but are bottled (Vichy, Seltzer, Heilbrunnen, Bilin, &c.) in very large quantities and exported to other countries. The following tabulation exhibits the chief or effective constituents of some of these celebrated waters—omitting, of course, the other ingredients (lime, potass, &c.) which are generally present in greater or less abundance :—

	Carb. of soda.	Carb. of magn.	Common salt.	Carbonic acid.	Temp.
Vichy,	37.7	5.0	5.0	26.0	105
Bilin,	30.0	5.4	3.8	26.0	...
Gleichenberg,	25.1	7.8	19.5	27.0	...
St Nectaire,	24.6	6.7	26.9	24.0	111
La Bourboule,	19.4	2.8	39.6	23.0	125
Vic sur Père,	18.6	6.0	12.3	21.0	...
Heilbrunnen,	18.2	10.7	14.1	36.8	...
Salzbrunn,	17.4	6.3	1.7	46.0	...
Chateauneuf,	16.20	4.3	3.1	36.0	100
Ems,	13.9	2.8	10.1	18.9	115
Royat,	13.4	6.7	17.2	6.0	95
Selters,	8.0	4.6	22.7	20.3	...
Neuenhar,	7.8	4.4	0.9	18.8	92
Mont Dore,	6.3	0.9	3.8	...	114
Wildungen,	5.9	8.6	10.5	29.3	...
Néris,	4.1	1.8	1.7	...	125

Some of these waters are used chiefly for drinking, some chiefly for bathing, and others indiscriminately for drinking and bathing. When taken internally, they are said to be efficacious in cases of dyspepsia, liver complaint, diabetes, gravel, gout, and bronchial affections; when used externally, or both internally and externally, they are recommended not only for the preceding cases, but for rheumatism, enlargement of the joints, neuralgia, hysteria, and certain female diseases. Their reputation as tonics, diluents, and dissolvents, has led to their artificial manufacture, and a very large trade is now carried on, especially in Britain, in the production not only of alkaline, but of earthy, saline, and other mineral waters. Given, for example, the composition of a Vichy water, as—

Carbonate of soda,	37.7
,, potash,	2.7
,, magnesia,	5.0
,, lime,	3.1
Sulphate of soda,	2.9
Chloride of soda,	5.3
Carbonic acid gas,	26.0

with minute quantities of phosphate of soda, arsenate of soda, and carbonates of strontian and iron—there is no great difficulty in chemically imitating the original. Indeed some prefer the artificial to the natural, as being less vapid, and more sparkling and palatable; but where the latter has been freshly obtained, and properly secured, the Faculty give it, of course, the preference.

Purgative Waters.

Under the head of Purgative Waters are usually arranged such as contain sulphate of magnesia and sulphate of soda in notable proportions; those in which the former salt is present being regarded as the *stronger*, and those from which it is absent the *weaker* varieties. Germany is the great headquarters of purgative waters; France, Italy, and Spain contain comparatively few; and in England they are represented by such springs as those of Cheltenham, Leamington, Scarborough, Epsom, Beulah, Streatham, and Trowbridge. Many of these springs arise from Secondary formations: some are cold, others hot; some are used solely for drinking; some for drinking and bathing; several of them are extensively bottled and exported (Püllna, Friederichshall); a few (Seidlitz, Epsom, &c.) imitated and artificially prepared; and some (Cheltenham) evaporated and manufactured into salts. Generally speaking, they have a fair reputation, and some of them (Karlsbad, Marienbad, Elster, &c.) are annually frequented by visitors from all parts of Europe. The following tabulations are given by Dr MacPherson, as exhibiting, in a general way, their characteristic ingredients:—

Stronger Purging.

	Solids.	Sulph. magn.	Sulph. soda.	Com. salt.	Carb. acid.
Ofen, ...	350.48	160.1	159.1	...	5.2
Püllna, ...	322.8	121.	167.1	...	5.2
Friederichshall, .	252.4	51.4	62.5	118.7	6.9
Saidochütz, . .	233.3	109.9	66.1	...	...
Kissingen, . .	230.7	57.4	60.5	79.4	4.5
Uriage, ...	141.1	25.6	22.9	72.3	...
Beulah, ...	129.3	92.	...	22.2	3.2
Cheltenham, . .	117.	18.2	23.2	71.	...

Weaker Purging.

	Solids.	Carb. soda.	Sulph. soda.	Com. salt.	Carb. acid.	Tem .
Karlsbad, . .	54.2	13.6	25.2	11.3	7.6	164°
Marienbad, .	95.4	12.9	0	20.	29.6	... .
Elster, . .	57.5	5.1	29.4	18.6	21.7	...
Tarasp, . .	121.6	35.5	25.4	38.3	45.4	...
Bestrich, . .	17.5	1.8	9.2	4.9	3.3	90°
Füred, . .	22.7	1.0	9.5	.9	30.5	...
St Gervais, . .	51.6	1.2	28.2	17.9	...	126°
Leamington, .	134.9	...	52.7	52.3	...	...

While the purgative waters of Germany are much esteemed and largely frequented, those of England seem to have fallen into disrepute, or at all events are not now sought after as they used to be. Epsom and Beulah are rarely heard of; Cheltenham, formerly crowded by thousands, has fallen into comparative neglect; Trowbridge is much in the same condition; Streatham has still its local visitors; Leamington continues to be a favourite resort for certain health-seekers; and Scarborough is much more sought after for its sea-baths, and as a place of fashionable relaxation, than for its mineral waters. Various causes may have contributed to this: the handier use of saline laxatives at home; greater facilities of visiting the stronger German waters; and last, but not least, perhaps, the mere caprice of fashion, which unaccountably removes its favours from such places as Bath and Cheltenham, and as unaccountably transfers them to others, as Brighton and Scarborough. The composition of the Beulah, Cheltenham, and Leamington waters has been already indicated; the following is that of the South Well at Scarborough in grains per gallon:—

Chloride of sodium, . . .	39.63 grains.
Sulph. of magnesia, . . .	225.00 ,,
Sulph. of lime, ...	48.21 ,,
Protox. of iron, ...	1.48 ,,
Nitrogen, ...	6.3 cubic inches.

Among the diseases said to be removed or alleviated by the use, external and internal, of these purgative waters, are enumerated—dyspepsia, habitual constipation, affections of the liver, internal congestions, urinary complications, and general obesity. Many of them, from the amount of carbonic acid they contain, are pleasant to drink; some are agreeably saline, and not a few are slightly acidulous.

Chalybeate Waters.

Chalybeate or iron springs have long been celebrated for their tonic qualities, and indeed few natural waters are palatable without a small percentage of the carbonate of that metal. They occur abundantly in all formations, from the metamorphic schists to the tertiary inclusive, and are easily detected by the ochrey tinge that marks the sides of their channels, the rusty iridescent scum which frequently floats on their surface, and their pleasant astringent taste.

Wherever there is iron in the crust, whether in veins, in beds, or in minute dissemination through any stratum, there the permeating waters will act upon it, and in their upward course bring more or less to the surface. In this way, and as iron is by far the most abundant metal, there is scarcely a district without chalybeate springs, although it is only those in which the proportions are considerable that are sought after for medicinal purposes. And yet several of those which have a reputation are not one whit stronger than (if indeed so strong as) dozens we have met with among the metamorphic rocks, the Silurian, the old Red, and the Carboniferous formations of our own island. The following is given in the 'Baths and Wells of Europe,' as exhibiting the nature of some of the better known chalybeates :—

	Mineral constituents.	Carbonate of iron.	Carbonic acid.
Tunbridge, . . .	1.3	.6	2.
Wildungen, . .	3.1	.35	24.8
Schwalbach, . .	4.3	.6	53.5
Spa, ...	5.7	.5	17.
Neuhain, Soden, . .	8.	.48	40.
Malmedy, ...	12.6	.48	25.5
Wyh, ...	12.8	.25	41.
Liebenstein, . .	13.9	.56	23.
St Moritz, ...	14.4	.24	30.2
Elster, ...	20.9	.62	25.
Marienbad, . .	21.5	.42	12.
Pyrmont, ...	23.4	.56	27.6
Griesbach, ...	26.4	.56	29.4
Tarasp, ...	36.5	.33	37.2
Homburg, ...	40.	.47	41.

Among these chalybeate springs, Schwalbach, Spa, St Moritz, Wildungen, and Liebenstein have a high reputation, and are much frequented; while the waters of others are not only drunk on the spot, but bottled and exported. Britain, though containing numerous common chalybeates, is not rich in those impregnated with carbonic acid; hence their minor reputation as compared with those of the Continent. Tunbridge is still frequented; and the chalybeates of Buxton, Harrogate, Gilsland, &c., are taken by those seeking the other waters of these places; but there are dozens of springs scattered through the country, and in some instances therapeutically taken by the local inhabitants. Among these we may notice the Melrose spring, which is favourably spoken of, and next to "Muspratt's Chalybeate" at Harrogate, regarded as the richest chalybeate in Britain. According to Professor Dewar it contains 78.1 grains of solid ingredients per gallon, namely—

Carbonate of iron, ...	17.5	grains per gallon.
Alumina, ...	1.8	,, ,,
Silica, ...	8.5	,, ,,
Sulphate of magnesia, . . .	7.8	,, ,,
Chloride of calcium, ...	16.0	,, ,,
Carbonate of lime, ...	4.1	,, ,,
Alkaline chlorides, ...	11.4	,, ,,

The stronger iron-waters, or those containing sulphate of iron (Sandrock, Isle of Wight, Hartfell near Moffat, Vicars Bridge near Dollar, &c.), are generally impregnated with lime and alum, and are too unpalatable to be taken internally. The Dollar water is not unfrequently applied externally as a powerful astringent. Chalybeates are chiefly esteemed for their tonic qualities—dyspepsia, anæmia, internal hæmorrhages, chlorosis, general debility and relaxation, nervous affections, as hysteria and neuralgia, being among the complaints on which they are reputed to exert their beneficial influences.

Bituminous Springs.

Wells yielding petroleum or rock-oil have long been valued for their therapeutic virtues. They rise from many formations (see Chap. IX.), and seem to be the result of a slow natural distillation of bituminous shales, coals, and lignites. Chiefly of vegetable origin, and in some instances partly of animal, the bitumen usually issues forth with water, on which it floats as a dark-brown scum, having a soft oily feel, and rich empyreumatic odour. Petroleum occurs in many parts of Asia, and was there early used as an unguent for sores and cutaneous affections. It is found most abundantly in North America, and there applied (Seneca oil) as a lubricant, a healer of old sores, and an ointment in skin affections by the Red Indians. In Europe, though now almost out of use, it is still occasionally employed—the old oil-well of St Catherine near Edinburgh, for example, being yet in reputation, and its petroleum skimmed off and applied as a medicament in various skin diseases, and in glandular and rheumatic affections. From early notices of this "sacred well" its oil seems to have been similarly employed by the populace of the district during the last four or five hundred years. The oils of our shale-works, though at first producing a slight cutaneous eruption, are said to have subsequently a beneficial influence on the health of those engaged in their manufacture.

Mud-Springs.

In many volcanic regions, as well as in other districts from which vulcanism has long since departed, there occur mud-springs of various composition and temperature—*fumaroles*, *solfataras*, *hornitos*, *salses*, &c. Some of these discharge hot sulphurous muds and vapours; some hot water, steam, and mud; some acidulous waters and mud; and others, steam, gases, and mud of complex composition and varied consistency.

Owing partly to their temperature, and partly to their mineral constituents, several of them have acquired therapeutic reputations as baths, and are visited by invalids suffering from rheumatism, affections of the joints, partial paralysis, and analogous diseases, and not unfrequently with beneficial results. St Amand in the Pyrenees, and Abano, Acqui, and Valdieri, in Italy, may be taken as examples of such mud-baths; the peat-baths and sand-baths of Germany are artificial preparations. Analyses of these discharges from the Azores, the Yellowstone, Andes, New Zealand, &c., show great variety of ingredients, not only of a mineral and metallic, but also of an organic nature, and for whose presence it is extremely difficult to account. Silica, alumina, and sulphur, with salts of lime, soda, and magnesia, are generally the predominating constituents.

From what has been stated in the preceding pages, it will be seen that mineral and thermal springs have not only a scientific interest, but a direct commercial or industrial value. Apart altogether from their therapeutic importance to those benefited by their waters, and which cannot be estimated in a pecuniary way, their economic aspects present themselves in a three-fold form. First, many of them are annually visited by thousands, thus bringing population and wealth to the districts in which they are situated; second, the waters of several are bottled and exported in large and increasing quantities;* and third, the efficacious salts of others are recovered by evaporation, and become part of the stock-in-trade of the chemist and druggist. Viewing them in either way, they are as important to the economic geologist as the rocks, minerals, and metals of the solid crust; and it should be his endeavour to observe and bring under notice such springs as contain any marked amount of mineral ingredients, or from whose waters there may be any sensible escape of gases. Such springs may be struck in field-draining, in quarrying, in railway cuttings, or in borings for coal; and the intelligent observer should ever be on the outlook for their occurrence. The experienced field-geologist does not require to carry a laboratory with him to detect such waters. There is always enough in the taste, in the odour, the bubbling up, or in the temperature, to indicate, in a general way, the character of a spring; and it is such indications that

* We have no statistics of these exports; but judging from the general use in Britain of such waters as those of Vichy, Seltzer, Carlsbad, Püllna, Friederickshall, Marienbad, Kissingen, Schwalbach, Ems, Valls, Saratoga, Carrara, &c., the amount must be very considerable.

should lead him to the chemist, and from the chemist to the medical practitioner.

The discovery of a mineral spring may be, as the commercial phrase goes, "the making of a place." Many of the watering-places of France and Germany have risen during the current century from obscure hamlets to populous and fashionable towns; and at home, Bath, Buxton, Cheltenham, Harrogate, Moffat, and similar places, have been the direct creation of their thermal and mineral springs. The beauty and amenity of a place may occasionally have much to do with its popularity; but no such adjuncts have contributed to the rise of Harrogate, Buxton, or Moffat. But for its springs, there is no special claim in the landscape of Harrogate; and but for its spa, no one would ever think of spending the summer months among the monotonous solitudes of Shap. What ironstone is to Cleveland, coal to Newcastle, and granite to Aberdeen, so are these mineral and thermal springs to the districts in which they are situated—sources of wealth and promoters of general industry. The discovery of a mineral spring may be as important to a locality as the discovery of a seam of coal, with this essential difference, that while the coal may be worked out in a few years, the waters of the spring will continue to flow unchanged for centuries; and that while the coal requires expensive and dangerous labour to bring it to bank, the mineral waters gush forth into the open day in readiness to be used and utilised.

Enough, we think, has been said to show the importance of the mineral and thermal waters that issue from the rocky crust. Therapeutically, it is extremely difficult to account for the action of several ingredients they contain, and especially of those which, like iodine, bromine, lithium, and arsenic, occur in such infinitesimal quantities. Still, there is the fact of these waters being taken and believed in; and however much doctors may differ as to their special properties and effects, many of them have been frequented from time immemorial, and still continue to be frequented by increasing numbers as nations get wealthier and more luxurious, and as facilities for travelling become more general and extended.

Works which may be consulted.

Macpherson's 'Baths and Wells of Europe;' Macpherson's 'Our Baths and Wells, or the Mineral Waters of the British Islands;' Lee's 'Watering-Places of England;' Lee's 'Baths of Germany;' Watt's 'Dictionary of Chemistry.'

XVI.

MINERAL MEDICINES.

THE mineral preparations used in medicine, though small in amount compared with those employed in the ordinary arts, are still, commercially speaking, of considerable value. It is not so much the bulk of the materials, as the skill and care bestowed on their purification and duly-proportioned admixtures, that add to their pecuniary importance. As these preparations are all derived from the earths and metals described under other sections, it would be superfluous in the present chapter to do more than merely allude to the names and relative amounts of the natural substances. It would be still further out of place, in a work on Economic Geology, to enter upon their therapeutic virtues, and all the more that medical practitioners are often at variance both as to reputed efficacy, bulk of dose, and mode of administration. All that is here needed is a mere enumeration of the mineral *materia medica*, that the student may perceive how intimately every product of the earth is connected with man's wellbeing and comfort, and consequently becomes a marketable or commercial commodity. Nor is it alone the raw materials and their pharmaceutical preparations, but the medical skill in testing their efficacy, and the chemist's care in dispensing, that must be taken into account in estimating the material importance of the mineral medicines. A large amount of highly-skilled labour is expended upon them at every stage of their preparation; hence their mere bulk bears no proportion to their veritable value. Arranging these substances alphabetically, as in works on Materia Medica and Therapeutics, we have the following summary:—

Alum, in solutions and in powder as dried or burnt alum—used internally as an astringent and purgative; and externally as an astringent and escharotic.

Ammonia, as free ammonia, and in several preparations as the carbonate, bicarbonate, chloride, bromide, acetate, phosphate, &c. Used internally as stimulants, diaphoretics, diuretics, antispasmodics, &c.; and externally in liniments as rubefacients.

Antimony, in several preparations as sulphurated, tartarated, oxide, and chloride. Used internally as diaphoretics, expectorants, &c.; and externally in unguents as counter-irritants.

Arsenic, in many preparations as arsenite of potash, arsenite of soda, arsenite of iron, hydrochloric solution of arsenic, and hydriodate of arsenic and mercury. Used internally in small doses as an alterative and tonic in skin and nervous affections; and externally as a lotion in cutaneous diseases. Arsenious acid, or the white oxide of arsenic, is a powerful irritant poison.

Barium, in solutions of the chloride (a very poisonous salt) as an alterative in glandular affections.

Bismuth, in several preparations, as the carbonate, subnitrate, and citrate. Administered internally in solutions, in powder, and in lozenges, as a sedative; and externally as a sedative. The subnitrate forms the well-known cosmetic, "pearl powder."

Bromine, in the free state, as a local irritant and caustic, and in the preparation of bromide of potassium, and bromide of ammonium; now largely employed (especially the former) as a remedial agent in nervous affections.

Cadmium, in the preparation of the iodide and sulphate. Used chiefly externally as ointments and lotions for scrofulous sores and swellings.

Cerium, in the preparation of the oxalate, oxide, and nitrate. Used internally as sedatives and nervous tonics.

Chlorine, dissolved in water as a lotion, and inhaled in the form of vapour as a stimulant and irritant.

Copper, in the preparation of the sulphate (blue vitriol) and the subacetate (verdigris). The former used internally and externally as an astringent, &c.; the latter, in powder as an escharotic.

Gold, in the double chloride of gold and sodium, is occasionally employed, and appears to act in a manner similar to mercury. Gold-leaf is used in dentistry for stopping teeth.

Iodine, used in the free state, as well as in the preparation of several liniments, lotions, tinctures, and ointments for external applications, in cases of scrofula, tumours, glandular enlargements, and the like; and inhaled as vapour for bronchial and lung affections.

Iron, employed in many preparations as the carbonate, sulphate, arseniate, phosphate, perchloride, peroxide, pernitrate, tartrate, citrate, &c., and occasionally in the pure or reduced state. Used chiefly internally in the form of solutions, syrups, pills, and lozenges, as astringents, tonics, and correctors of the blood.

Lead, in many preparations, as the oxide, iodide, acetate or sugar of lead, subacetate or Goulard's lotion, carbonate, and nitrate. Applied, for the most part, externally in lotions, ointments, plasters, &c., as sedatives and astringents.

Lime, in preparations, as quicklime, prepared chalk, chloride, and phosphate. Used internally as antacids, astringents, antiscorbutics, &c.; and externally as caustics, tooth-powders, and in liniments for burns. The chloride and chlorinated are extensively employed in the preparation of chloroform, and as disinfectants and antiseptics.

Lithia, in the preparation of the carbonate and citrate, which are used chiefly in effervescing draughts, as antacids and diuretics.

Magnesia, largely employed in the preparation of the oxide, carbonate, sulphate, citrate, and other salts. Used internally, and chiefly in solutions as antacids, aperients, and purgatives.

Manganese, in the preparation of the sulphate and carbonate, which are occasionally employed as purgatives, and in cases of anæmia. The permanganates of potass and soda are largely employed as deodorisers and disinfectants.

Mercury has been long and largely used in medicine, partly in the free state, but chiefly in the preparation of such compounds as the subchloride (calomel), the perchloride (corrosive sublimate), ammoniated mercury (white precipitate), iodide of mercury, sulphide, nitrate, &c. It has also been variously administered, internally and externally, in powder, pill, plaster, ointment, and liniment. Its preparations bulk largely in the pharmacopœia, and have been as variously employed as alteratives, purgatives, in biliary affections, in syphilis, reduction of malignant tumours, in certain skin diseases, &c., &c. Corrosive sublimate is also employed as an antiseptic.

Petroleum, employed internally as a stimulant, diaphoretic, and expectorant; and externally in squamous skin diseases and in rheumatism. Carbolic acid is extensively employed as a deodoriser and disinfectant.

Phosphorus, used chiefly in the preparation of phosphoric acid, which is occasionally given in weak solutions as an astringent, and in cases of osseous tumours and scrofulous affections.

Potass, in many preparations, such as solution of potass, caustic potash, the carbonate, bicarbonate, acetate, citrate, tartrate, sulphate, nitrate, permanganate, bromide, iodide, &c. Administered in solutions, pills, and lozenges, largely consumed as potash-water, and applied externally as lotions and unguents. Variously given as antacids, sedatives, febrifuges, refrigerants, diuretics, &c. The permanganate is employed as a deodoriser and disinfectant.

Silver, in preparations as the nitrate and oxide. Used internally as an astringent, tonic, and alterative; externally in lotions, as an astringent and irritant—the nitrate in the solid state being caustic.

Soda, in many preparations, as the carbonate, bicarbonate, sulphate, sulphite, biborate, tartrate, citro-tartrate, chlorate, and chloride of sodium or common salt. The salts of soda are largely employed in the manufacture of soda-water, and administered in solutions and lozenges as aperients, purgatives, diuretics, and antacids.

Sulphur, as flowers of sulphur and milk of sulphur in confections and ointments. Used internally as a stimulant, laxative, &c.; and externally as a stimulant, and in skin diseases. Inhaled as vapour; and employed in weak solutions of sulphuric and sulphurous acids as a refrigerant, tonic, and astringent.

Zinc, in several preparations, as the oxide, chloride, sulphate or white vitriol, carbonate, acetate, and valerianate. Generally employed internally as tonics, astringents, and emetics; and externally as desiccants, astringents, and escharotics. The chloride (Burnett's solution) is largely used as a deodoriser and disinfectant.

The minerals and metals being described in other chapters, the preceding is the merest summary of those whose preparations are employed in medicine. Some are very sparingly used, and others, as the salts of magnesia, potash, and soda, very largely consumed; but, whether sparingly or largely, they have all a commercial value, and consequently come within the cognisance of the economic geologist. In many instances their industrial applications are noticed under other heads; but a summary like the preceding brings them at once under the eye of the student, and enables him better to comprehend the nature and amount of *materia medica* derived from the mineral kingdom. Their preparations and specific applications lie beyond the scope of his science; but the substances from which they are obtained—their nature, position, and abundance—belong exclusively to his research and determination.

Works which may be consulted.

Neligan's 'Materia Medica;' Royle's 'Manual of Materia Medica and Therapeutics;' Garrod's 'Essentials of Materia Medica and Therapeutics.'

XVII.

THE GEMS AND PRECIOUS STONES.

THE Gems and Precious Stones have always been to man—whether savage or civilised—objects of the liveliest interest and attraction. Their sparkle and play of colours, their untarnished beauty and durability, have ever made them the coveted ornaments alike of the troglodyte of the cave and the prince of the palace. The most gorgeous wreath of flowers scarcely survives the day it is woven, the most brilliant head-dress of feathers is soon sullied and worn, but the necklace or amulet of gems retains its glitter and freshness for generations. No wonder, then, that they have been so universally prized, so long the essential adjuncts of barbaric splendour, and still the most esteemed and precious ornaments of refinement and civilisation. As minerals they bulk very slenderly in the crust of the earth, being druses in veins and fissures, segregated as geodes in the pyrogenous rocks, or developed as accidental or accessory crystals in the older metamorphic strata. In whatever formation or position they occur, they are never found in masses; and when found, comparatively few have sufficient purity and brilliancy to render them specially attractive. For this reason most of them retain a wonderful uniformity in value; and though fashion may occasionally enhance or diminish the demand for certain sorts, yet in the long-run the finer gems and precious stones can ever secure a ready and remunerative market.

Looking at them from a lapidary's point of view, it were endless, and useless as endless, to enumerate the forms into which they may be cut, or the variety of names by which they are known. Mineralogically, the most esteemed and better known—that is, those most abundantly employed in the ornamental arts—can be arranged into a few groups according to their prevailing chemical constituents; and to this arrangement we shall in the present chapter adhere. The division into *Gems* and *Precious Stones* is an old and familiar one, including under the former the diamond, sapphire, emerald, ruby, topaz, hyacinth, and chrysoberyl—and under the latter such as rock-crystal, amethyst, opal, agate, carnelian, jasper, and malachite; but it is too wide for scientific purposes. The gems or jewels are, no doubt, more select than the precious stones; but the arrangement conveys no idea of their respective compositions; and so, without much scientific error, the whole may be intelligibly ranked as carbons, hydro-carbons, silicas, aluminas, and silicates of alumina, the less known and esteemed being variable compounds of these and other mineral substances.

I.—THE CARBON GROUP.

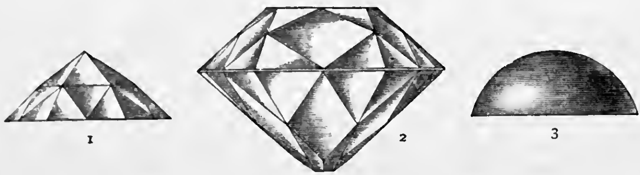
Diamond.

Foremost in this group, as among all the other gems, stands the *Diamond*, so called from its unparalleled hardness (Gr. *adamas*). It has ever been the most precious of gems, and, chemically speaking, consists of carbon or charcoal in its pure and crystallised form, having a hardness of 10, and specific gravity of 3.5. This form is primarily that of a regular octahedron, but of this there are numerous modifications—the crystals having often curved faces less or more approximating to spheres. These crystals are cleavable, easily frangible, are not acted upon by acids or alkalies, but burn and are dissipated at a heat under the melting-point of silver. They occur loose in alluvial sands and gravels—or singly, imbedded in a matrix of sandstone in India, and of mica-slate in Brazil and South America. Geologically, they have been found most abundantly in the old drifts of India and Borneo, Brazil, and the Cape district; more sparingly, and in minor crystals, in those of the Urals, Carolinas, Mexico, and Australia. The "Diamond Sandstone" of India, which furnishes the *detritus* in which most of the specimens are found, is said to be of Tertiary origin; the micaceous schists, which yield the diamonds of Brazil and the Urals, are probably as old as the Cambrian and Laurentian; while the diamantiferous drifts of the Cape seem to be derived from igneous rocks of Jurassic or later origin. Whatever the age of the original matrix, they are now found at no great depth from the surface in gravelly drifts—the *cascalho* of Brazil being an alluvium consisting of quartzose gravel, stained by oxide of iron, and containing besides the diamonds variously-coloured topazes and grains of gold; and that of the Cape consisting of gravelly debris, imbedding pebbles of rock-crystal, agate, and carnelian. According to Dr Gardener ('Travels in Brazil'), the diamond diggings of that country consist of—

Reddish sandy clay, ...	20 feet.
Tough yellow clay, ...	8 ,,
Coarse reddish sand, ...	2½ ,,
Loose gravel (*Cascalho* *), ...	4 ,,
Hard clay (variable), ...	— ,,
Schistose rocks, ...	— ,,

* *Canga* when the gravel is compact and conglomerated.

Diamonds are found of various colours and in various degrees of purity, the dark and inferior being known as *bort*, and the amorphous as *carbonado*, and only used (see Chap. XI.) as cutting and polishing materials; the colourless, or those which have some very decided tint (blue or yellow) are most esteemed; those slightly discoloured are the least valuable. Diamonds are cut and polished only by their own dust or powder—an art known from remote antiquity in the East, but introduced into Europe only about the end of the fifteenth century, and now centred principally in Amsterdam. They are cut chiefly into two forms—*rose* and *brilliant;* the latter having the finest effect, but requiring a greater sacrifice of bulk, some crystals being reduced nearly one-half in weight



1. Rose; 2. Brilliant; 3. en Cabochon.

by the operation. When washed from the matrix, the diamonds occur in all sizes, from mere points to one or two hundred carats (of 3⅙ grains each) in weight, larger crystals being extremely rare and often apocryphal. The largest and finest diamonds have hitherto been found in India; the largest amount—perhaps 800 or 1000 lb. a-year—has been procured from Brazil; but a greater proportion of large stones to small ones has recently been obtained from Africa, though slightly "off colour" as compared with those of India and Brazil.

Respecting the origin of the diamond, neither chemistry nor geology has thrown much light on the subject. We know that it consists of carbon in its purest and most concentrated form;

but whether the carbon is of vegetable or of animal origin, or whether it may not be a purely chemical elaboration altogether apart from organic growth, science has not yet determined. It is true that some observers have thought they detected traces of vegetable structure in the ashes of the diamond, but their observations have not been confirmed; and none of the specimens containing foreign matter have as yet given any hint of their formation. It has been remarked that their occurrence in mica-slate does not favour the idea of their immediate vegetable origin, nor does their occurrence in soft quartzose sandstone indicate the operation of excessive heat. Indeed their combustible nature forbids the idea of intense heat in connection with their formation; and yet high heat under pressure, or a long-continued low heat manifesting itself in chemical change, may have effected the crystallisation of carbon in decaying organic matter. Chaucourtois (as quoted by Dana) observes that the formation from a hydrocarburetted vapour or gas is analogous to that of sulphur from hydrosulphuretted emanations. In the oxidation of the latter by the humid process, the hydrogen becomes oxidised, and only a part of the sulphur changes to sulphurous acid, the rest remaining as sulphur; so in the humid oxidation of a carburetted hydrogen, the hydrogen is oxidised, part of the carbon becomes carbonic acid, and the rest remains as carbon and may form crystallised diamonds.

Amber.

Amber (Arabic), well known as an ornamental substance, is a fossil gum or gum-resin, usually found in connection with Tertiary lignites. In hardness it ranges from 2 to 2.5, is rather brittle, easily cut, of various shades of yellow, from almost pale white to orange brown, and semi-transparent. It is very light (specific gravity 1.08), becomes negatively electric by friction, and burns like other hydrocarbons with much smoke and flame. It consists of about 78 carbon, 12 hydrogen, and 8 oxygen, and frequently encloses fragments of leaves, insects, and the like—showing that it must once have been in the state of a gummy or viscous exudation. It occurs in irregular nodules, from the size of a hazel-nut to that of a man's head, the latter size, however, being rare. It is found in Sicily, Poland, Saxony, Burmah, Siberia, and Greenland, in Tertiary clays; on the Yorkshire coast of our own country; but in particular on the Baltic coast of East Prussia, where it is thrown up after storms, and strewn along the shore. It is also, but very seldom, obtained by digging down to the lower beds of the Tertiary lignites in North Germany; and there it occurs in connection with coniferous trunks and branches. These forests of amber-pines (*Pinites succinifer*) seem to have been situated in the north-eastern part of what is now the bed of the Baltic, and were probably destroyed at the commencement of the Drift period. The insects enclosed in the amber cannot be referred by entomologists to living species; but it has been observed that in their general characteristics they resemble more the insects of warm climates than those of temperate latitudes.

As an ornamental substance, amber was at one time much more valued in this country than now; but it is still highly prized in the East, and some of the pale-yellow translucent pieces bring extravagant prices. It has been, and is still, employed in the manufacture of necklaces, bracelets, ear-drops, toilet-boxes, cane-handles, mouth-pieces of pipes, and other small works of art; and industrially for the distillation of succinic acid and the oil of amber—the residue forming the basis of one of the finest black varnishes.

Ambrite.

Ambrite is the name given by Dr Hochstetter to a fossil or sub-fossil resin occurring in the soil of the province of Auckland, New Zealand, and somewhat resembling amber in colour and quality. It is found in pieces from the size of a hen's egg to that of the head, and consists of about 77 carbon, 10 hydrogen, and 13 oxygen. It resembles the resin of the Australian pine (*Dammara Australis*), but wants the rich colour and transparency of amber. Some of the finer pieces have been manufactured into ornaments; but its principal use is in the preparation of varnishes.

Jet.

Jet, so extensively used for personal ornaments, is a compact, highly lustrous variety of lignite, deriving its name (jayet, gagita) from Gaga, a river in Asia Minor, whence it was obtained by the ancients. It occurs in many countries—Turkey, Spain, France, Prussia, England—and in formations ranging from the Tertiary to the Lias inclusive. It is found in lumps and branch-like fragments—the coarser pieces often revealing their ligneous texture; while the fine are of an intense velvety black, compact, resinous in lustre, and breaking with a conchoidal fracture like asphalt. It is almost as light as amber, is electric when rubbed, sectile, but rather brittle, and requires delicate handling.

Jet is largely manufactured for mourning ornaments, for ear-drops, beads, rosaries, necklaces, buttons, bracelets, clasps, rings, and other articles of personal decoration. In France, the departments of Aude, of the Var, the Pyrenees, of Ariége, and of Ardennes, are celebrated for this manufacture, which is also carried on, though to a less extent, in Northern Germany. In our own country, Whitby in Yorkshire is the head-centre of production, the raw material being obtained in great purity and beauty from the bituminous shales of the Upper Lias in that locality. About £20,000 is mentioned as the annual value of the Whitby manufactures. Jet is occasionally imitated by glass and vulcanite, but the imitation is readily detected by the greater weight and hardness of the former, and by the inferior lustre and sulphurous odour of the latter, when rubbed or held for a while in the warm hand.

Bogwood.

Oak and other hard woods that have lain long in peat-bogs and marshes containing iron, assume a dark hue from the action of the metal on their tannin. Trunks of fine and firm grain, when slowly dried and skilfully cut and polished, make handsome mourning ornaments, as brooches, bracelets, beads, &c. Irish bogwood, which is often intensely black (though its colour can be artificially heightened), set with rock-crystals (Irish diamonds), was at one time much sought after for such purposes. Many of the so-called "bogwoods," however, are merely stained imitations.

Cannel-Coal.

Some of the more compact varieties of *Cannel-Coal* have, like jet, been manufactured into necklaces, brooches, vases, candlesticks, table-tops, and the like, but these more as objects of local curiosity than as articles of regular trade, for which the inferior texture and lustre of the material renders it unsuitable.

II.—THE ALUMINA GROUP.

Corundum, or *Corundum-stone* (Hindoo, *Korrund*) is the name given to crystallised forms of alumina, and consists of from 95 to 98 alumina and 3 water, with traces of lime, silica, and magnesia. It usually occurs in six-sided prisms, and in obtuse and acute six-sided pyramids, but is likewise found granular and massive, having a hardness of 9, and a specific gravity of 4. It is chiefly of a greyish or greenish tint, but is sometimes nearly colourless and slightly translucent; uneven in fracture, tough when compact, and the hardest of all known minerals except the diamond. It occurs in the old crystalline rocks—granites, gneisses, mica-shists, quartzites, and crystalline limestones, and is found in India, China, Asia Minor, Scandinavia, and the United States—especially in North Carolina, where it occupies veins in serpentine, traversing the country for nearly 200 miles. Indifferent specimens are said to occur in Cumberland, Cornwall, and the Mourne Mountains.

"The name *corundum*," says Mr Bristow, "is commonly confined to the opaque rough crystals and cleavable masses, generally of a dingy colour, and often dark; while the term *emery* embraces the more or less impure, massive, granular, and compact kinds; and *sapphire* and *ruby* comprises the transparent, brightly tinted varieties." Only the transparent and tinted varieties are employed as gems: the opaque and massive sorts reduced to powder are used for polishing and cutting, as already noticed in Chapter XI.

Ruby.

Ruby (from the Lat. *rubeo*, to flush with red) is a mineralogical as well as lapidary's term for the fine red transparent varieties of spinel and corundum. The finest red and violet varieties are obtained from Ceylon, Ava, Burmah, and other parts of the East, hence known as *Oriental Ruby;* and when uniform in colour, free from flaws, and large, rank next to the diamond among gems. Restricting the name *Ruby* to the red transparent varieties of corundum, it is customary to speak of the full carmine-red as *Spinel Ruby;* the pale rose-red, as *Balas Ruby;* the orange-red, as *Vermeille;* the yellowish-red, as *Rubicelle;* and the violet, as *Almandine;*—but of course there are many intermediate shades, as there are diversities of composition, among the so-called "rubies" of the lapidary and jeweller. The "corundums" proper consist almost entirely of alumina, with minute but varying proportions of iron peroxide or other colouring matter; the "spinels," on the other hand, contain from 10 to 20 per cent of magnesia, with minute but varying proportions of silica, lime, and iron—hence their superior hardness.

The rubies are generally set in rings, brooches, and other personal ornaments, and surrounded by brilliants. They bring high prices,—a perfect ruby of 1 carat being worth, it is said, 10 guineas; of 2 carats, 42 guineas; of 3 carats, 100 guineas; and of 6 carats, above 1000 guineas.

Sapphire.

Sapphire (Gr.) is the name usually given to brightly coloured varieties of corundum, other than the red or oriental ruby. The blue are generally called *Oriental Sapphire;* the transparent or translucent yellow or white, *Oriental Topaz;* the green, *Oriental Emerald;* the violet, *Oriental Amethyst;* the hair-brown, *Adamantine Spar;* when transparent, with a pale reddish or bluish reflection, *Girasol Sapphire;* and with pearly opalescence, *Chatoyant* or *Opalescent Sapphire.* Like the rest of the corundum family, the sapphire consists chiefly of alumina (98.5, according to Klaproth), with traces of iron peroxide and other colouring matter. It occurs in prismatic crystals in the crystalline rocks of Ceylon, Burmah, India, Bohemia, the United States, and other countries, but is chiefly found in rolled pebbles in the *detritus* of streams and river-courses. As already mentioned, sapphire is the hardest of known substances except the diamond. It is therefore cut by means of diamond-dust, and polished on copper and lead wheels with emery-powder. A good stone of 10 carats is said to be worth £50, and one of 20 carats, worth £200.

Turquois.

The *Turquois*, of which there are two sorts—the Oriental or Mineral Turquois, and the Occidental or Bone Turquois—when cut in low *cabochon*, is much employed in jewellery on account of its beautiful tone of colour (a peculiar blue or bluish-green), which contrasts well with diamonds, pearls, and gold. The mineral turquois is a hydrous phosphate of alumina, with phosphate of lime, silica, and oxides of copper and iron—47 alumina, 27 phosphoric acid, 3 phosphate of lime, 2 oxide of copper, 1 peroxide of iron, and 19 water. The finest specimens have hitherto been obtained from Persia, Tibet, and Arabia, where it is said to be imbedded in sandstones of unknown age. The bone turquois, or *odontolite*, on the other hand, is merely bone or ivory coloured sky-blue or bluish-green by phosphate of iron, and is chiefly obtained from the sub-fossil deposits of ivory in northern Asia, the mammoth-drifts of Siberia and the adjacent islands.

The turquois is much esteemed as a setting on account of its fine uniform blue, which is unimpaired in gas or candle light. It is often imitated; but the solid subdued tone of the real gem is readily distinguished from the vitreous lustre and gloss of the paste imitation on the one hand, and from the flawed-like aspect of odontolite on the other. Besides, odontolite effervesces with acids, gives out a fetid odour when heated, and is also inferior in specific gravity.

III.—THE SILICA-ALUMINA GROUP.

Topaz.

The silicates of alumina constitute a numerous class of minerals; but only those of fine colours and translucency are ranked among the gems. One of the most esteemed is the *Topaz*—so called, it is said, from its being obtained by the ancients from *Topazos*, an island in the Red Sea. In composition, it is a fluo-silicate of alumina, occurring in finely streaked prismatic crystals, transparent in various degrees, vitreous, electric when heated or rubbed, and of various colours or colourless—the yellow, blue, and white being the most esteemed. It is also found in indistinctly crystalline masses and rounded fragments. It occurs chiefly in the granitic and crystalline rocks, mostly in drusy cavities, and frequently associated with rock-crystal, tourmaline, and beryl, or with fluor-spar and other minerals containing fluorine. It stands 8 in the scale of hardness, and has a specific gravity of 3.5. A specimen from Saxony yielded to Berzelius 34.24 silica, 57.38 alumina, and 14.99 fluorine.

The topazes are highly valued as ornamental stones, and are often of large size compared with other gems. The chief supplies are obtained from Brazil and Siberia, though good specimens are also occasionally procured from Burmah, Ceylon, Asia Minor, Bohemia, the Scottish Highlands, Mourne Mountains, Mexico, the United States, and Australia. Those from Brazil have generally deep yellow tints, but become pink or pale crimson on exposure to heat; and many "Brazilian rubies" are said to be merely topazes that have been successfully treated in this way. The blue or "Brazilian sapphire" of the lapidary is simply a topaz of a deep celestial blue, which has a fine effect when well cut and set; and the colourless and transparent from the same region, known as *gouttes d'eau*, or drops of water, when skilfully facetted, is said to come close to the diamond in lustre and brilliancy. Those from Siberia have usually a bluish tinge resembling aquamarine, and are often very limpid and transparent. The Saxon topazes are of a pale wine-yellow; and those found in the Scottish Highlands of a sky-blue, often with a tinge of reddish-brown. Indeed the topazes are very variable in colour and transparency, resembling in this respect the rock-crystals, from which, however, they may be distinguished by their greater hardness and more vitreous lustre.

Emerald.

The *Emerald*, which has long ranked high as a gem, is generally of a rich deep-green colour; the less brilliant and colourless varieties being known as *beryls*. The crystals occur in hexagonal prisms, rarely in columnar aggregates, and usually marked with longitudinal striæ. They are transparent to subtranslucent, rather brittle, 7.5 in hardness, and 2.7 in specific gravity. The emerald is found either imbedded or in druses, in most countries in the old crystalline rocks; but in the celebrated modern locality of Muzo, New Granada, in a Secondary limestone abounding in ammonites. The finest specimens are brought from South America; but fair varieties have been found in Columbia, Norway, Abyssinia, India, and Siberia.

According to Vauquelin, who, in analysing the emerald, first discovered the earth *glucina*, the purest specimens consist of 65 silica, 14 alumina, 13 glucina, 2.56 lime, and 3.50 oxide of chromium, to which last the gem was supposed to owe its fine green colour. According to the more recent researches of M. Lewy, however, the colouring matter is considered to be a carburet of hydrogen, and of animal origin—a supposition to which its presence in the fossiliferous limestone of Muzo gives great support. The colour of the emerald can easily be destroyed by heat—a circumstance which does not occur in those gems that are coloured by oxide of chromium.

As a precious stone, the emerald is said to rank next to the ruby in value. It may be distinguished from all other gems by its pure unbroken green. It is usually table-cut; and appears to greatest advantage when surrounded by brilliants, the lustre of which contrasts agreeably with its own quiet tints.

Beryl.

Beryl (Lat. *beryllus*) is the mineralogical as well as the lapidary's term for the less brilliant and colourless varieties of the emerald. The finest beryls or *aquamarines* (so called from their sea-green tints) are found in Siberia, chiefly in druses or veins in granite, along with rock-crystal, or tourmaline, and topaz. Some crystals exceed a foot in length and several inches in diameter, but others of still more gigantic dimensions have been found in the United States. Esteemed gems also occur in the granite of Wicklow and Aberdeen, in Norway, Bavaria, the tin-mines of Bohemia, Brazil, and many other localities. When pure, aquamarine is much esteemed in jewellery, especially in ornamenting articles of dress, and the ancients employed it occasionally in the engraving of medallions.

"Pebbles of quartz," says Bristow, "are sometimes taken for beryls, and *vice versa*. The two may be distinguished by observing that the crystals of beryl are striated longitudinally, while those of quartz are striated transversely, or at right angles to the axis of the prism. Moreover, the fracture of the two minerals is widely different; for the beryl breaks in smooth planes, the faces of which are at right angles to the axis of the crystals, whereas the fractured surface of quartz is invariably conchoidal."

Lapis Lazuli.

Lapis Lazuli is a well-known mineral of an ultramarine or fine azure-blue colour, of various intensity. When crystallised it occurs in dodecahedrons, but is generally found massive and disseminated; of a finely granular or compact texture, hardness about 5.5, and specific gravity 2.4. It varies considerably in composition; but, on the whole, may be said to consist of from 45 to 50 silica, 30 to 32 alumina, 6 sulphuric acid, 9 soda, with minor and varying proportions of lime, iron peroxide, chlorine, and sulphur. The depth of the colour seems to depend on the amount of iron and sulphur. It is found chiefly in crystalline limestones, but occurs also in the granitoid and crystalline schists. The finest specimens are obtained from Siberia, China, Tibet, and Tartary. When sufficiently large and pure it is employed as an ornamental stone; but its chief use is in the preparation of the fine pigment called *ultramarine*, as already noticed in Chapter XIII. Lapis lazuli takes a pretty good polish, and notwithstanding its deficiency in lustre, the beauty of its colour has caused it to be used in jewellery, generally for brooches, clasps, eardrops, ring-stones, and shirt-studs. It is seldom employed for seals on account of its softness. The more richly coloured varieties are used for mosaics, and are also fashioned into vases and other costly ornaments.

Felspars.

To these more valued silicio-aluminous gems may be added several of the *Felspars*, which occasionally exhibit a fine opalescent play of colours. Among these may be noticed Adularia felspar, or *moonstone*, a translucent potash variety, which, when cut *en cabochon*, displays a pale-blue opalescence; Labrador felspar, or *Labradorite*, a soda-lime variety, which produces a pearly iridescence when light falls on it in certain directions: *Amazon-stone*, another potash variety, of a bluish-green or sometimes verdigris green, exhibiting when cut a peculiar spangly iridescence; and *variolite*, a dark-green variety, containing disseminated sphericles of a paler hue. Most of these felspars are found of considerable size, and are well fitted for inlaid work, and for the manufacture of caskets, snuff-boxes, and similar ornaments.

Garnets.

The *Garnets* constitute an extensive and extremely variable family, according as alumina, iron, lime, magnesia, or similar bases are associated with the silica which composes about half the mineral. They are all, in fact, silicates of one or more of these bases, and are usually arranged into six sections—viz., alumina-lime garnets, alumina-magnesia garnets, alumina-iron garnets, alumina-manganese garnets, iron-lime garnets, and lime-chrome garnets. They occur chiefly in gneiss, mica-schist, and other crystalline strata, but are found also in granite, trap, and other igneous rocks. The garnet proper appears in dodecahedral crystals and druses, in grains, and occasionally massive, or so thickly interspersed in the gneiss or mica-schist as to become *garnet-rock*, and in this case, when crushed to powder, employed as a cutting and polishing material under the name of "red emery" (Chap. XI.) The hardness of garnet varies from 6 to 7, and its specific gravity from 3 to 4. In colour it is usually deep amber-red, reddish-brown, or black, but occasionally olive-green passing into yellow; its lustre is resinous or vitreous; and it is transparent in all degrees.

Of the better known and more valuable varieties we may mention the *Almandine*, or noble garnet, of a beautiful columbine-red; the *Grossalar*, or olive-green; the *Hessonite*, or *Cinnamon-stone;* the *Colophonite*, or resinous garnet; the *Pyrope*, *Fire-garnet*, *Alabandine*, or *Carbuncle* (when cut *en cabochon*)*;* and the *Topazolite*. Garnets have a world-wide distribution, but those of commerce are chiefly obtained from Bohemia, Ceylon, Pegu, and Brazil. They are extracted from the matrix; gathered from river-drifts; and occasionally, as near Elie in Fifeshire (Elie rubies), found in the shore-sands which fringe the trap-tuffs from which they are weathered and detached.

"Garnet," according to Bristow, "is easily worked, and, when facet-cut, is nearly always (on account of the depth of its colour) formed into thin tables, which are sometimes concave, or hollowed out on the under side. Cut stones of this latter description, when skilfully set with bright silver-foil, have often been sold for rubies."

Zircons.

The *Zircons*, of which there are several varieties—the *jargoon*, colourless or smoky, the *hyacinth*, bright red or reddish-orange, and the *zirconite*, reddish-brown—are valuable gems, consisting of about 66 zirconia and 34 silica, having a hardness of 7.5, and specific gravity of 4.5. They occur in the older metamorphic and granitic rocks, and are found in Ceylon, Italy, Saxony, Scandinavia, Scotland, Canada, and Greenland. The Cingalese jargoon is a highly lustrous variety, known as the "Matura diamond," and occasionally sold for the real gem; and the bright red of the hyacinth renders it suitable for finger-rings and pendants. Though less in fashion than formerly, the zircons form bright and durable ornaments, being perhaps the least alterable of minerals. It was in the zircon that Klaproth discovered the earth zirconia, in 1789.

IV.—THE SILICA GROUP.

The Silicious Gems or Quartzes present a very numerous family, but here we have to deal only with the more transparent, lustrous, and brilliantly coloured *varieties*. These, without much scientific error, may be arranged into four sections: 1. The *Vitreous*, or those which have a bright glassy lustre—as rock-crystal, rose-quartz, siderite, cairngorm, amethyst, avanturine, &c.; 2. The *Chalcedonic*, or those which display the subvitreous or waxy lustre and transparency of chalcedony—as agate, carnelian, chalcedony, onyx, &c.; 3. The *Opaline*, or hydrous varieties, having the resinous lustre and semi-transparency of opal—as fire-opal, hyalite, cacholong, &c.; and 4. The *Jaspery*, or those presenting the duller colours, lustre, and opacity of jasper—as blood-stone, jasper, Lydian stone, and the like.

Rock-Crystals.

Rock-crystal, though usually colourless and transparent, occurs in various shades, and the term is even extended to smoke-coloured and perfectly black varities. It is customary, however, to distinguish the coloured varieties by separate names; hence the violet-blue are known as *amethysts;* the wine-yellow, *topazes;* the cinnamon-yellow or brown, *cairngorms;* the indigo-blue, *siderites;* the reddish-pink, *rose-quartz;* and so forth. Rock-crystal is found in veins, fissures, and other cavities in every geological formation, but chiefly and most perfectly in the older crystalline and granitic rocks. The primary form is rhombohedral; but it usually occurs either in six-sided prisms, acutely terminated by six planes; in acute, simple, six-sided prisms; or in such prisms and pyramids doubly terminated. The largest and finest specimens are obtained from the Alps, Pyrenees, Siberia, Brazil, Ceylon, Madagascar, and in a less degree from Saxony, Norway, Ireland, and the Scottish Highlands. The purest sorts consist almost entirely of silica (99 and upwards), with a trace of alumina, lime, iron oxide, or other colouring matter; have a fine vitreous lustre, a specific gravity of 2.5 to 2.8, and a hardness of 7, being in this respect only inferior to the topaz, corundum, and diamond.

The purest colourless varieties are cut into spectacle-lenses, and also largely used as gems under the names of Bohemian diamonds, Irish diamonds, Bristol diamonds, &c. Some highly transparent crystals, when skilfully cut, have a wonderful sparkle, and were extensively used when shoe-buckles, knee-buckles, and similar ornaments were more in fashion. Larger crystals are cut into seals, cups, vases, pendants, buttons, and the like; and fair specimens are said to be worth from five to twenty shillings a pound, according to size and transparency. The amethystine varieties (coloured by the oxide of manganese) are more highly prized for personal ornaments, but lose their tints under gas or candle light. The cairngorms (from the mountains of that name in Banffshire), when of fine hue, are much valued for brooches, bracelets, ear-drops, seal-stones, and other objects of jewellery; and it is stated by Nicol in his 'Mineralogy,' that at one time an Edinburgh lapidary cut £400 worth out of a single crystal! Green and red varieties, when skilfully cut and polished, also furnish handsome stones—the latter, under the name of "Bohemian ruby," being sometimes passed off for the spinel ruby, though naturally inferior in lustre and hardness.

There are other varieties, such as asteriated (star-quartz), avanturine (spangled-quartz), &c., used for ornamental purposes; but to notice all would be to present a lapidary's catalogue of stones which differ only in some slight peculiarity of colour or structure, while essentially the same in nature and origin. Those imbedding minute crystals of other minerals and metals are often very pretty; and by heating quartz, and plunging it it in coloured solutions, curious effects in colour and lustre can be produced, which are apt to be mistaken for natural appearances.

Calcedonies.

The *Calcedonic* or semi-pellucid varieties—calcedony, agate, carnelian, onyx, &c.—have long been employed for ornamental purposes. Calcedonies (Chalcedon in Asia Minor) of fine uniform colour are prized for seals—their toughness allowing them to be cut with great clearness and precision. *Chrysoprase* (Gr. *chrysos*, gold; *prasos*, leek) is a fine apple-green or yellowish-green variety of calcedony, owing its colour to a small percentage of nickel oxide. Though not much used in this country, chrysoprase is highly valued in Germany and the East, where it is cut into brooches, ring-stones, seal-stones, bracelets, and other kindred ornaments. Geologically, the calcedonies proper occur in geodes and vein-bands, but more frequently as an incrustation or sinter, having a wavy internal structure and mammillated surface.

The *agates*, found mostly in geodes in the amygdaloidal trap-rocks, or in gravels derived from these rocks, occur in many varieties—ribbon or striped agates; fortification-agates, showing the alternating bands in zigzag arrangement, like the plan of a fortification; brecciated agates, as if composed of cemented fragments; moss-agates, exhibiting minute dendritic ramification like moss-growth, &c. The name, according to Theophrastus, is derived from *Achate*, a river in Sicily, where fine varieties were found; but others think it more probably a corruption of the Punic and Hebrew word *nakad*, spotted, in allusion to their varied colours. The finest agates are usually designated *oriental*; the moss-agates, *Cambay-stones*, or *Mocha-stones* from Mocha in Arabia; and the banded varieties, as *Scotch pebbles*, from their frequent occurrence in the traps of Scotland—Kinnoul Hill near Perth, the Ochils, and Usan shore near Montrose, being well-known localities. The colouring matter of agates being due to metallic oxides, factitious colours of greater intensity can be produced by boiling in various chemical solutions. The agates are cut for brooches, ear-pendants, beads, seal-stones, and the like; and also, when of large size, for vases, snuff-boxes, knife-handles, mortars, burnishers, and similar objects. Besides those found in Scotland, agates to the value of £6000 or £7000 are annually imported from India, Saxony, and other countries.

The great emporium of the agates and carnelians, cut and uncut, is Cambay, from which they are sent to all parts of the world. Their finding and treatment is thus described by Forbes in his 'Oriental Memoirs:' Carnelians, agates, and the beautifully variegated stones improperly called Mocha-stones, form a valuable part of the trade of Cambay. The best agates and carnelians are found in peculiar gravelly strata, 30 feet under the surface, in a small tract among the Rajepiplee Hills, on the banks of Nerbudda. They are not to be met with in any other part of Gujerat, and are generally cut and polished in Cambay. On being taken from their native bed, they are exposed to the heat of the sun for two years; and the longer they remain so exposed the brighter and deeper will be the colour of the stone. Fire is sometimes substituted for the solar ray, but with less effect, as the stones frequently crack, and seldom acquire a brilliant lustre. After having undergone this process, they are boiled for two days, and sent to manufacturers at Cambay. The agates are of different hues; those generally called carnelians are dark, white, and red, in shades from the perfect yellow to the deepest scarlet."

The *carnelians*, so called from their reddish flesh-colours, are generally of uniform tint or clouded, but not striped and banded like the agates. They occur in the same way as agates, and are mostly used for the same purposes, some varieties being well fitted for engraving, and others taking on a very fine and durable polish.

The *onyxes*, so called from a fanciful resemblance to the hues of the human nail, are banded varieties, the alternating bands differing in hue, and thereby rendering them especially fitted for the manufacture of cameos, the lighter layer being carved in relief, while the darker forms the background to the figure. *Sard* and *sardonyx* are mere varieties—the former in bands of brown, red, and white; the latter, as its name implies, in alternating bands of sard and onyx. Brown and white, red and white, green and white, are the most frequent alternations of colour; but these can be intensified by boiling the stone for several days in honey and water, and then soaking it in sulphuric acid.

Opals.

The *Opals*, or *Opaline* varieties, are, as already stated, hydrous silicas, consisting of from 90 to 95 of silica, with from 5 to 10 of water, and coloured by traces of iron peroxide, potash, soda, lime, alumina, &c. They are of various colours, milk-white, pearl-grey, reddish-brown, and green; have a vitreous or resinous lustre; and often exhibit a beautiful play of colours by refracted and reflected light. They are widely distributed in connection with the igneous rocks, and chiefly as concretions, sinters, and incrustations. Bohemia and Mexico yield esteemed varieties, and fair specimens are occasionally found in Cornwall and Antrim. There are many varieties, some of which are highly esteemed by the lapidary and jeweller. The better known are — 1. Precious or noble opal, exhibiting a beautiful play of colours; 2. Hydrophane, or those sub-varieties of noble opal which become transparent on being immersed in water; 3. Sun or fire opal, or girasol, transparent, and having a brilliant vitreous lustre, and generally of a bright hyacinth-red when held between the eye and the light; 4. Hyalite, or glassy opal, occurring in very glassy, transparent, mammillary incrustations; 5. Common opal, semi-transparent, and of various colours; 6. Semi-opal, duller and less pellucid; 7. Cacholong, or mother-of-pearl opal, having a pearly resinous lustre; 8. Wood opal, or wood converted into opal by silicious infiltration, and of fibrous structure; 9. Menilite, or liver opal, a compact semi-resinous variety, from Mount Menil, near Paris; and 10. Jasper-opal, or such ferruginous varieties as pass imperceptibly into common variegated jasper.

Jaspers.

The *jaspery* varieties of quartz are all less or more opaque, and appear striped or mottled in many colours—red, yellow, brown, green, grey, white, and black. From their colours, they are usually known by such terms as striped, ribbon, clouded, yellow, red, mottled, or Egyptian. All the varieties are tough, and most of them are coloured by the oxides of iron; they are found abundantly in veins, bands, and nodules, in rocks of all ages; and some varieties, like the "porcelain-jaspers," are evidently beds of slaty shale, altered by the action of heat—dykes and overflows of basalt, or even in coal-mines which have been on fire. Most of them are susceptible of a fine polish, and are largely manufactured into brooches, bracelets, snuff-boxes, vases, knife-handles, inlaid work, and other ornamental articles. Though some of the finest varieties are brought from Asia Minor and Egypt, very beautiful specimens are found in Ayrshire (yellow mottled), on the coasts of Forfar, Kincardine, and Banffshire (red and green, striped and mottled), and on the Dunbar coast (deep-red, banded, and variously mottled). One of the most esteemed is the *heliotrope* or *jasper blood-stone*, having a green ground with deep red spots; fine specimens of which are found in Siberia, India, Transylvania, Bohemia, and occasionally in Italy, Ireland, and Scotland.

V.—MISCELLANEOUS GROUP.

Under this section we include such mineral substances as cannot be properly arranged under any of the preceding groups, and yet which are occasionally employed in jewellery and the ornamental arts. One of the best known of these is *Malachite*, the green carbonate of copper, consisting of 71.8 copper protoxide, 20 carbonic acid, and 8.2 water, and deriving its name from the Greek *malachè*, the marsh-mallow, in allusion to its colour. It occurs in copper-mines in reniform, concretionary, and stalactitiform masses, more or less compact, and in concentric bands of various shades. When cut and polished, it is highly prized for ornamental purposes—brooches, snuff-boxes, vases, inlaid work, &c.; but its softness renders it of less value than it would otherwise be to the lapidary and jeweller. The finest specimens are obtained from Siberia, the Urals, and Burra Burra in Australia.

For other ornamental stones, not strictly regarded as "precious," the student is referred to Chapter V.

VI.—PASTES, OR ARTIFICIAL GEMS.

From their rarity and value, the gems and precious stones very early became the objects of imitation, and this often with considerable success. As chemistry advanced the imitations became more perfect, and now factitious gems are frequently produced which require all the skill of an expert to detect. These artificial products are made of very pure, fusible, transparent, and dense glass, termed *strass* or *paste*, with the addition of metallic oxides to impart the necessary tints. This strass consists of silica, alumina, oxide of lead, and potash, with traces of borax and arsenious acid to increase its clearness and brilliancy. The success of an artificial stone depends chiefly upon the exact imitation of the tint of the real stone, but also in no small degree upon the cutting, polishing, setting, and foiling. Being essentially a *glass*, the artificial products differ from the natural in hardness, specific gravity, and power of conducting heat, and may be detected by their inferiority in these important properties. The hardest glass rarely exceeds 5, while the gems range from 7 to 10; glass seldom exceeds 2.5 in specific gravity, the gems range from 2.6 to 4.5; glass has not the same cold feel when touched by the tongue, its conductivity being inferior to that of the precious stones.

In the preparation of pastes, the ingredients are separately reduced to a fine powder, then mixed and sifted, next carefully fused, and ultimately allowed to cool very slowly. The more tranquil and continuous the fusion, and the more gradual the cooling, the greater is the density and beauty of the product. The proportions of the admixtures and their treatment are strictly matters of chemistry and technology; but we may notice a few to show that they are wholly mineral and metallic, and in this respect come within the cognisance of Economic Geology. The imitation of the *diamond* is obtained by pure silex 100 parts, red oxide of lead 150, calcined potash 35, calcined borax 10, and oxide of arsenic 1 part; the *topaz* by 1000 strass, 40 antimony, and 1 purple of cassius; the *ruby* by 1000 strass, 5 peroxide of manganese, and a trace of purple of cassius; the *emerald* by 1000 strass, 8 oxide of copper, and 0.2 oxide of chromium; the *sapphire* by 1000 strass and 15 oxide of cobalt; the *amethyst* by 1000 strass, 8 peroxide of manganese, 5 oxide of cobalt, and 0.2 purple of cassius; the *beryl* by 1000 strass, 7 glass of antimony, and 0.4 oxide of cobalt; the *carbuncle* by 1000 strass, 500 glass of antimony, 4 purple of cassius, and 5 peroxide of manganese; and so on with many others—different fabricators using different proportions, according to their success in the imitation.

Occurring in drusy cavities as geodes and as accessory minerals, the gems and precious stones do not bulk largely in the rocky crust, but appear (as the Arabic poet has it) merely as "the blossoms of the mineral kingdom;" hence the high esteem in which they have ever been held, and the uniform values they have maintained. In early times they were procured principally from the East, and the term "Oriental" was and is still regarded as a mark of distinction; but in recent times they have been obtained from the Urals, from Mexico, Brazil, and Southern Africa, in equal purity and perhaps in greater abundance. Notwithstanding these new sources of supply, their money value has been little affected; the diamonds of Brazil, and more recently those of the Cape, though increasing the numbers, scarcely, if at all, diminishing the price of these, the most brilliant of mineral productions. This arises partly from the greater demand, and partly from the greater wealth of modern society; and as these are ever increasing factors, there is little likelihood of the gems and precious stones falling much in value, any more than they are likely to fall in favour for their brilliancy and beauty.

The practical geologist has thus every incentive to search; and as new regions are every year being more minutely explored, new sources of supply may reward his diligence, just as we have seen within the current century the gold-fields of California and Australia, and the diamond-fields of the Cape, made known through the keener and more intelligent observation of their first discoverers. The Earth is an exuberant and undenying mother, but she does not thrust her bounties upon her children; and if they would enjoy these, they must make intelligent endeavour to discover and reasonable effort to secure them. The structure of the globe is better known now than it was fifty years ago, the relations of the rock-formations are more fully understood, and their respective constituents more minutely determined; and thus the researches of the geologist become more definite, and his commercial success more certain. The discovery of a coal-field may, in many respects, be more important than that of a diamond-field; but while it takes the skill and labour of generations to develop the resources of the one, the treasures of the other may be revealed during the toil of a single summer. It is this suddenness, this condensation of wealth within the least possible sphere of time and labour, which becomes the great incentive to gem-hunting; and though often hazardous and uncertain, there is no reason why correct observation and sound deduction should not reduce such uncertainty to a minimum.

Works which may be consulted.

Dana's 'System of Mineralogy;' Bristow's 'Glossary of Mineralogy;' Jackson's 'Minerals and their Uses;' Greg and Lettsom's 'Mineralogy of Great Britain and Ireland.'

XVIII.

THE METALS AND METALLIC ORES.

THERE is no chapter in Geology more interesting than that which deals with the Metals and Metallic Ores. These substances lie at the foundation of all the higher arts and industries, and little progress can be made, even in civilisation, without some acquaintance with their nature and uses. Man restricted to tools and implements of wood, bone, or stone, can never successfully combat with the forces of nature, or modify them to his service and comfort. He is essentially a savage. But the moment he can arm himself with a weapon of metal, or handle a metallic tool, he gains an ascendancy over external nature, and his course, mentally as well as physically, is thereafter onwards and upwards. He always passes through the successive stages of stone, bronze, and iron; and not till he has arrived at the last can he be said to possess tools, implements, and machinery sufficient for the arts and industries of civilised existence.

To the metals man owes his finest and most efficient tools, implements, and machinery; his most beautiful and durable ornaments; his most brilliant dyes and pigments; his most convenient medium of exchange; and, indeed, very much of that power which, as an intelligent being, he exercises over the domain of nature. They run through all his arts and industries—his endless machinery, instruments, and apparatus—his steam-engines, railways, ships, and telegraphs. In fine, there are few or none of his economic processes in which they do not directly or indirectly bear a part. As they are found in nature, it is usual to speak of them as *Native Metals* and *Metallic Ores*—that is, as metals occurring in a pure and simple state, or as metals chemically combined with other substances—thus forming oxides, sulphides, carbonates, silicates, and the like. In the present chapter we shall direct attention principally to their geological recurrence, their abundance, and the facilities with which they can be procured, leaving the processes by which they are reduced, smelted, alloyed, and manipulated, to the metallurgist and technologist.

I.—NATIVE METALS.

Comparatively few of the metals occur in a free or uncombined state — that is, as pure and simple elementary substances. Those most frequently found are—gold, platinum, palladium, silver, mercury, copper, arsenic, antimony, bismuth; and those less frequently and doubtfully—iron, lead, zinc, and tin. There also occur, though less abundantly, a series of double-metals, or amalgams of gold and mercury, of silver and mercury, of gold, silver, and mercury, of platinum and iridium, of iridium and osmium, and the like; but these we need not especially refer to.

Gold.

Gold, so well and widely known, occurs in various shades of gold yellow, has a hardness from 2.5 to 3.0, and a specific gravity from 16.0 to 19.5, according to its purity. It has extreme permanence in air and fire, being little tarnished by any amount of exposure, and melts at 2016° Fahr. It is also extremely malleable and ductile, its malleability being such that it may be beaten into leaves not more than $\frac{1}{280,000}$ of an inch in thickness, and its ductility so great that one grain is capable of being drawn out into 500 feet of wire. It readily forms alloys with other metals; and in coinage, as well as in the arts, is generally so alloyed (with copper, silver, &c.) to improve its hardness, and so render it better able to resist the tear and wear of circulation, handling, and cleaning. If 24 carats be taken as the standard of purity, any stated number below 24 will indicate the amount of admixture. Gold is not acted upon by the common acids, but yields to chlorine and nitro-muriatic acid, forming a chloride of gold which is soluble in water.

Geologically, gold is a widely distributed metal, and occurs, with few exceptions, in quartz-veins which traverse the metamorphic or older schistose and slaty rocks. It appears in minute disseminated particles, in scales, strings, arborescent plates, and in nuggets from a few grains to many pounds in weight. When not found *in situ* in the veinstone, it is usually distributed in stream-drifts of sand and gravel which have been wasted and worn, and transported in course of ages from the mountain-veins to the valleys below. It was from such drifts that the ancients gathered their gold in dust, and scales, and pellets; and it is still from such deposits in the Urals, California, Australia, New Zealand, and other regions, that the great commercial supply of the metal is obtained. It is not till the drifts get exhausted, or in districts where stream-working is not remunerative, that the auriferous veins are attacked; though, generally speaking, where the vein is a fair one, it forms the steadiest and most reliable source of supply. What are termed "gold ores" are not *ores* in the strict sense of the term; for whether native amalgams or ores of other metals, the gold they contain, as may be seen by referring to the next section, is still in the free and uncombined metallic condition. According to the present state of our knowledge, the metal is always native, whether occurring in veins of quartz, calc-spar, and baryta, disseminated through the older schistose rocks, incorporated with other ores, or scattered abroad in drifts of sand and gravel.*

While gold occurs notably in the drifts of the Urals, Brazils, California, Nevada, Colorado, British Columbia, Australia, and New Zealand, it is also found in minor quantities along the river-courses of many other regions—India, Africa, the United States, and Southern Europe—and very sparingly in our own islands, as in Wicklow, Devon, Wales, and the Scottish Highlands. It is mined in Brazil, Central America, Mexico, California, Australia, Spain, Hungary, Transylvania, the Urals, Altai Mountains, and in Sweden; but attempts at mining in Britain (Devon and Wales) have hitherto proved unremunerative. The metallurgical processes for the reduction and refining of gold lie beyond our province; but whether by washing and smelting, by amalgamation with mercury, by treatment with alkalies or other modes of liquation, some of them require considerable chemical skill and nicety of manipulation.

The statistics of gold are very imperfect, and in most cases

* With regard to the occurrence of gold, the following remarks by P. B. Smyth, Secretary of Mines for the Colony of Victoria, may be of use to the geological student: "Gold is now found to occur not only in quartz-veins and the alluvial deposits derived from these and the surrounding rocks, but also in the claystone itself; and, contrary to expectation, flat bands of auriferous quartz have been discovered in dykes of diorite, which intersect the upper Silurian or lower Devonian rocks. Quartz of extraordinary richness has been obtained from these bands, and the new experience of the miner is leading him to look for gold in places hitherto entirely neglected. It is probable that some time may be lost, and that his labours may not always be well directed or successful, but it is commendable that he should not be deterred from explorations by warnings and remonstrances founded on surmises often baseless. If he had already followed the older precepts, we should at this moment have been dependent for our yield of gold on the shallower alluviums, and the surface only of the veins of quartz."

little better than guesswork. Not only does the quantity raised in any given locality vary from year to year, but new localities are unreported, and the success of mining adventures is often either kept secret, or exaggerated for speculative purposes. Roughly estimated, the total yield of the world may be set down at 460,000 lb. troy, representing an approximate value of £23,000,000.

The uses and applications of gold in the arts and industries are innumerable. It is employed for coinage, for domestic and personal ornaments, for the formation of alloys, for the preparation of pigments, and for gilding of other metals, wood, plaster, and paper-hangings, and for the preparation of wire and leaf in all their multifarious applications. The extension of its use is generally the test of a nation's wealth, and year after year it is more and more employed in the fabrication of articles of luxury and ornament.

Platinum.

The metal *Platinum* or *Platina*, discovered in 1741 in the mines of Peru, and so named by the Spaniards in allusion to its silvery colour—*platina*, the diminutive form of *plata*, silver—is found only in a native or metallic state. What is termed "platinum ore," or crude platinum, is merely an admixture with other metals, such as palladium, rhodium, osmium, iridium, titanium, gold, silver, iron, and copper. Since its discovery in Peru it has been found in Brazil, California, the Urals, Borneo, and other countries. It is usually obtained from drifts in rounded grains or flattened pellets, of a metallic lustre and white colour. When pure it has very much the colour of silver, but of inferior lustre. It is the heaviest of known metals, its specific gravity after hammering being about 21.5. It is exceedingly ductile, malleable, tenacious, and difficult of fusion, but capable of being welded at a high temperature. It undergoes no change under the combined action of air and moisture, resists the strongest heat of a smith's forge, but can be melted by voltaic electricity, or by the oxyhydrogen blowpipe. It is not acted upon by any of the pure acids, but is dissolved by chlorine and nitro-muriatic acid, and is oxidised at a high temperature by pure potassa and lithia.

A metal possessed of such properties is eminently fitted for chemical works and laboratories; hence it is manufactured into crucibles, evaporating dishes, stills for concentrating sulphuric acid, spoons, blowpipe-points, tongs, forceps, wire, and similar articles. It is also used for galvanic apparatus, ornamental work in chains and trinkets, medals, and at one time by the Russian Government for coin. It forms alloys with iridium, with iridium and rhodium, and with gold, which are said to possess properties of resistance superior to the pure metal; and with equal parts of steel it constitutes the best white speculum-alloy known. According to Wagner, the amount of metallic platinum annually produced does not exceed three tons, and of this the greater portion comes from the Urals.

Palladium.

The metal *Palladium* (*Pallas*, the goddess), discovered by Wollaston in 1803, is usually found in very small grains, of a steel-grey colour and fibrous structure, in auriferous and platiniferous sands. Its specific gravity is about 11.5; and in fusibility it stands intermediate between gold and platinum. When native it is alloyed with a little platinum and iridium, or with gold and silver, as in the *Porpezite* of Peru, which consists, according to Berzelius, of 85.98 gold, 9.85 palladium, and 4.17 silver. It is ductile as well as malleable, and is considerably harder than platinum. It is oxidised and dissolved by nitric acid; but its proper solvent is nitro-hydrochloric acid. It forms alloys, most of which are brittle, with arsenic, iron, bismuth, lead, tin, copper, silver, gold, and platinum; the alloy with nickel is ductile. It is sometimes used for the finely divided scales of mathematical and astronomical instruments; for the smaller chemical weights; and 1 per cent added to steel produces a smoother cutting edge.

Silver.

The early and well-known metal *Silver* is found *native* in the older rocks, in threads and strings, in arborescent moss-like aggregates, and in plates and nuggets often of considerable magnitude. In its native state it often occurs as an *alloy* with gold, platina, mercury, copper, or arsenic—more frequently, perhaps, with mercury than with any other metal. Two specimens of "native silver" from Allemont, in Dauphiné, yielded respectively to Mr Church's analysis 26.15 and 18.34 of mercury. Being principally obtained from its ores, or from other ores with which it is in intimate union, its nature, properties, and uses will be better considered under the section, "Metallic Ores."

Mercury, Copper, Iron, &c.

The same may be said of *Mercury*, *Copper*, *Arsenic*, *Antimony*, and *Bismuth*, which, though occasionally found *native*, or as native alloys, yet occur in quantities too unimportant to affect their commercial values. The remark is still more applicable to *Iron*, *Lead*, *Zinc*, and *Tin*, which are all less or more doubtfully *native*, and even when found only in fragments interesting to the mineral collector. With regard to native iron, it occurs in two states—1st, *meteoric iron*, which has fallen from the heavens in stones and masses sometimes of considerable size, and contains nickel along with cobalt and traces of other metals; and 2d, *telluric iron*, which occurs in minute grains and scales in other mineral veins, and contains carbon, or occasionally some other metal, but not nickel. It is sometimes very difficult, however, to assign an origin to certain masses of iron—as those, for example, discovered by Nordenskiöld in 1870 at Ovifak in Greenland. There, fifteen huge masses of native iron (one of them calculated at eighteen tons) were found within an area of 150 square feet, and apparently associated with a basaltic rock, which also contained many fragments of metallic iron. We say apparently associated, for these detached blocks were partially incrusted with basalt, and the whole evidently owed a common origin. Nordenskiöld and Wohler would assign to these masses an extra-terrestrial origin; while Daubrée and Berthelot are inclined to regard them as products of fusion and eruption from below—the enveloping basalt sometimes containing as much as twenty per cent of iron oxide. The following are the results of Daubrée's examination:—

Iron, metallic, ...	40.94
Iron, combined with oxygen, sulphur, and phosphorus, .	30.15
Carbon, combined, ...	3.00
Carbon, free, ...	1.64
Nickel, ...	2.65
Cobalt, ...	0.91
Oxygen, ...	12.10
Arsenic, sulphur, phosphorus, silica, copper, water, &c.,	8.61
	100.00

On the whole, the native metals, with the exception of gold, platinum, silver, and mercury, are of no great commercial importance; and it is almost exclusively from the ores that we derive by ingenious and often difficult processes our main metallic supplies.

II.—THE METALLIC ORES.

As already stated, the great majority of the metals occur in nature, not as free and simple elements, but in combination with other substances, forming what are termed *ores*. These ores have all, more or less, a stony aspect; but in general their higher specific gravities, their more varied colours, and their metallic lustres, in the fresh fracture, serve generally to distinguish them from ordinary stones. Almost all of them occur in veins traversing the older rock-formations—the clay-band and black-band ironstones, and the copper-slates of the stratified systems being the chief exceptions. They present numerous varieties, and are often very complex in composition—their reduction to the metallic state requiring, in some instances, great chemical skill and expensive manipulation. Mineralogically, they are classed and treated as oxides, sulphides, carbonates, silicates, &c.; and in many respects this arrangement, which has already been given in Chapter II., has much to recommend it. Occasionally they are arranged, according to their metallic bases, as ores of iron, ores of copper, and ores of lead; and these metals, again, treated according to their physical properties of weight, hardness, brittleness, ductility, malleability, and capability of being welded. In metallurgy, this plan has many advantages, as bringing each metal, with its several ores, distinctly and directly under the eye of the inquirer. Industrially, it matters little what plan of arrangement is followed, so long as the geological sources and nature of the ores are described, the peculiarities of the metals explained, and their uses in the arts and manufactures briefly indicated. Adopting this view, we shall take the metals in alphabetical order, as sufficient for economic purposes, and as affording, perhaps, the readiest means of reference. It is true that some of them are unknown in the arts; but even these, in the rapid progress of industry, may yet be utilised, and acquire a commercial value. And economically speaking, there are few substances on which more labour and capital are expended than on the ores and metals—in the mining, the transport, and the reduction of the former, and in the working, fashioning, and myriad applications of the latter. Metallurgy in all its branches is a gigantic art, whether as regards the science and ingenuity displayed, the amount of labour and capital employed, or the value and importance of the substances produced. And gigantic as it seems, it is yearly on the increase, not merely in the amounts produced, but in the adoption of more skilful methods, by which production is cheapened and improved, and substances formerly thrown to the waste-heap utilised and invested with commercial importance.

Aluminium.

Aluminium, though never found in a free or native state, is extensively diffused in nature in the different compounds of alumina. Commercially, it is obtained from *cryolite* and *Bauxite*—the former a double fluoride of sodium and aluminium found in Greenland, and the latter a hydrous sesquioxide of iron and alumina occurring abundantly near Beaux in France. It is now principally manufactured in France, the works instituted by Mr Isaac L. Bell at Washington in Durham having ceased to prepare it several years ago. As a metal it is silvery white, but less lustrous than silver; has a specific gravity of only 2.56, and when hammered of 2.67; has a fusing-point between those of zinc and silver; is very tenacious; resists oxidation even in moist air; is dissolved only by hydrochloric acid; conducts electricity eight times better than iron; but is easily affected in its character by admixture with other metals. One of the most important of its alloys is *aluminium bronze*, consisting of 90 copper and 10 aluminium. This bronze is extremely hard, tenacious, and ductile, has the colour and brilliancy of gold, and bars of it may be worked hot as easily as the best quality of steel. Both the pure metal and the bronze are possessed of many properties to recommend their use in the arts and manufactures—lightness, toughness, and resistance to corroding agencies—but somehow neither are manufactured on a large scale, the demand being chiefly for trinkets and smaller articles of ornament. The ores of aluminium are abundant enough, but no process sufficiently cheap has yet been discovered for the elimination of the metal on a large scale.

Antimony.

Antimony as a metal is of a tin-white colour, with a greyish or yellowish tarnish; somewhat sectile, but so brittle as to be easily reduced to powder by trituration; fuses at 900°; and has a specific gravity of 6.712. It is sometimes found native as an alloy with silver, iron, and arsenic; but it is obtained most abundantly from the sulphide or grey ore of antimony (*stibnite*), which consists of 74 antimony and 26 sulphur. This ore occurs in veins in the older crystalline and granitic rocks, and is found in Germany, Hungary, Spain, Borneo, Australia, and in Cornwall. Occasionally it is compact or massive, but more frequently occurs in long, prismatic, fibrous-looking crystals, sectile and somewhat flexible, cleavable, and easily fusible. There are other ores of antimony,—as *Allemontite*, or arsenical antimony; *Cervantite* and *Valentinite*, or oxides often arising from the alteration of the sulphide; and *Kermesite*, or red antimony, a compound of the sulphide and oxide; but these are commercially unimportant. The ores of antimony are easily reduced to the metallic state, and the metal is chiefly employed in making the alloys called type-metal (6 lead, 2 antimony), stereotype-metal (6 lead, 1 antimony), music-plates, and Britannia metal, which are variable compounds of lead, tin, and antimony. It is used also in anti-friction compositions, in the production of "iron black," and some of its preparations are employed in medicine, in the production of orange and yellow pigments, and in the "blue fire" of the pyrotechnist. Our supply of antimony—about 2000 tons a-year—is wholly imported, none of its ores being at present mined in the British Islands.

Arsenic.

Arsenic (Gr. *arsenikon*, masculine), so called from its possessing strong or powerful properties, occurs chiefly in veins in the crystalline and transition strata, along with ores of antimony, silver, and lead; and the purest specimens usually contain traces of antimony, iron, silver, or gold. The native metal is generally found in granular irregular masses or disseminated; is brittle; has a whitish lead-grey colour when newly broken; but soon tarnishes on exposure to the atmosphere, and becomes coated with a black sub-oxide of the metal. When struck or heated, it gives off a strong garlicky smell, known as the "arsenical odour;" and on being pulverised and moistened, it undergoes spontaneous combustion. It has a strong tendency to combine with other metals; hence such natural compounds as *arsenic-silver*, *arsenic-antimony*, *arsenic-glance*, &c. It is found in France, Germany, Bohemia, Transylvania, Norway, United States, and other regions, and usually in combination with other metals. Its more abundant ores are *arsenical antimony* (63.62 arsenic, 36.38 antimony); white arsenic, or *arsenolite* (65.76 arsenic, 24.24 oxygen); *realgar*, or red arsenic (70.09 arsenic, 29.81 sulphur); and *orpiment*, or the yellow sulphide (61 arsenic, 39 sulphur). Both realgar and orpiment are artificially prepared as pigments, as noticed in Chap. XIII.

The metallic arsenic of commerce is chiefly obtained from *mispickel*, or arsenical iron pyrites. It is used in small quantities in the preparation of several alloys; in the manufacture of opal-glass; in the making of shot, to which it imparts a certain degree of hardness; in pyrotechny and signalling, as a brilliant white light; in various pharmaceutical preparations; in the production of realgar, the red proto-sulphuret, and of orpiment, the yellow sesqui-sulphuret, or king's yellow; and the well-known pigment, *Scheele's green*, is an arsenite of copper. The metal and all its compounds are violent poisons. According to the returns received by the Mining Record Office in the year 1872, the amount of arsenic produced in the United

Kingdom (Devon and Cornwall) was 5172 tons, valued at £17,964.

Barium.

Barium (Gr. *barys*, heavy), or the metallic basis of the earth baryta, was discovered by Sir H. Davy in 1808, by the voltaic decomposition of the moistened carbonate of baryta in contact with mercury. It occurs in nature only as an oxide—baryta; and of this there are two well-known varieties, the carbonate and sulphate, whose characters and uses have been described in Chap. XIII. Like sodium and potassium, barium is known only to the chemist. It is of a whitish-grey colour, has little lustre, and on exposure to the air or water becomes rapidly converted into its oxide. In 1872 there were prepared in Cornwall 65 tons chloride of barium, the estimated value of which was £130.

Bismuth.

The metal *Bismuth* occurs in various states and combinations. Its colour is silver-white, with a slightly reddish tinge; it is very sectile; brittle when cold, but somewhat malleable when heated; and readily fusible, even in the flame of a candle. Its specific gravity is 9.727; hardness from 2 to 2.5; and fusing-point, 476° Fahr. It occurs *native*, associated with the ores of silver, cobalt, and tin, in veins traversing the older crystalline strata. It is found also as an oxide under the name of *bismuth ochre;* as a sulphuret called *bismuthine* (81.6 bismuth, 18.4 sulphur); as a sulphuret with copper, cupreous bismuth or *tannenite* (62 bismuth, 19 sulphur, 19 copper); as a sulphuret with copper and lead, *Aikinite* or *needle-ore;* and in several other less important combinations. It is found in the mines of Cornwall and Cumberland; but the principal commercial supply, which is said not to exceed 20 tons a-year, is obtained from Schneeberg in Saxony, from South America, and from South Australia. In 1872, the amount produced in Britain did not exceed two tons. From its fusibility it is easily reduced; but the demand for the metal is limited. The metallic bismuth of commerce is never quite pure, but contains from 3 to 5 per cent of other ingredients, as copper, sulphur, antimony, and arsenic.

Bismuth is chiefly employed in the formation of alloys with other metals—with tin, which it renders more elastic and sonorous; with tin and lead to form soft solder, *clichés* for stereotype, and cake-moulds for toilet-soaps; and with tin and lead, in the proportion of 8 bismuth, 5 lead, and 3 tin, to form *fusible metal,* which melts at 200°, and is useful in taking casts and other impressions.* It is also used in medicine, in the preparation of pearl-powder; and the nitrate, mixed with a solution of tin and tartar, has been employed as a mordant in calico-printing. Preparations of the oxide enter into the composition of some kinds of glass, and are also employed in porcelain-painting and glass-staining.

Cadmium.

Cadmium is rather a rare metal, and is found chiefly in connection with the ores of zinc, the Silesian native oxide of zinc containing from 1½ to 11 per cent of cadmium; that of the United States usually from 3 to 4. It was discovered by Stronmeyer and Herman in 1817, and received its name from its association with zinc, the *cadmia fossilis* of the older mineralogists. As a metal, it is of the colour and lustre of tin; soft, sectile, and ductile; but rather harder and more tenacious than tin. Its specific gravity is about 8.6; its melting-point considerably under redness; and when heated in the atmosphere it readily takes fire, and burns with a brownish-yellow inodorous smoke. It forms alloys with other metals, but its rarity—not more than 20 or 25 cwts. (2839 lb. in 1872) being annually prepared in Europe—prevents its use in the arts. Its price is about 5s. per lb. The iodide and bromide are occasionally employed in photography; the sulphuret is used as a yellow pigment and in pyrotechny; and mixed with lead, tin, and bismuth, cadmium forms a fusible metal (Wood's alloy), occasionally employed for stopping teeth. This alloy, which melts at 158°, consists of 15 bismuth, 8 lead, 4 tin, and 3 cadmium.

Cæsium.

The chloride of *Cæsium*, one of the alkali metals, was discovered in 1860 by Bunsen and Kirchoff in the mother-liquor of certain of the saline springs of Germany, and so named from the two blue lines (Lat., *cæsius*, sky-blue) of its peculiar spectrum. It belongs to the same group of elements as lithium, sodium, potassium, and rubidium, and occurs in the waters of Durckheim, Kruznach, Vichy, Baden-Baden, and other springs,

* As bismuth enters to a greater or less extent into all the soft solders and fusible metals, the composition and melting-points of a few of these alloys may be given :—

8 parts bismuth,	5 lead,	3 tin,	. . . .	212°	Fahr.
2 " "	1 "	1 "	. . . .	201°	"
5 " "	3 "	2 "	. . . .	199°	"
15 " "	8 "	4 "	3 cadmium,	158°	"

as well as in lepidolite, lithia-mica, carnallite, and other minerals. It is always found in company with rubidium, and, though its compounds are pretty numerous, has never been obtained in the pure metallic state.

Calcium.

Calcium, the metallic basis of lime, was first discovered by Sir Humphry Davy, in 1808, by the electric process. It is a substance of a brilliant pale yellow; sectile, ductile, and malleable; has a specific gravity of 1.578; is oxidised on exposure to air; and rapidly decomposes water. It is unknown in the industrial arts and manufactures, and, indeed, is only occasionally seen in the chemical laboratory; but its compounds — the carbonate, sulphate, fluoride, phosphate, and silicate—are among the most abundant of natural products, forming the various limestones, gypsums, fluor-spars, apatites, and cherts of the geologist.

Cerium.

Cerium is another of those metallic substances known only to the scientific chemist. It was discovered in 1803, simultaneously by Klaproth, and by Hissinger and Berzelius. It exists, together with lanthanium and didymium, in cerite, allanite, orthite, and a few other rare minerals, and appears as a greyish-brown infusible powder, which assumes a metallic lustre by friction.

Chromium.

Chromium, discovered by Vauquelin in 1797, is known to the chemist as a hard, brittle, and greyish powder, having a decided metallic lustre. Of itself, it has received no industrial application; but several of its compounds are extensively used as brilliant and durable colouring materials. It is found in *chrome-ochre* (sesquioxide), in chromate of iron or *chromite* (sesquioxide combined with protoxide of iron), in chromate of lead or *crocoisite*, in some iron ores, and as the colouring principle of many minerals—emerald, serpentine, olivine, &c. Its most abundant ore is the *chromate of iron* found in various parts of Germany, France, the Urals, Norway, United States, Scotland, and the Shetland Islands. According to Von Kobell, a Norwegian specimen consisted of sesquioxide of chromium, 54.08; protoxide of iron, 25.66; alumina, 9.02; magnesia, 5.36; and silica, 4.83. By treatment of this ore are obtained the chromates of potash, the beautiful yellow chromate, and the red bichromate; and from these again are prepared chromic acid, the green oxide of chromium, the blue oxide of chromium, chromate of lead, and other salts so largely employed in dyeing, calico-printing, and the colouring of glass and porcelain. The chrome colours, whether yellow, orange, red, green, or blue, are amongst the most brilliant and beautiful we possess, and entitled to be ranked among the most successful achievements of modern chemistry.

Cobalt.

As a metal, *Cobalt* is not of itself employed in any of the industrial arts; but its oxide (prepared by nickel refiners) is extensively used in imparting a fine rich blue to glass, and in the glazing and painting of porcelain and stone-ware. Metallic cobalt exhibits a steel-grey colour with a reddish tinge, is susceptible of a brilliant polish, is malleable and ductile, tougher than iron, and requires a very high temperature for its fusion. Its principal ores are *arsenical cobalt*, consisting of cobalt, arsenic, iron, and nickel; and *grey cobalt*, containing cobalt, arsenic, iron, sulphur, and nickel. These ores occur in Sweden, Germany, Cumberland, and Cornwall, in veins associated with other ores. They are picked, ground, and roasted in reverberatory furnaces, after which they undergo various chemical treatments and admixtures to produce what are termed *zaffre*, and *smalt*, or azure-blue. This azure-blue, which is essentially a glass of cobalt, silicious sand, and potash, is ultimately reduced to powder, and becomes the fine blue pigment, or "cobalt-blue" of commerce. What are known as cobalt-ultramarine, cæruleum, cobalt-green, cobalt-yellow, cobalt-bronze, &c., are various colours and pigments obtained from cobalt and admixtures by ingenious chemical processes belonging strictly to the domain of technology. Germany is the great manufacturer of *smalt*—upward of a thousand tons being annually prepared from her ores of cobalt. According to the returns received by the Mining Record Office in 1872, there was only one ton of cobalt raised in the United Kingdom—value £20.

Copper.

Copper (Lat. *cuprum*, a corruption of *Cyprium*, from the island of Cyprus, whence it was originally brought), is one of the most abundant and earliest known metals—having been the chief ingredient in bronze for domestic utensils and weapons of war, long before the discovery and reduction of iron. As a metal it is distinguished by its peculiar red (copper-red) colour; has a hardness of from 2.5 to 3; specific gravity from 8.5 to 8.9; is malleable and ductile; less tenacious than iron, but more than gold, silver, or platinum; and requires a temperature of nearly 2000° Fahr., or that of white heat, to fuse it. In dry air it remains untarnished; but in a damp atmosphere is soon covered by a green rust or "verdigris." It is readily acted on by acids, which form with it green or blue salts of a poisonous nature; hence the necessity of care in the employment of copper utensils for culinary and domestic purposes. It is easily detected in solutions by the bright blue produced by the addition of liquid ammonia, by the brown precipitate formed by the ferro-cyanide of potassium, or by its speedily coating a slip of polished steel or iron (a penknife blade, for example) with a film of metallic copper.

Copper occurs native in the metamorphic and igneous rocks in threads and strings and arborescent incrustations; also investing, massive, and disseminated, but rarely in loose grains or lumps. Occasionally it is found deposited in mines from water containing the sulphate, after the manner of the electrotype process; and not unfrequently large anomalous masses weighing from 1600 to 6000 lb. (like those of Lake Superior and South America) are found in the igneous rocks. Native copper is also found in Siberia, the Faröe Islands, Cornwall, the Kilbarchan hills, Brazil, Chili, and Peru—the American specimens usually containing a small percentage of silver. More frequently and more abundantly it occurs as an ore in many formations—the yellow copper ores (pyrites), the grey copper ores, and some of the copper salts being the more important and valuable. These ores, with the exception of the copper-slate of Germany, which is a stratified deposit, are found in veins generally traversing the older rock-systems—Metamorphic, Cambrian, and Silurian.

The ores most frequently used by the metallurgist, are *cuprite*, or the red oxide (88.80 copper, 11.20 oxygen); *melaconite*, the black oxide, resulting from the decomposition of other ores (from 90 to 98 copper); *Redruthite* (Redruth in Cornwall), the grey sulphide or vitreous copper (79.12 copper, 20.36 sulphur); *chalcopyrite*, or copper pyrites, a double sulphide of copper and iron (34 copper, 30 iron, 36 sulphur, &c.); *erubescite*, another double sulphide of copper and iron, so called from its iridescent or pavonine tints (60 copper, 14 iron, 25 sulphur, &c.); *tetrahedrite*, a double sulphide of copper and antimony, with zinc, iron, &c., (from 30 to 40 of copper); *azurite*, the blue carbonate (69 copper oxide, 25 carbonic acid, and water); *malachite*, the green carbonate (70 copper oxide, 21 carbonic acid, and water); *chrysocolla*, the hydrous silicate of copper, a mixed ore, usually containing about 40 copper oxide, 28 silica, 24 water, with iron and alumina; and *atacamite*, or the native oxychloride, from Chili and Peru. The salts of copper —arsenides, phosphates, sulphates, &c.—though extremely numerous, are of more interest to the mineralogist than to the metallurgist and economic geologist. The ores of copper, being of a mixed nature, require various processes of washing, smelting, and refining, to reduce them to the metallic state—the resultant metal usually containing traces of other metals, as lead, iron, and antimony.

In 1872, the copper ores raised within the United Kingdom (chiefly in Cornwall, Devon, Cheshire, Anglesea, and Ireland), amounted to 91,983 tons, valued at £443,738; and the metal obtained to 5703 tons, computed at £583,232. During the same year there were imported into the United Kingdom 43,656 tons copper ore, 28,779 regulus, 731 old copper for remanufacture, and 47,669 unwrought and part wrought, besides copper manufactures to the value of £71,278.

Copper is extensively employed in the arts and industries of all civilised countries, either alone or as an alloy. Alone, it is used for boilers, pans, &c., in sugar-works, distilleries, breweries, &c.; for domestic and culinary utensils; for ship sheathing; for telegraph and other wires; and for a great variety of well-known purposes. As an alloy its employment is still more extensive and varied, whether as *brass* (two parts of copper to one of zinc); *mosaic gold* (65 copper, 35 zinc); *Bath metal* (78 copper, 22 zinc); *pinchbeck* (3 of copper and 1 of zinc); *ancient bronze* (from 4 to 15 of tin); *gun-metal* (91 copper, 9 tin); *bell-metal* (78 copper, 22 tin); *gong-metal* (80 copper, 20 tin); *statuary bronze*, varying proportions of copper, tin, zinc, and lead; *German silver*, or *argentane*, an alloy of copper, nickel, and zinc, in varying proportions, according to the colour or hardness required; or *standard metal*, an admixture of copper and manganese. The salts of copper (sulphates, oxides, &c.), are also largely used in the preparation of blue and green pigments, and some of them are likewise employed in medicine.

Didymium.

Didymium, one of the rarer metals, of whose properties little is yet known, was discovered by Mosander in 1841, and so called because found as twin-brother (Gr. *didymos*, twin) with *lanthanum* in the oxide of cerium. In the metallic state it appears as a grey lustrous powder; its oxide is a dark-brown powder; and its salts are of pinkish or amethystine hue. It has no commercial value, and few of its compounds have yet been examined.

Glucinum.

Glucinum, the basis of the earth glucina, is another of the rarer metals, only known as yet to the scientific chemist. It is of a white silvery colour; has a density of 2.1; has a melting-point below that of silver; and, according to Debray, can be forged and rolled into sheets like gold. Its earth, *glucina*, was discovered by Vauquelin in 1798, constituting nearly 14 per cent of the beryl and emerald, which owe to it their fine green colour. It combines with all the acids, and forms with them sweetish salts; hence its name. Neither earth nor metal is used in the arts, though chemists anticipate that the former may probably be employed in the production of artificial gems.

Gold.

Gold, as mentioned in the preceding section, is found only in the metallic state, either pure and simple, or as an amalgam with silver (*electrum*), with palladium (*porpezite*), and with rhodium. Even when it occurs as auriferous pyrites it is still in the native state, and not as a sulphide, for though invisible in the fresh ore, it becomes visible on the decomposition of the pyrites, as minute shining metallic particles. In the amalgams it rarely forms less than 70 per cent of the mass—the remainder being silver, palladium, or rhodium, with traces of iron and copper; * and in the pyrites it occurs usually in small but very variable proportions. Whether disseminated in rocks or appearing in veins, gold is always a native metal — the iron pyrites, copper pyrites, arsenical pyrites, galena, and blende, with which it is incorporated, being mere accompaniments, like the quartz, calc-spar, and baryta, which usually constitute the matrix or veinstone.

Indium.

This metal, which was discovered in 1862 by Reid and Richter in the zinc-blende of Freiberg, and so named from the two indigo-coloured lines which characterise its spectrum, has hitherto been obtained in such small quantities as to prevent its thorough examination. It is of a lead-grey colour, soft, very malleable, and marks paper like lead. Its compounds impart a violet tint to the flame of a Bunsen's burner.

Iridium.

Iridium, one of the rare metals discovered by Dr Wollaston, is of a greyish-white colour, brittle, very infusible, and has a

* Two specimens of Scottish gold—one from Wanlockhead, and another from Sutherlandshire—yielded respectively to Mr Church's analysis 12.39 and 20.71 per cent of silver.

specific gravity of about 18.6. It occurs in nature in connection with platinum, palladium, and osmium—osmium-iridium, or "native alloy," being its most abundant form. It derives its name from the variety of hues (Gr. *iris*, a rainbow) which the mixture displays while dissolving in hydrochloric acid. It is the most infusible of the known metals, and is used chiefly in porcelain-painting to produce black and grey colours. It is also used for the nibs of gold pens, and is said to be worth £24 an ounce. It forms alloys with copper, gold, mercury, and platinum — that with the latter being malleable and capable of being worked and less easily attacked by chemical reagents than pure platinum.

Iron.

Iron, of all the metals the most useful, is likewise the most abundantly diffused in nature. It is found, though sparingly, as a *native* alloy; occurs as an *ore* in rocks of all ages, and in every country is met with in most mineral springs; and appears in the tissues and fluids of many plants and animals. Though readily tarnished, rusted, or oxidised by exposure to air and moisture, metallic iron has in the fresh fracture a peculiar grey colour known as "iron-grey" or "steel-grey," and when polished possesses much lustre. It is not very malleable, but extremely ductile and very tenacious. At common temperatures it is hard and unyielding, but at a red heat it is soft and pliable, and at a high red heat two pieces can be inseparably united by hammering—or *welded* into one mass. It is very difficult of fusion, requiring for that purpose the highest heat of the blast-furnace. In this state it can be run into moulds, and is then known as *cast-iron*, which is hard, brittle, and of a granular texture. Subjected to repeated heating and hammering (*puddling*, as it is termed) it becomes less fusible, assumes a fibrous texture, gets tough and malleable, and is then known as *forged* or *wrought iron*. The average specific gravity of cast-iron is 7.27; that of forged, 7.78. Iron is attracted by the magnet, and is of itself susceptible of being rendered magnetic—a property possessed by no other metal except nickel. Most of the iron of commerce contains variable quantities of carbon, silicon, sulphur, and phosphorus—impurities which deteriorate its quality; hence the scientific efforts of the iron-founder to reduce these to a minimum. Iron is capable of forming alloys with several of the metals, though in this state little used; and with a small proportion of combined carbon it forms *steel*,* a substance which, from its hardness, strength,

* "Those varieties of iron," says Phillips in his 'Elements of Metallurgy,' "in

and susceptibility of receiving a fine cutting-edge, is of incalculable importance to all the industrial arts and manufactures.

As mentioned in the preceding section, *native iron* is a very rare and in some instances doubtful substance; and all the iron of commerce is derived from *ores* (oxides, carbonates, &c.), either pure or in combination with various earthy ingredients forming *ironstones*. These ores and ironstones occur in rocks of all ages—the ores chiefly in veins and abnormal masses among the older rocks, and the ironstones in layers and nodular bands among the strata of the carboniferous, liassic, oolitic, and other later systems. As metal-producers, these ores and ironstones are usually regarded under two sections—1st, the SPARRY IRON ORES, the most important member of which is *siderite*, *spathose iron*, or *carbonate of iron*, and which include the *clay ironstones* or "clay-bands" and "black-bands" of the coal and other stratified formations; and, 2d, the OXIDISED IRON ORES, embracing such well-known species as *magnetite* or magnetic iron, *hæmatite* or specular iron, and *limonite* or brown iron ore. The former section require roasting or calcination before being smelted, and are regarded as ores of easy reduction; the latter go direct to the furnace, and are considered of difficult reduction. Besides these ores, iron is found in many chemical combinations, as chromates, phosphates, sulphates, and sulphides, which are of great value in the arts, though not used for the production of the metal. Its presence in water is readily detected by the tincture of galls, or by ferro-cyanide of potassium—the former turning weak solutions purple or dark-blue, and forming a black precipitate where the metal is more abundant; the latter producing Prussian-blue under similar circumstances. The following ores may be noticed as of chief commercial importance:—

Magnetite, Magnetic Iron, or *Black Oxide of Iron*, is a rich and valuable ore, consisting, when pure, of 72.40 iron and 27.40 oxygen, or 69 iron peroxide, and 31 iron protoxide. It occurs chiefly in the igneous and metamorphic rocks, either in distinct octahedral crystals disseminated through the mass, or more

which the amount of carbon is below the minimum of that contained in cast-iron, and above the maximum of that present in wrought-iron, are known as *steel*. The distinguishing peculiarity of this substance is its property of becoming hardened by rapid cooling, and softened by being slowly cooled. Steel being in its composition intermediate between cast and wrought iron, is fusible like the one and malleable like the other; but requires a higher temperature for its fusion than cast-iron, and does not draw so readily under the hammer as wrought-iron. Steels in which the proportion of carbon is large, are known as *strong steels*, and are harder and more easily fusible than *mild steels*, in which the amount of that substance is less considerable."

frequently in beds and masses of a granular brittle texture, and very rarely in veins. It is found in Sweden, Norway, Russia, Germany, Elba, and Spain, in Europe; in Siberia; and in North America—the celebrated "Codorus ore" or "steel-ore" of Pennsylvania. From its bedded position it is often worked, as at Dannemora in Sweden, in open quarry; and though difficult of fusion, is an esteemed ore, especially for the manufacture of steel and certain makes of iron. The impurities most frequently present in magnetite are pyrites, alumina, magnesia, and phosphate of lime.

Hæmatite, or *Red Oxide of Iron*, is a still more abundant ore, occurring in rocks of all ages, sometimes in veins and sometimes in nests or amorphous masses, as in the Furness and Whitehaven districts. It appears in several well-known varieties, as *kidney-ore*, in reniform masses, having a radiated crystalline texture, as *compact* when void of the crystalline texture, as *red-ochre* or argillaceous hæmatite when soft and clayey, as *specular iron* when in crystals of a dark steel-grey colour, and as *micaceous iron* when foliated, with a soft unctuous feel. Its distribution is world-wide—Scandinavia, Saxony, Elba, Cornwall and Devon, North Lancashire, and West Cumberland, being the most important European localities. It produces an excellent iron, 69 per cent being not unusual in pure varieties.

Limonite, or the *Brown Oxide of Iron*, is another valuable ore, occurring in several varieties—*brown ironstone*, *pea-iron*, *bog-iron*, and *yellow-ochre*—all hydrous oxides, varying alike in mineral aspect and yield of iron, and arising in most instances from the decomposition of other ores. As its name indicates (Gr. *leimo*, meadow), it is frequently found as a deposit in bogs and marshes, and occurs also in bands and nodules in the secondary and later formations. From its origin, it contains more impurities than magnetite or hæmatite, and is said to be better fitted for castings than for wrought-iron.

Ilmenite, *Menaccanite*, or *Titaniferous Iron*, is another important ore, consisting of ferric and ferrous oxides, titanic oxide, and magnesia, in varying proportions. A specimen from *Menaccan* yielded to V. Kobell 42.57 $\ddot{Ti}$, 23.21 $\ddot{Fe}$, 29.27 $\dot{Fe}$, 1.22 $\dot{Mg}$, and 50 Ca. Titaniferous iron-ore is widely distributed; Norway, Sweden, the Ilmen mountains (hence the name), Canada, United States, Mexico, France, and Menaccan in Cornwall (hence the name), being well-known productive districts. It occurs also as titanic iron-sand, or *iserine*, in several countries, in which form it is said to produce a very hard and tough variety of iron. (See Titanium.)

Siderite, Spathose Iron, or *Carbonate of Iron*, is one of the most important sources of the metal, whether found in veins and stratiform masses in the old gneisses and clay-slates, or in beds in the coal, lias, oolite, and later formations. It occurs in crystallised, concretionary, granular, oolitic, and earthy varieties, all differing widely in mineral composition and value. The clay ironstones of the coal-formation appear in earthy bands and nodules (clay-bands), or in beds, mingled with coaly or bituminous matter sufficient for its own calcination (black-bands); while those of the lias, oolite, and later formations are found in shelly bands, clayey bands, and nodules or septaria. Productive ores are worked in the old rocks of Germany; in the coal-fields of France and Britain; in the lias and oolite of England, and at one time in the Wealden. The amount of metallic iron may range from 20 to 50 per cent; but ores yielding less than 28 are seldom regarded as of commercial importance.

Franklinite (from Franklin county, New Jersey), is a compound ore, which has recently risen into great commercial importance. An average of several analyses by Rammelsberg gives 45.16 iron, 9.38 manganese, 20.30 zinc, and 25.16 oxygen. The ore occurs in metamorphic limestone of Silurian age, forming a bed from 20 to 30 feet thick, which is overlaid by 6 or 8 feet of red zinc ore. Both minerals are first treated for zinc, and the residues afterwards smelted for *spiegeleisen*. All iron ores containing manganese are found to produce excellent iron for the manufacture of steel. (See Manganese.)

Iron Pyrites, so universally distributed, "is never directly treated" (we quote Phillips's 'Metallurgy') "for the sake of the iron it contains, but is frequently employed as a source of sulphur in manufactures of alum and sulphuric acid. When heated in the burners attached to sulphuric acid chambers, good pyrites yield about 46 per cent of sulphur, which is burned and oxidised in the usual way; but the sulphuric acid thus obtained always contains traces of arsenic. Iron pyrites frequently contains small quantities of gold and silver, but these are seldom present in sufficient proportion to allow of their being profitably extracted. Very large quantities of cupreous iron pyrites are now annually imported into this country from Spain and Portugal, and after being burnt for the manufacture of sulphuric acid, the 'cinders' are treated for copper by a process of wet extraction. The ferruginous residues ('Blue Billy') thus finally obtained yield on an average 96 per cent of ferric oxide, and are extensively employed, both in the blast-furnace and for 'fettling' puddling-furnaces. By far the largest portion of that produced, amounting to several hundred thousand tons annually, is used for the latter purpose." The amount of iron pyrites or sulphur ores raised within the United Kingdom in 1872, exceeded 65,916 tons, the computed value of which was £39,470.

There are other ores yielding iron, but the preceding are the most important and abundant, and are those usually reduced in Britain. In 1872, the iron ores raised in the United Kingdom amounted to 16,584,857 tons, valued at £7,774,874; and the pig-iron produced 6,741,929 tons, worth £18,540,804. The following table, from Hunt's 'Mineral Statistics,' shows the districts from which the ores were obtained, the nature of ore, and their respective amounts and estimated values:—

District.	Description of Ore.	Tons.	Value.
Cornwall, . . .	R. and B. hæmatite, . .	48,199	£27,033
Devon, ...	B. hæm. and magnetite, . .	26,361	15,524
Somerset, . . .	Brown hæmatite, ...	30,913	30,163
Gloucester, . .	Hydrated oxide, ...	199,453	149,588
Wilts, ...	Hydrated oxide, ...	96,117	36,168
Oxfordshire, . .	Brown hæmatite, ...	63,536	47,652
Northampton, .	Hydrated oxide, ...	1,004,093	377,736
Lincoln, . . .	Hydrated oxide, ...	318,802	79,675
Shropshire, . .	Argillaceous carbonate. . .	408,425	153,669
Stafford, N., . .	Hydr. ox. and argillaceous, .	361,603	216,961
,, S., . .	Argillaceous carbonate, . .	641,950	420,135
Warwick, . . .	Argillaceous carbonate, . .	43,375	16,246
Derbyshire, . .	Argillaceous carbonate, . .	307,183	184,308
Lancashire, . .	Red hæmatite, ...	852,064	1,063,186
Cumberland, . .	Red hæmatite, ...	917,452	1,141,416
York, N. Riding,	Argillaceous carbonate, . .	4,974,950	1,863,081
,, W. Riding,	Argillaceous carbonate, . .	466,305	171,864
Durham and Northumberland, .	Argillaceous carbonate, . .	97,953	36,730
North Wales, . .	B. hæm. argill. carbonate, .	27,775	19,710
South Wales and Monmouthshire,	B. hæm. argill. carbonate, .	1,247,594	744,465
Isle of Man, . .	Spathose ore, ...	994	497
Scotland, . . .	Argill. and black-band, . .	3,270,000	817,500
Ireland, . . .	B. haem. pea-ore and B.-band,	176,550	158,562
	Total iron ore, ...	15,584,357	£7,774,874
	"Burnt ore" from cup. pyrites, . .	252,239	
	Iron ore imported, ...	801,503	
	Total, ...	16,638,599	

During the same year (1872) there were imported into the United Kingdom—

	Tons.	Value.
Iron in bars, unwrought, ...	82,888	£918,808
Steel, unwrought, ...	39,602	1,170,201
Iron or steel, wrought or unwrought, .	7,557	109,494
Total, ...	130,047	£2,198,503

The uses of iron and steel in the arts and manufactures are so universal and miscellaneous as to render any enumeration impossible. In various forms, as tools, implements, instruments, utensils, and machines, these metals appear in our agriculture, our architecture, shipbuilding, national defence, railways, telegraphs, engineering, spinning, weaving, baking, brewing, tanning, printing, dyeing, household furnishings and implements, and, in fine, through all the industries—domestic and national—that are characteristic of civilised existence. Before the current century they were little used in agriculture, architecture, or shipbuilding; and then our railways, telegraphs, and gigantic spinning and weaving factories were unknown. But now they enter into every art and manufacture, and year after year witnesses new extensions and new adaptations of their employment. Nor is it alone in the metallic state that iron is so universally useful; its chemical preparations are likewise of value as pigments, dyes, and mordants, and some of them have been long and favourably known in medicine.

Lanthanum.

Lanthanum, or *Lanthanium*, is one of the rare metals discovered by Mosander in 1841, associated with didymium in the oxide of cerium, and so called from its properties being *concealed*, as it were (Gr. *lanthano*, I conceal), by those of cerium. Like its associate didymium, it is as yet known only to the scientific chemist as a soft, dark, lead-grey, metallic powder.

Lead.

Lead and its ores, mineralogically as well as commercially speaking, are of great interest and importance. As a metal it has been long and widely known; is of a bluish-grey colour, soft, flexible, and inelastic; and though ductile and malleable, yet possessed of very little tenacity. Its specific gravity varies from 11.3 to 11.4; its usual hardness is 1.5, and it fuses at a temperature of about 600° Fahr. In close vessels it does not appear to be volatile at a white heat; but melted in open vessels, it soon oxidises and passes into a grey powder, which, upon further exposure to heat and air, becomes yellow, and forms *massicot*, or protoxide of lead. "Pure lead," says Dr Ure, "is not affected by perfectly pure water free from air; but if air be present, the metal is oxidised at its expense, and the oxide thus formed, combining with carbonic acid, is deposited on the lead in minute crystals as a basic carbonate of lead. The water will then be found to contain lead in solution, and such waters drawn from impure cisterns often produce very distressing consequences. If the water contains any sulphates, the lead is thrown as a sulphate of lead, which is insoluble."

Lead, as noticed in the preceding section, is rarely found *native*, and that chiefly in volcanic rocks, where it appears to be a product of fusion. Commercially, it is wholly obtained from the *ores*, and these occur in rocks and formations of all ages—almost always in veins with various spars, as in the metamorphic schists and carboniferous limestones of our own country. Mineralogically, the ores of lead are numerous, and of great interest from their compositions and transformations; commercially, comparatively few are used for the extraction of the metal. The chief ore is *galena*, *lead-glance*, or *sulphide of lead*, which occurs in veins in the metamorphic schists of the Highlands; in the Cambrian and Silurian slate-rocks of Cornwall, Devon, and Wales; and in the mountain limestones of the Mendips, Derbyshire, Yorkshire, Cumberland, Northumberland, and Durham. It is found abundantly in almost every country—France, Spain, Germany, Sweden, North and South America; and usually consists of from 85 to 87 lead, from 13 to 14 sulphur, with traces of iron and other impurities, and not unfrequently an available percentage (2 to 5) of silver. As a mineral it belongs to the cubic system, has a specific gravity of 7.75, is of a lead-grey colour, and exhibits a strong metallic lustre.

Other ores of lead of more or less importance are *Bournonite*, or antimonial lead ore; *cerussite*, or carbonate of lead; *pyromorphite*, phosphate of oxide of lead; *mimetesite*, arseniate of oxide of lead; *Anglesite*, sulphate of lead; *Cromfordite*, chloride of lead; and molybdate of lead. The rarer ores (chromates, tungstates, vanadiates, &c.) are interesting only to the mineralogist, not to the metallurgist. According to the returns received by the Mining Record Office in 1872, there were 455 lead-mines in Britain, which yielded 83,968 tons of ore—the estimated value being £1,146,155. The metal obtained amounted to 60,455 tons, computed at £1,209,115; while during the same year we imported 14,560 tons of lead ore, 69,841 of pig and sheet lead, and 441 of lead manufactures.

The metal obtained from the ore, by roasting or by precipitation, is largely used in the arts and manufactures, partly in the pure state, partly as an alloy, and partly in numerous preparations. As lead it is used variously—in architecture, for roofing, roans, &c.; in chemical works, for pans, cisterns, linings for sulphuric acid chambers, &c.; for gas and water pipes; for gun-shot, and numerous other purposes. As an alloy with tin, with bismuth, and with antimony, it is employed in the preparation of soft solder, white metal for domestic utensils, organ-pipes, type and stereotype metal, ships' nails, lining for tea-chests, and kindred uses too multifarious to mention. The preparations from the metal are also exceedingly numerous—red-lead, white-lead, yellow-lead, litharge, acetate of lead, &c., used variously as pigments, in porcelain-painting, glass-making, dyeing, calico-printing, and in medicine.

Lithium.

Lithium, the metallic basis of lithia, is another of those rare substances known chiefly to scientific chemists. Lithia occurs in petalite, amblygonite, lepidolite, tourmaline, and other minerals; is found in many mineral waters (see Chap. XV.), and has been detected in the ashes of certain plants. The metal has a silvery colour, but quickly tarnishes on exposure to air; is softer than lead, but harder than potassium or sodium; is sectile and somewhat ductile; and is the lightest of all known solids, its specific gravity being only 0.589. It is much less oxidable than sodium or potassium; melts at 186°; ignites at a light temperature, and burns quietly with an intense white light. When thrown on water it oxidises, but does not burn like sodium. As a metal it is unknown in the arts, but its oxide and some of its compounds are employed in medicine.

Magnesium.

Magnesium, the metallic basis of magnesia, is another silvery-looking metal, obtainable in any quantity from such an abundant earth, though only produced on a small scale owing to its limited commercial applications. It was first obtained by Davy, but recently in larger quantities by other chemists. Like aluminium, it is prepared by several chemical processes, and when pure is ductile and malleable, has a specific gravity of 1.75 and hardness of 3, fuses about the same temperature as zinc (770°), burns in the air with a bright white light, and in oxygen with intense and dazzling brilliancy. It has been employed for signalling, and in the production of light for instantaneous photography.

Manganese.

Manganese, originally discovered by Gahn, is a hard, brittle, greyish-white metal, somewhat resembling iron; has a specific gravity of 8; is fused with great difficulty, but is readily oxidised. As an oxide it is abundant in the mineral kingdom, and traces of it have been found in the ashes of plants and in mineral waters. The ores of manganese are numerous, and often occur associated with those of other metals in the older rocks. The better known and more abundant are *manganite*, or the grey oxide; *wad*, or the earthy protoxide; *cupreous manganese; pyrolusite*, or the black peroxide; *psilomelane*, a compound of the oxide and baryta; *Hausmannite*, a peroxide occurring with other ores of the metal; and *Braunite*, a binoxide in combination with iron peroxide, silica, and magnesia.

The ores of manganese are largely used in the arts—in glass-making, in pottery painting and glazing, in glass-staining and enamel, in the production of oxygen, chlorine, and chloride of lime, and as an admixture for improving the make of iron and steel. The celebrated *spiegeleisen* of Germany is such an admixture, and is either produced by artificial admixture, or by the use of iron ores (like Franklinite) containing manganese. It also appears, from recent experiments, that manganese can be substituted for nickel in the manufacture of German silver, without affecting the appearance or general character of the alloy. In 1872, the ores of manganese raised within the United Kingdom (chiefly in Devonshire) amounted to 7773 tons, having a value of £38,865.

Mercury.

Mercury, so well known in the arts and manufactures, is in many respects a peculiar and anomalous metal. At temperatures higher than —39° it is always fluid; and hence, from its mobility and silvery lustre, is usually called "quicksilver." At temperatures below —40° it becomes solid, and has a specific gravity of 15.6; when fluid its gravity is only 13.5; under the blowpipe it is altogether volatile, or leaves a slight residuum of silver. It occurs in rocks of all ages, but is rarely found in a state of *native purity*, in which condition it is interspersed through the matrix in small shining globules. Its more abundant ores are *cinnabar*, or bisulphuret of mercury (86.29 mercury, 13.71 sulphur); *native amalgam*, an ore containing 36 silver and 64 mercury; and *calomel*, or chloride of mercury (84.9 mercury and 15.1 chlorine). Cinnabar is the chief ore of commerce, and frequently occurs associated with iron pyrites in a matrix of quartz, calc-spar, or spathic iron ore. It is found in Spain, various parts of Germany and Hungary, the Urals, China, Japan, Borneo, Mexico, Peru, and abundantly in California. The annual production of mercury is said to be upwards of 4000 tons, of which California yields nearly two-thirds, and Spain one-third. The best known mercury-mines in Europe are Almaden in Spain, and Idria in Carniola. At Almaden the mercury is said not to form veins, but to have impregnated the vertical strata of quartzose sandstone associated with carbonaceous slates; in the Asturias the mines are worked in carboniferous strata; and in Carniola it is disseminated in beds of grit, bituminous shale, or compact limestone of more recent formation.

The industrial applications of mercury and its compounds are exceedingly numerous. The metal is used in the construction of many scientific instruments—thermometers, barometers, steam-gauges, &c.; in the preparation of amalgams with other metals from its property of ready combination; in the extraction of gold and silver from their ores; in silverising mirrors and reflectors; in arming the cushions of electrical machines; in the preparation of corrosive sublimate, mercuric-chloride, which is variously employed in preserving, dyeing, printing, etching, &c.; in the manufacture of vermilion pigments; in the preparation of the fulminate for percussion-caps, and other applications too numerous for detail.

Molybdenum.

Molybdenum, one of the rare metals, was discovered by Hjelm in 1782. It is of a whitish colour, brittle, very infusible, has a specific gravity of 8.625, and hardness of 8. It is obtained from *molybdenite*, or sulphide of molybdenum, an ore occurring in the granites and crystalline schists, in veins with tin and other ores, very much resembling the sulphide of lead, hence the name (Gr. *molybdos*, lead). It is also obtained from *wolfenite*, or molybdate of lead. The sulphide is found in the metalliferous veins (*magnetite* and *cassiterite* especially) of Cornwall, Cumberland, Saxony, Scandinavia, and Greenland, and at numerous places in the United States of America. The metal is not industrially employed, but its sulphide is used in the preparation of a blue pigment for pottery-ware.

Nickel.

Pure *Nickel* has a silver-white colour with a slightly yellowish tinge, is ductile, malleable, hard, and easily polished, but very difficult of fusion. When quite pure it can be drawn into wire, rolled into sheets, hammered, and forged; has a tensile strength exceeding that of iron; and hammered, its specific gravity is about 9. It is not altered by exposure to the air and moisture at ordinary temperatures, but is slowly oxidised at a red heat. It is found, as already stated, in all meteoric iron; but its principal ore is a copper-coloured mineral found in various parts of Germany, and called *nickeline*, or *kupfer-nickel* —"nickel" being a term of detraction used by the miners, who expected from its colour that it would contain copper.

Since the manufacture of German silver, or *argentane*, nickel has become an object of considerable importance, and is extracted from several ores, as from *Gerfsdorffite*, or nickel-glance, containing 35 per cent; *nickeline*, or copper-nickel, 44; *antimonial nickel*, 31; *arsenical nickel*, 29; *Beudanskite*, or silicate of nickel, 13; and from other sulphuretted ores of cobalt, iron, &c. These ores are found in many countries—Germany, Russia, Sweden, Italy, Spain, Brazil, and the United States—and are mostly difficult of reduction. As already mentioned, nickel is chiefly employed in the preparation of German silver, nickel-silver, or white metal, and similar alloys, consisting of variable proportions of copper, nickel, and zinc. Its salts are mostly of a grass-green colour, and the ammoniacal solution of its oxide of a deep blue. Within a very few years the price of nickel, according to Phillips's ('Elements of Metallurgy'), has risen from 4s. to 11s. per lb.; and its present production, which is estimated at 600 tons annually, appears to be rapidly becoming unequal to the demand.

Niobium, &c.

Niobium, or *Columbium*, *Pelopium*, and *Tantalum*, are all very rare and closely associated metals—indeed, the same metal—derived by complex processes from the minerals known as *Tantalates*. These tantalates (of iron, manganese, tin, &c.) are found in the older granitoid and crystalline schists of Sweden, Greenland, Spain, and North America. The metals are known only to the scientific chemist, and have received their names, classical, geographical, and fanciful, in allusion to circumstances connected with their discovery or reduction.

Osmium.

Osmium was discovered by Smithson Tennant in crude platinum, and so named from the strong disagreeable odour (Gr. *osme*, a smell) given out by its oxide. Two native alloys of osmium and iridium are known to mineralogists under the names of *osmiridium* and *iridosmium*, both of which are found in flattish grains or scales in the gold and platinum sands of the Urals and California. (See Iridium.)

Potassium.

Potassium, the metallic basis of potash, was discovered by Sir Humphry Davy, by the voltaic process, in 1809. It is a soft metal, can be cut like wax with a knife, has a white silvery brilliancy in the newly cut surface, but quickly tarnishes on exposure. It is fluid at 120°, is malleable at 50°, with a specific gravity of 0.865, and at 32° becomes brittle, with a crystalline texture. Its strong affinity for oxygen renders it difficult of preservation in a metallic state—hence the necessity of keeping it in stoppered phials under naphtha. When heated in the air it takes fire and burns vividly with a violet light; and when thrown on water decomposes it with violence—the hydrogen and volatilised metal burning with a beautiful rose-red flame, while the oxygen combines to form potash. It is chiefly interesting to the geologist as being the base of an earth which enters so largely and multifariously into the composition of the rocky crust.

Rhodium.

Rhodium, one of the rare metals discovered by Wollaston in 1803, is usually associated with iridium, osmium, and palladium, in ores of platinum. It derives its name from the red colour (Gr. *rhodon*, a rose) of its solutions, though its own colour is a whitish silvery-grey. It most resembles platinum in its character; is hard and very infusible, ductile, and malleable; has a specific gravity of 12; and forms alloys with other metals. Its alloys with steel are extremely hard and tough, and take on a fine polish; the metal itself is used for nibbing gold pens.

Rubidium.

Rubidium, one of the alkali metals, was discovered by Kirchoff and Bunsen in 1860 by the method of spectral analysis, and so named from the two red lines (Gr. *rubidios*, dark-red) of its spectrum. It is found in several of the German mineral waters, in lepidotite, petalite, lithia-mica, and other minerals, and in the ashes of many plants. As a metal it is obtained by intricate chemical processes, and is described by its discoverers as having a white colour with a tinge of yellow, and a silvery lustre. It has a specific gravity of 1.52; is as soft as wax even at 0.10°; melts at 38.5°; and is converted even below a red heat into a greenish-blue vapour. When exposed to the air, it instantly becomes covered with a bluish-grey film of sub-oxide, and takes fire in a few minutes, even more readily than potassium. When thrown on water, it takes fire with violent evolution of hydrogen, and burns with a flame exactly like potassium.

Ruthenium.

Ruthenium, another of the platinum metals, discovered by Claus in 1846, is closely related in its characters to iridium, but of much less density, its specific gravity being only 11.4 instead of 18.6. It is extremely refractory, and unknown in the arts.

Selenium.

Selenium (Gr. *selenè*, the moon), so called from its colour and lustre, was discovered by Berzelius in 1817. It occurs associated with ores of tellurium, bismuth, gold, silver, copper, and iron pyrites. It is difficult of extraction; has a specific gravity of 4.3; fuses at a temperature little more than that of boiling water; and is known only to the scientific chemist. In its properties it is closely allied to sulphur, and is often associated with that element in the mineral kingdom.

Silicium.

Silicon or *silicium*, the base of silica, was discovered by Berzelius in 1823. It is a dark-brown powder, heavier then water, infusible before the blowpipe, non-volatile, and known only to the scientific chemist. Its oxide silica, the silicates, and silicious rocks and earths, constitute, however, a large portion of the ponderable crust (perhaps one-fourth), and are of extreme interest to the geologist.

Silver.

Silver, one of the early and well-known metals, is, when pure, of a peculiar white colour (silver-white), brilliant lustre, next in malleability and ductility to gold, harder than gold, but softer than copper. Its specific gravity is from 10.5 to 11; its melting-point about 1000° Fahr.; and though unaltered by air or moisture, it is readily tarnished or blackened by sulphuretted hydrogen. It resists the action of the caustic alkalies; but is readily attacked by nitric and strong sulphuric acids, and by chlorine, iodine, and bromine.

It occurs *native* in the older rocks, in threads and strings, in arborescent moss-like aggregates, and in plates and nuggets, often of considerable magnitude. In this state it is found at Konigsberg in Norway, in Germany, Peru, Mexico, and in several parts of the United States—New Jersey, Lakes Michigan and Superior. In its native state it is often found as an alloy with gold (electrum), with platinum, copper, arsenic, and antimony (dyscrasite); and from such compounds much of the silver of commerce is extracted. It is also largely obtained from *ores*, generally as a *sulphide*, and often in intimate union with ores of lead, antimony, bismuth, &c.; so that the ores yielding silver are, strictly speaking, ores of other metals. These ores are found chiefly in the older granitoid and crystalline schists, though argentiferous lead ores occur abundantly in secondary strata, as in the thick-bedded carboniferous limestones. The more important ores, commercially speaking, are *argentite*, or the vitreous sulphide, containing about 85 per cent of silver; *Stephanite*, the brittle, grey, antimonial sulphide, containing about 65 of silver; *pyrargyrite*, the red antimonial sulphide, 60 of silver; *polybasite*, the cupreous sulphide, upwards of 60 of silver; and *cerargyrite*, or the chloride (horn silver), containing 75 of silver. These and other ores are mined, crushed, picked, smelted, or amalgamated, for the production of the metal, the mode of treatment varying with the nature of the ore.

The richest silver-yielding countries are Mexico, Nevada, Colorado, and Lake Superior, in N. America; Chili, Bolivia, and Peru, in S. America; and Norway, Hungary, Russia, Transylvania, Saxony, and Spain, in Europe;—the total annual produce of the world being estimated at 4,100,000 lb. troy, of an approximate money value of £13,000,000. There are no silver-mines proper in the United Kingdom, but in 1872 there were extracted from argentiferous lead ores 628,920 ounces, valued at £157,230. As the lead smelted in 1872 amounted to 60,455 tons, this would give upwards of 10 ounces to the ton of metal.

The industrial applications of silver are numerous and important. Being too soft when pure for general use, it is invariably alloyed with copper, whether for plate, for coin, or for ornamental purposes. It also forms alloys with lead, zinc, bismuth, tin, copper, and gold; and such compounds under various names have numerous applications in the arts. It is extensively used for silvering other metals; and some of its salts, like the nitrate, are largely employed in medicine, as marking-ink, and in photography.

Sodium.

Sodium, the metallic basis of soda, was discovered by Sir Humphry Davy, by the voltaic process, in 1807. As a metal it has a bright lustre, and a white silvery colour, with a tinge of red. It is soft, and readily moulded at 60°, melts at 194°, and rises in vapour at a red heat. It is lighter than water, its specific gravity being only 0.972. It is rapidly oxidised on exposure to the air; and on being thrown on cold water floats about and quickly disappears, being converted into soda, which is dissolved in the water. When heated in the air it ignites and burns with a bright yellow flame. Sodium is now prepared on a commercial scale, and is employed in the manufacture of aluminium and magnesium, and in the silver-amalgamation process. Its affinity for oxygen prevents its occurrence in nature as *sodium;* but the compounds of *soda* are sufficiently abundant, forming rock-masses in the solid crust, occurring in the ocean and other saline waters, entering into the composition of many rocks and minerals, being present in all marine and in many land plants, and appearing likewise in the structure of the higher animals, which all instinctively swallow large quantities of its chloride.

Strontium.

Strontium, the metallic base of strontia, was procured from the carbonate (strontianite) by Sir H. Davy in 1808. It is analogous to barium, but has less lustre; is fused with difficulty, and is not volatile. When exposed to the air it attracts oxygen, and becomes converted into strontia or protoxide of strontium. Strontium is harmless, while barium and all its compounds are poisonous. It occurs in nature as a carbonate (*strontianite*) and as a sulphate (*celestite*), both of which are noticed in Chapter XIV.

Tellurium.

Tellurium, another of the rare metals, was discovered by Klaproth in 1782, and named by him after the Earth-goddess *Tellus.* It is of a tin-white brilliant colour; brittle and crystalline in texture; easily fusible; and generally found massive and disseminated along with quartz, gold, silver, antimony, arsenic, and iron pyrites, in some of the mines of Germany and Hungary—Nagyag, in Transylvania, being one of its most abundant sources. Though decidedly metallic, it has close analogies to sulphur and selenium, and is usually classed with the sulphur family. It is rarely found pure, but contains a minute percentage of gold or of iron; and the ores enumerated by mineralogists are complex and uncertain mixtures, as *graphic tellurium*, consisting of tellurium, gold, silver, and lead; *white tellurium*, of tellurium, gold, silver, and sulphur; and *black tellurium*, of copper, in addition to the preceding ingredients. Commercially, its rarity and cost exclude it from any useful application.

Terbium, &c.

Terbium, *Erbium*, *Thallium*, and *Thorium*, are rare and very little known metallic bases, derived from minerals equally rare, and of interest only to the professed mineralogist and chemical investigator.

Tin.

Tin, well known to the ancients, and employed in the manufacture of their bronzes, is a metal of a silver-white colour, slightly tinged with grey, having a peculiar taste, and an odour which may be readily recognised when held for a while in the warm hand. It is considerably harder than lead; has a specific gravity of 7.3; and fuses at 442° Fahr.—a temperature 170° below the melting-point of lead. It is very malleable when heated to about 200°, and is readily beaten into leaf or *tinfoil;* but it is not very ductile, though it may be drawn into wire of feeble tenacity. It is flexible, bending with a crackling noise, apparently the result of its crystallised texture, the fused metal crystallising in regular octohedrons. It is not found *native* (or at least very doubtfully so*); but it is obtained from *cassiterite*, pyramidal tin-ore or oxide of tin, which occurs in veins in the granitic and crystalline rocks, and in stream-drifts derived therefrom, in Cornwall, Spain, Saxony, Sweden, East India Islands, China, Australia, Peru, Bolivia, United States, Siberia, and other countries. *Stannine*, or tin pyrites, is a mixture of tin-, copper-, and iron-pyrites, in which the copper predominates, and is usually sold in Cornwall as an ore of copper.

Hitherto, the chief tin-yielding districts have been Cornwall and Devon, Saxony, Banca, Billiton, Bolivia, and Peru; but of recent years stream-drifts and veins of great richness have been discovered in Queensland and New South Wales. From reports on the stanniferous tracts of Australia it would appear that the drifts cover a wide area, and that the veins (traversing granites, porphyries, and crystalline schists) are numerous and accessible, thus promising to revolutionise entirely the commercial relations of tin and tin productions.

* The nuggets known in Cornwall as *Jews' tin*, though sometimes found at considerable depths in the soil, are clearly artificial productions, occurring for the most part in connection with charcoal, and in the neighbourhood of old smelting-houses.

Cassiterite, the only commercial ore of tin, is usually associated with wolfram, copper, iron pyrites, and other minerals. It is found either in blackish-brown pyramidal or prismatic crystals, or massive in granular aggregates, and not unfrequently in rounded fragments in gravelly *detritus*. The name *wood-tin* is given in Cornwall to the kidney-shaped masses, which have a finely fibrous or radiated structure; *toad's-eye tin* to the same variety when the concretions are small and berry-like; and *stream-tin* to the gravel-like ore found with *detritus* in the gullies and water-courses of metalliferous districts. As an ore it consists of 77.50 tin and 21.50 oxygen, with traces of iron and silica; and being disseminated through the veinstone, the rock must be pounded and washed before the ore can be smelted. As a geological generalisation, it is asserted that in Cornwall tin usually occurs in the upper portion of the veins, while copper is found below. In 1872, the tin ore raised in Britain (Cornwall and Devon) amounted to 14,266 tons, valued at £1,246,135, and the metal extracted therefrom to 9560 tons, the value of which was £1,459,990. During the same year there were imported 1024 tons of ore, and 8342 tons of tin in blocks, bars, and ingots. The islands of Billiton and Banca are said to yield about 9000 tons of metal annually; Russia, from the stream-drifts of Siberia, 1700 tons; and already Australia is producing upwards of 4000 tons!

The industrial applications of tin are numerous. As a metal it does not readily tarnish, and is therefore used for coating iron (tin-plate) and copper, for the manufacture of chemical vessels and apparatus, and for gas and water pipes. With other metals it forms valuable alloys,—with lead, *pewter;* with antimony, *Britannia metal;* with copper, in different proportions, *bronze, gun-metal, bell-metal,* &c.; with zinc, the silver-foil or *leaf-silver* of commerce; and its foil with quicksilver, the reflecting surface of glass mirrors. Its salts, dissolved in muriatic acid, are employed in dyeing and calico-printing; and its foil is largely used in packing chocolate, soap, cheese, fruit, &c., against the injurious effects of the air.

Titanium.

Titanium, so called from its falling to a calx or lime, was discovered by Gregor, in 1789, in the *menaccanite* of Cornwall. It is of a dark copper-red colour, with a strong metallic lustre, which readily tarnishes on exposure to the air. As titanic acid it is a constituent of several minerals — sphene, menekite, Brookite, rutile, and anatase. One of its most important compounds is *titaniferous iron-sand*, or *iserine*, occurring in roundish grains, generally in tertiary volcanic districts, and sometimes in such abundance as to be used for the manufacture of steel, of which it produces a very tough and superior kind. (See Iron.)

Tungsten.

Tungsten (Swed., heavy-stone) was discovered by Scheele in 1781. It is a hard brittle metal, of a light steel-grey colour and brilliant metallic lustre, having a specific gravity of 17.5. It is barely fusible at the greatest heat of the smith's forge, but when heated to redness in the open air it is converted into the peroxide (tungstic acid). Its ores, tungstates of lime, iron, and manganese, are very frequently associated with those of tin, which they greatly injure. These are *wolfram*, tungstate of iron and manganese; *stolzite*, tungstate of lead; *scheelite*, tungstate of lime; and *tungstic ochre*. The metal is not used in the arts, but tungstic acid and tungstate of soda are employed in dyeing, in the production of bronze powder, and for some other purposes. The amount of wolfram raised in Britain in 1872 was upwards of 88 tons, valued at £993.

Uranium.

Uranium was discovered by Klaproth in 1789, and so named by him after the planet Uranus, which was detected in the same year. It is obtained from several mineral species, and is, when separated, a powdery substance of a greyish-black colour, with a metallic lustre, very combustible, burning with a white light, and forming a dark-green oxide. It is reduced with great difficulty, is infusible, and has a specific gravity of 18.4. Preparations of uranium (which usually bring from 24s. to 36s. per pound) are employed in imparting fine orange tints to glass and to porcelain enamel; and the uraniate of potash affords a splendid orange to the artist. The various minerals containing uranium are in general easily distinguished by the hues of yellow they communicate to glass. The following are the principal: 1. *Uranium ore*, *pechurane*, or *pitch-blende*; 2. *Uranite*, *uran-mica*, *uran-glimmer*, or lime uranite; and 3. *Chalcolite*, or copper uranite—all derived from the older granitoid and crystalline schists.

Vanadium.

Vanadium, another of the rarer metals, of a greyish-silvery colour, was discovered by Sefström in 1830, in iron prepared from the iron ore of Taberg in Sweden, and named after *Vanadis*, a Scandinavian deity. It has since been discovered in the form of vanadianate of lead, or *vanadinite*, a mineral occurring in many localities. As a metal, the properties of vanadium are yet little known. It is regarded by modern chemists as belonging to the same series as arsenic, antimony, and bismuth.

Yttrium.

Yttrium is the metallic base of the earth yttria, which was discovered by Gadolin in 1794, in the quarries of Ytterby in Sweden. When separated from the silica, lime, iron, and manganese with which it is associated in yttria, the metal appears as a fine white powder, tasteless, inodorous, infusible, and insoluble in water. The ores of yttria are *yttro-cerite*, *yttro-tantalite*, *yttro-titanite*, &c.—all complex in composition, and occurring in the older granitic and crystalline rocks.

Zinc.

Zinc, so well known in the arts, is a metal of a bluish-white colour, with a fine granular fracture, foliated structure, specific gravity about 7, harder than lead, but may easily be cut with a knife. At common temperatures it is tough and intractable under the hammer; but when heated to between 220° and 320° it becomes malleable and ductile, so that it can be beaten into plates, or rolled into sheets and leaves, or drawn into wire. If heated, however, to 500° or so, it becomes brittle, and fuses at 770°. It tarnishes on exposure to the air; but is little oxidated, the first-formed film of oxide long resisting the action of air and water, and thus preventing further decay.

As a metal, zinc does not occur *native*, or at all events, very rarely and doubtfully—the most authentic specimens being from Victoria, in Australia. Its chief ores are—*calamine*, or the carbonate, occurring most abundantly in veins traversing thick-bedded limestones, along with calc-spar, ores of lead and iron, and other ores of zinc; *sphalerite* or *blende*, the sulphide, or "black-jack" of the miners, found also in veins in the crystalline and sedimentary rocks with other ores; *goslarite*, or the sulphate, arising apparently from the alteration of blende; *zincite*, or the red oxide; and *galmei*, or the silicious oxide, usually found in connection with calamine. The ores of zinc are readily determined by first roasting and then fusing by the blowpipe on charcoal with copper-filings. If zinc is present, the copper will be converted into a button of brass. The ores of zinc are world-wide—Germany, Belgium, Spain, and Sardinia being the main Continental repositories; Cornwall, Devon, Derbyshire, Cumberland, Shropshire, Wales, the

Isle of Man, and Ireland, the chief sources at home. In 1872, the amount of ore raised in the United Kingdom was 18,542 tons, valued at £73,951; the amount of metal produced 5191 tons, valued at £118,076; while there were imported 14,761 tons zinc ore, 32,662 tons metal, and 12,357 tons of zinc manufactures. The ores of zinc require calcination, grinding to powder, and smelting for their reduction, and the resultant metal generally contains traces of other metals, such as lead, cadmium, iron, and copper.

Zinc being a cheap and light metal, is very largely employed as a substitute for lead in architecture—roofing, spouts, tanks, &c. It is also used in galvanising iron, for ornamental castings, in galvanic batteries, in chemical laboratories, in the production of zinc-white as a pigment,* of white vitriol, or sulphate of zinc, as a mordant in dyeing and in medicine, and in the preparation of several other salts, of which the most valuable are the chromate as a pigment, and the chloride as a preservative and disinfectant. It forms various alloys—with copper, the well-known and extensively employed compound, *brass*. The Prussians, according to Wagner, make use of zinc for cartridges.

Zirconium.

Zirconium, the metallic base of the earth *zirconia*, was discovered by Klaproth in 1789, in zircons from Ceylon—zircon being a silicate of zirconia, more or less coloured by iron oxide. The metal is obtained in the form of a black scaly powder, resembling that of graphite; lustrous when rubbed; and when ignited, burning with considerable violence. It is unknown, as yet, beyond the scientific laboratory.

Such is a brief indication of the nature, position, abundance, and industrial applications of the metals and metallic ores. Depending upon the geologist and mineralogist for their discovery and description, upon the miner and mining engineer for their winning, the chemist and metallurgist for their reduction, and the fabricator and machinist for their applications, they involve at once the highest scientific skill, and widest adaptive ingenuity.

The labour and capital required at every stage of their treatment are enormous; and paramount with the Fuels, they

* From its perfect whiteness, as well as from the circumstance of its not becoming blackened by sulphuretted hydrogen, "zinc-white" is, according to Phillips ('Elements of Metallurgy'), for many purposes to be preferred to the different preparations of lead.

are undoubtedly the most important of mineral productions. Their preparations and uses are endless, running through all our implements, utensils, and machines; our shelter, defence, and modes of conveyance; our articles of ornament and luxury; our dyes, pigments, and enamels; our drugs and therapeutic appliances. Ours is essentially an age of metals and machinery. Our houses, bridges, railways, telegraphs, ships, weapons of warfare, steam-engines, and countless machines for spinning, weaving, milling, baking, brewing, printing, and the like, all more or less involve the application of the metals, and every year is marked by new uses and extensions. From the tiniest implement to the most gigantic machine, from the child's toy to the nation's armament, the metallic element runs through the whole; hence the necessity of some acquaintance with their properties, preparations, and sources.

To the Economic Geologist they hold out the strongest incentives to further research; for much as mineralogy and metallurgy have accomplished, there are still numerous substances to be examined, and new deposits to be revealed. The discovery of a new ore may change entirely the industrial aspects of a district; the cheapening of a metal by a few shillings a ton may increase its applications a hundredfold. It is his duty to be ever on the alert, allowing no substance to escape his notice, and no indication of an ore to pass without sufficient examination.

To Britain, her metalliferous products are of the utmost importance—not only employing millions of her population in their winning, smelting, and fabrication, but conferring upon her unrivalled mechanical power, and opening to her a way and a market in every region of the globe. Some idea of their magnitude and value may be gathered from the following summary of the Mineral Produce of the United Kingdom for the year 1872:—

Ores.

Iron ore,	15,586,357	tons,	valued at	£7,774,874
Copper ore,	91,983	,,	,,	443,758
Tin ore,	14,266	,,	,,	1,246,135
Lead ore,	83,968	,,	,,	1,146,155
Zinc ore,	18,542	,,	,,	73,951
Pyrites ore,	65,916	,,	,,	39,470
Manganese ore,	7,773	,,	,,	38,865
Arsenic ore,	5,171	,,	,,	17,964
Wolfram ore,	88	,,	,,	993
Chloride of barium,	65	,,	,,	130
Ochres and umbers,	3,326	,,	,,	8,227
Bismuth ore,	2	,,	,,	...
Cobalt ore,	1	,,	,,	20
				£10,790,542

Metals.

Pig-iron,	6,741,929 tons,	valued at	£18,540,504
Copper,	5,703 ,,	,,	583,232
Tin,	9,560 ,,	,,	1,459,990
Lead,	60,455 ,,	,,	1,209,115
Zinc,	5,191 ,,	,,	118,076
Silver,	628,920 ounces	,,	157,230
Other metals,	(estimated)		2,500
			£22,070,447

Salts and Earthy Minerals.

Rock-salt,	1,309,497 tons,	valued at	£654,748
Clays,	1,200,000 ,,	,,	450,000
Barytes,	9,092 ,,	,,	7,078
Fluor-spar,	80 ,,	,,	40
Coprolites,	35,000 ,,	,,	50,000
Other earthy minerals,	(estimated)		650,000
			£1,811,826

Total Mineral and Metallic Produce.

Metals, value of, as above,	£22,070,447
Coals, ,, ,,	46,311,143
Minerals, earthy, &c., ,,	1,811,826
	£70,193,416

Works which may be consulted.

Dana's 'System of Mineralogy;' Percy's 'Metallurgy;' Phillips's 'Elements of Metallurgy;' Kerl's 'Metallurgy,' translated, with additions, by Crookes and Röhrig; Wagner's 'Chemical Technology;' Knapp's 'Chemical Technology;' Ure's 'Dictionary of Arts and Manufactures;' Watt's 'Dictionary of Chemistry.'

XIX.

GENERAL SUMMARY.

Having described the relations that subsist between geology and the arts and manufactures, it may be of use to present a summary of the various mineral and metallic substances derived from the respective rock-systems. In this way the student will perceive at a glance, not only the lithological nature of the products obtained, but the comparative industrial importance of each production. It is true the lithology of the systems may differ in different localities; but generally speaking, there is considerable similarity over pretty wide areas, and the study of this summary may lead to a search for similar substances within the limits of the same formation. At all events, the outline will indicate, better than any lengthened description, the character and value of the products derived from the several systems, and in particular as developed in the British Islands.

POST-TERTIARY SYSTEM—SUPERFICIAL ACCUMULATIONS.

Silicious sands, for mortar, metal-moulding, glass-making, tempering of pottery and brick clays, and kindred purposes.

Shell-sands and shelly debris from sea-beaches, for agricultural purposes, and occasionally as a substitute for lime.

Gravels and *shingle*, for footpaths, roadways, filter-beds, and the manufacture of concretes and artificial stones.

Shore and *drift flints* (calcined and ground), for pottery admixtures.

Clays of various kinds, for the manufacture of bricks, tiles, drain-pipes, earthenware, porcelain, tobacco-pipes, and other fictile objects; for agricultural admixtures, &c.

Clays and *river-muds* of a calcareo-ferruginous character, for the manufacture of hydraulic cements.

Silicious silts and *microphytal earths*, for bath-bricks and other polishing preparations; for giving body and consistency, under the name of *kiesel-ghur*, to dynamite.

Shell and *clay marls* from lakes and old lake-sites, for agricultural purposes, top-dressings, and manurial admixtures.

Peat, for fuel and preparations of artificial fuels; charred for metal-smelting and for purification of sewage; occasionally distilled for its bituminous products, and often employed, both in the raw and charred state, as a manurial admixture.

Bogwood from peat-mosses and morasses, for ornamental purposes.

Bituminous exudatious, as naphtha, petroleum, and asphalt, largely and variously used in the arts and manufactures—lighting, cements, solvents, lubricants—and in medicine.

Ambrite from the soil of old forest-growths of the *Damnara Australis* in New Zealand.

Copal from the soil of old forest-growths of the *Plæocarpus*, &c., in Mexico and the Zanzibar coast of Africa.

Coral and *coral-stone;* some varieties for ornamental objects; others for building-stone and the preparation of lime.

Saline incrustations, and *deposits* of common salt, nitrates of soda and potash, borax, borate of lime, sal-ammoniac, &c, from brine-springs, salt-lakes, and salinas. Extensively and variously employed in the arts and manufactures, in medicine, and as top-dressings and stimulating manures.

Sulphur and *sulphur-earths*, found among volcanic ejections and in the mud discharged by *solfataras*. Largely used in the arts and manufactures—gunpowder, sulphuric acid, vulcanite, medicines, &c.

Guano, the desiccated and semi-mineralised droppings of sea-birds, found on islets in rainless regions, as Peru, and prized as one of the most energetic of manures.

Bone-breccias and *osite*, cemented masses of bones found in fissures and caverns, and occasionally as islets (Sombrero) or old upraised bone-shoals; employed in the preparation of phosphatic manures.

Metalliferous stream-drifts of sand and gravel, containing gold, platinum, tinstone, gems, and precious stones. Extensively dug, washed, and sifted in various regions for their gems and metallic treasures.

Bog-iron ore, a recent deposit in bogs and marshes, occasionally employed as a commercial source of the metal, and in the purification of gas.

Titanic iron-sand, found along many shores, and sometimes collected as an ore of iron.

TERTIARY SYSTEM.

Silicious sands, for mortar, metal-moulding, glass-making, and similar purposes.

Flint gravels, for walks, roadways, concretes, porcelain admixtures, &c.

Clays of various qualities, for the manufacture of bricks, tiles, pipes, pottery, porcelain, and other fictile purposes.

Limestones of various origins and qualities, for mortar, agricultural and other purposes.

Septaria, or argillo-calcareous nodules from the clay-beds, for the manufacture of hydraulic cements.

Gypsums of various qualities, for the manufacture of plaster-of-Paris, stuccoes, cements, and the like; also for agricultural top-dressings and admixtures.

Phosphatic nodules, or *coprolites*, collected, cleaned, crushed, and used in the preparation of phosphatic manures.

Burrstones, or calcareo-silicious deposits, extensively employed in the construction of the finest and most durable millstones.

Lignites, or *wood-coals*, of various qualities, and abundantly developed in some tertiary areas, used for fuel, for gas-making, and occasionally for the distilling of bituminous products.

Amber, a gum-resin occurring in some lignitic beds, and used in the fabrication of ornamental articles, and occasionally in the preparation of varnishes.

Clay ironstone in nodular masses, as in the Bracklesham beds of the south of England.

Magnetic iron-sand and *pisolitic iron-ore*, occasionally used for the production of the metal.

CRETACEOUS SYSTEM.

Chalk, for quicklime, mortar, cement-making, furnace-flux, whiting, agriculture, and indeed for all the purposes of ordinary limestone; also for the cheap production of carbonic acid.

Compact limestones (often indurated chalks), for building, furnace-fluxes, cements, and agricultural uses.

Septaria, or argillo-calcareous nodules, for the manufacture of hydraulic cements.

Flints, for road-material, rustic walls, gun-flints, and for glazes and admixtures in the manufacture of glass and porcelain.

Fuller's earth, for fulling woollen fabrics, and for other detergent purposes.

Phosphatic nodules, for the preparation of artificial manures.

Firestones, or soft refractory sandstones, for ovens, kilns, and smelting-furnaces.

Calcareous freestones, or ragstones, for local building purposes.

Malm-rock, a soft silicious sandstone, containing a large percentage of soluble silica, and used for the procuring of this substance.

Lignites and *bituminous coals*, occurring chiefly in foreign countries, as in the Western States of North America.

WEALDEN FORMATION.

Sands, for mortar, metal-moulding, and glass-making.

Clays, for the manufacture of bricks, tiles, and drain-pipes.

Sandstones and *flagstones* of fair quality, for building and paving purposes.

Ironstones (clay carbonate), in bands and nodules—at one time worked as an ore of iron.

Shelly marbles (Paludina, Sussex, and Petworth marble), at one time, and still occasionally, used for ornamental purposes.

Gypsum, of compact, white, and pure quality, discovered in the sub-Wealden boring of 1873-74.

OOLITIC FORMATION.

Oolitic limestones, or *calcareous freestones*, for building, decoration, mortar, agriculture, and allied uses.

Shelly freestones (Forest marble), occasionally used for ornamental purposes.

Lithographic limestone, extensively and variously employed in the art of lithography.

Flagstones and *tilestones*, for paving and roofing.

Fuller's earth, at one time very extensively, and still occasionally, employed in the fulling or deterging of woollens.

Bituminous shales, occasionally used, but with indifferent success, as fuels, and for the distillation of mineral oils.

Bituminous coals of various qualities (Yorkshire and Brora),—the most important coal-fields occurring in foreign countries (India, Indian Archipelago, Virginia, and perhaps China and Japan).

Ironstone (clay carbonate) of average quality—the English rarely exceeding 30 per cent of metallic iron.

LIAS FORMATION.

Blue clays of Lower Lias, dug along their outcrops, for brick-making.

Aluminous and *pyritous shales*, for the preparation of alum and copperas, and occasionally for the extraction of sulphur and sulphuric acid.

Argillaceous limestones, for the manufacture of hydraulic mortars and cements.

Jet, chiefly for the manufacture of personal ornaments.

Ironstones (clay carbonates), in thick beds like those of Cleveland, and yielding from 28 to 33 per cent of metallic iron.

TRIASSIC SYSTEM.

Sandstones, often of indifferent quality, for building and flagging purposes.

Shelly limestones (muschelkalks), for mortar, agriculture, and other purposes of ordinary limestone.

Gypsum and *alabaster*, the former for the manufacture of plaster-of-Paris, agriculture, &c.—the latter for ornamental purposes.

Rock-salt, used in the natural as well as in the refined state, for many purposes in the arts and manufactures, preparation of soda, earthenware-glazing, glass-making, agriculture, preservation of food, as a condiment, &c.

Brine-springs, yielding on evaporation from 4 to 7 per cent of salt, and of frequent occurrence.

Double salts of soda, potash, &c. (carnallite, polyhalite, &c.), from which are extracted salts of soda, potash, and the like—all largely made use of in the arts and manufactures.

PERMIAN SYSTEM.

Sandstones of various qualities, for building and flagging purposes.

Magnesian limestone of varied texture and composition, employed as a building-stone, as an ordinary limestone, and also for the extraction and preparation of magnesian salts, the carbonates and sulphates.

Copper-slate, a hard cupriferous slate, mined in Germany as an ore of copper.

CARBONIFEROUS SYSTEM.

Sandstones and *flagstones* of various colours, textures, and thickness, for building, flagging, millstones, grindstones, crushers, &c.

Shales, bituminous, aluminous, and *pyritous*, for the distillation of paraffin and paraffin-oils; for the preparation of alum and sulphate of iron; and for the extraction of sulphur and sulphuric acid.

Fire-clays, extensively used for the manufacture of fire-bricks, furnace and oven slabs, retorts, glass-smelting pots, sewage-pipes, and other purposes industrial and ornamental.

Limestones of various origin and quality, common and hydraulic, for mortar, cements, metal-fluxing, agricultural purposes, bleaching, tanning, &c.; and occasionally, when sufficiently crystalline and attractive in colour or figure, for marble.

Magnesian and *gypseous limestones*, found chiefly in foreign coal-fields, and used as ordinary limestones and gypsums.

Fluor-spar (blue John or Derbyshire spar), in veins and nests in the thicker-bedded limestones, and used for ornamental objects.

Barytic veins, yielding sulphate and carbonate, and used in glass-making, sugar-refining, pigment-admixture, and other purposes.

Bituminous coals and *anthracites*, in many varieties and qualities, suitable for common fuel, for coking, metal-smelting, steam-raising, gas and oil distillation, and numerous kindred purposes.

Ironstones (carbonates), in bands and nodules, known as clay-bands and black-bands—the latter containing sufficient coaly matter for its own calcination, and both often yielding upwards of 40 per cent of metallic iron.

Hæmatites, or oxides of iron, in nests and masses in carboniferous limestone (as in Furness), and often yielding upwards of 60 and 70 per cent of metallic iron.

Ochre, or the hydrated oxide of iron, resulting from the decomposition of ironstones, and largely used as a colouring material.

Metalliferous veins, or veins of lead, argentiferous lead, zinc, and antimony, in the thick-bedded carboniferous limestones.

OLD RED SANDSTONE AND DEVONIAN.

Sandstones of various colours and qualities, some of them durable, and well suited for building purposes.

Flagstones of unequalled straightness and varied thickness, for pavements, cisterns, lining-slabs, &c.

Tilestones of varied thickness and quality, for roofing purposes.

Limestones, chiefly in the Devonian strata, for building, mortars, agriculture, and also for ornamental marbles.

Barytic veins, occasionally of commercial value.

Rock-salts and *brine-springs*, as in North America.

Metalliferous veins, as hæmatite, lead, copper, silver, and doubtfully of mercury.

SILURIAN AND CAMBRIAN SYSTEMS.

Sandstones of indifferent quality, for building, for flagging, and for tilestones.

Clayey shales (outcrops of Wenlock beds), locally used for brick-making.

Limestones of various qualities, for building, mortar, fluxing, agriculture, and other purposes.

Slates of various colours and textures, of unrivalled quality for roofing, cistern-slabs, table-slabs, wall-linings, paving, enamelling for ornamental purposes, and other uses.

Barytes, sulphate and carbonate, in veins, and employed in glass-making, sugar-refining, pigment-admixtures, &c.

Apatite, or phosphate of lime, in veins, and mined for the manufacture of artificial manures.

Umber and *other ochres*, the products of decomposition, raised in considerable qualities for the preparation of pigments.

Pyrites (iron and copper), extensively raised in some localities for the manufacture of sulphur and sulphuric acid, copper being often recovered from the waste residue.

Metalliferous veins, often of vast richness and value, as gold, platinum, silver, mercury, copper, tin, lead, iron, manganese, and other metals.

LAURENTIAN AND METAMORPHIC.

Slates of various colours and qualities, for roofing, cisterns, table-slabs, wall-linings, paving, and similar purposes.

Limestones and *marbles*, used as ordinary limestones, but usually for ornamental purposes.

Quartzites, for grinding and crushing purposes.

Serpentines of various colours, employed in architectural decorations and ornament.

Asbestos, in veins, for steam-packing, lamp-wicks, gas-grates, and other fire-resisting purposes.

Meerschaum, in veins, for the manufacture of tobacco-pipes, &c.

Steatite, or *potstone*, for furnace-hearths, oven-soles, pipkins, and other refractory uses.

Magnesite, in veins and stratiform masses, for the extraction of magnesia, and the preparation of its salts.

Apatite, in veins, employed in the preparation of phosphatic manures.

Cryolite, in veins, used as an ore of aluminium.

Graphite, in nests and veins, extensively employed in the manufacture of writing-pencils, crucibles, &c., and as a polisher and lubricant in metal-working and machinery.

Umber and *other ochres*, in veins, for the manufacture of pigments.

Gems and *precious stones*, as accessory minerals in schists, and occurring in fissures, veins, and drusy cavities — rock-crystal, topaz, ruby, emerald, beryl, tourmaline, lapis lazuli, garnets, &c.

Metalliferous veins, yielding gold, platinum, silver, mercury, copper, tin, lead, zinc, antimony, cobalt, iron, manganese, and other useful metals.

VOLCANIC ROCKS.

Lavas of various colours and textures, for building, road-material, milling and crushing stones, &c.

Pumice, in blocks or powder, as a cheap and efficient reducing and polishing substance.

Obsidian, or *volcanic glass*, used by primitive people for cutting implements, spear and arrow heads, and the like.

Pozzuolana and *trass*, varieties of volcanic ash, used in the manufacture of Roman or hard-setting hydraulic cement.

Sulphur and *sulphur-earths*, for the extraction of sulphur, and used in the manufacture of gunpowder, sulphuric acid, and numerous other industrial and medicinal purposes.

Borax and *sal-ammoniac*, found in volcanic areas, and products of thermal action; used variously in the arts and in medicine.

Gems and *precious stones*, occurring as accessory minerals in volcanic systems—agate, calcedony, olivine, spinelle, vesuvianite, &c., &c.

TRAP-ROCKS.

Basalts and *greenstones*, for building-stones, causeway-courses, kerbstones, road-metal, and similar uses.

Felstones and *porphyries*, for building, causewaying, macadamising; and the latter occasionally for ornamental purposes.

Leckstones, or granular trap-tuffs, for oven-soles, furnace-hearths, and similar uses.

Precious stones, in geodes and drusy cavities, as rock-crystals, agate, carnelian, calcedony, jasper, olivine, &c.

GRANITIC ROCKS.

Granites and *porphyritic stones*, for building, for decoration, monumental monoliths, causeway-courses, kerbstones, road-metal, and kindred uses.

Granite blocks, for grinding and crushing purposes.

Felspathic or *decomposing granites* (Cornish stone), as an ingredient in porcelain manufacture.

Syenites and *syenitic granites*, less abundant, but employed for similar purposes as the ordinary granites.

Precious stones, as accessory minerals occurring in granite rocks — rock-crystal, amethyst, cairngorm, topaz, tourmaline, beryl, emerald, garnet, &c.

Such is a brief summary of the economic products usually obtained from the respective geological systems, and especially as developed in the British Islands. Lithologically speaking, the strata of a system may vary considerably at different parts of its development, and in distant countries may be still more dissimilar. Notwithstanding these variations, which must ever be incidental to sedimentary deposits, there is always a certain amount of resemblance, and it is this resemblance which should lead to a search for the same products in the same chronological system. Take, for example, the Trias of England and the Trias of Germany. Although the muschelkalk of the latter has no equivalent in the former, yet the other members of the system—sandstones, rock-salts, gypsums, and saliferous marls — are sufficiently alike to furnish the same kind of industrial products. Or take the coal-formations of Wales or of Nova Scotia. Although the limestones of the former be carbonates, and those of the latter magnesian and gypseous, yet all the other beds—sandstones, shales, fire-clays, coals, and ironstones—are so similar, that those from the one field might be mistaken for those from the other. The resemblance, or rather identity, of the unstratified or pyrogenous rocks is still more striking. The granites and syenites of Egypt and Norway, the basalts and greenstones of Scotland and Germany, and the lavas and tufas of Italy and the Sandwich Islands, are all but identical in composition; and the products obtained from any one of these groups in one region, may be sought for, with all but absolute certainty, in another. It is in this way that a systematic summary of economic substances becomes of use to the practical geologist; for whether surveying at home or abroad, he may naturally expect to find in the respective systems a certain similarity of available products. Not that there are not wide exceptions to this rule —the cretaceous system of England and the cretaceous system of North America, for example—but because it is useful to know that certain substances are characteristic of certain formations, where these formations are fully and typically developed.

The practical geologist should have a higher aim, however, than merely searching for substances already known, and on which the arts and manufactures have stamped a certain value. This is of itself good and commendable, and will bring with it its own reward; but he should at the same time endeavour to extend our knowledge by noting every rock, mineral, and ore that comes under his observation, examining its nature, and, in conjunction with the technologist, trying to discover in what way and how far it can be rendered available to the arts and industries. The utilisation within recent years, for instance, of the ironstones of Cleveland, the oil-shales of Scotland, and the phosphatic nodules of the greensand, with all the commercial and social consequences that have flowed and are flowing from them, are things which hold out the incentive to the careful inquirer of discoveries equally novel and equally remunerative. It is true the theoretic or scientific aspects of geology are replete with interest and attraction, and to many these form the bourne and boundary of their investigations; but it need not be necessarily so, for its practical or economic aspects are, though in another way, equally interesting and important. To trace the history of our planet through all her former aspects and mutations, is no doubt a high and inspiring theme; but science is never more exalted than when, following her legitimate functions, she stoops to administer to the wants of our common humanity. Whatever tends to increase man's mastery over the forces of nature extends his domain; whatever improves the physical conditions of human life, lengthens the lever of its intellectual and moral advancement; and thus the discovery of a new economic product is as important in its own way as the solution of a scientific problem. The scientific problem may interest only a few, and affect others remotely; the new product is a direct contribution to the general wealth and wellbeing of society.

But while this cannot be gainsaid, the student, as he values his own intellectual life and growth, should never forget that the discovery of scientific truths stands on a higher platform than mere invention, or the application of these truths to industrial requirements. Both are good and necessary, and cannot be ignored; but without discovery invention is helpless. The one creates, the other only adapts. Commercially speaking, invention may bring rewards which discovery cannot supply; but without discovery invention would soon languish in hopeless stagnation. The one is the spirit of progress, the other merely the bodily members which that spirit animates and controls.

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THE END.

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