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NEW-YORK

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THE GEOLOGICAL RECORD.

a represents the order of deposition of the various systems of the stratified rocks; *b* the same systems inclined at an angle, and illustrating the manner in which the lower and older systems have been brought by disturbance to the surface and made accessible.—*See Page* 174, §179.

E. B. Walsworth

WELLS'S

FIRST PRINCIPLES

OF

GEOLOGY.

A TEXT-BOOK

FOR SCHOOLS, ACADEMIES AND COLLEGES.

WITH OVER TWO HUNDRED ILLUSTRATIONS.

BY

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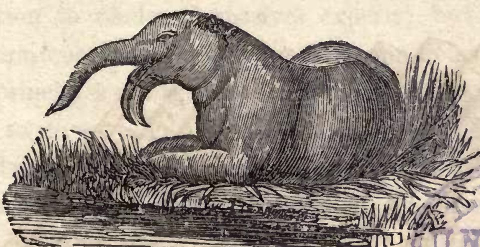

NEW YORK:
IVISON, PHINNEY, BLAKEMAN & CO.,
CHICAGO: S. C. GRIGGS & CO.

1864.

PREFACE.

THE design of the present work is to furnish a text-book on Geology, adapted to the limited time allotted to the study of this department of science in the majority of high-schools, academies, and colleges.

Intimately connected as Geology is with the great industrial interests of the country—especially with mining and agriculture—and constituting also an important member of the circle of the sciences, its place as an element in an English educational course is daily becoming more and more recognized. At the same time, the general educational requirement is, not for minute, detailed instruction (since comparatively few students have either the time or inclination to render themselves experts), but rather for the communication of such general, comprehensive views of the principles of Geology as shall prove most practically useful to those who propose to engage in other than scientific pursuits. With this view, the Author, in the present work, has endeavored to avoid that elaborate discussion of facts and theories, and that excessive use of technical terms which render some learned text-books so repulsively dry and wearisome to beginners ; but, on the contrary, without sacrificing scientific exactness and completeness, has aimed to interest, as the most efficient way to instruct.

In the preparation of the work, the author lays no claim to originality; but he has drawn from a multitude of sources such material—statements and illustrations—as has seemed most desirable for presentation to beginners. To the elementary treatises of Page and Jukes, (which at present hold the first place as elementary text-books on geology in Great Britain), he is, however, especially indebted for many suggestions. Great pains have also been taken to render the work in every respect correct, and in full accordance with the very latest results of scientific research.

In conformity with the general sentiment of teachers, questions have been appended to the text. It is suggested, however, that the student be not required to commit to memory any part of the text *verbatim*, but rather that he should make himself fully acquainted with the subject generally.

For further hints and suggestions relative to the study of Geology, reference is made to the Appendix.

FEBRUARY, 1861.

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FIRST PRINCIPLES OF GEOLOGY.

INTRODUCTORY OUTLINE.

1. **Geology** (from the Greek *γη*, the earth, and *λογος*, discourse) is that department of natural science which treats of the structure and mineral constitution of the earth ; the successive changes which have taken place in the organic and inorganic kingdoms of nature, and the agencies by which such changes have been effected.*

2. The science of geology admits of division into several departments, or sub-sciences, which are somewhat arbitrarily varied by different writers. The divisions, however, most generally recognized and adopted for convenience of study or reference, are as follows :—

(1.) **Descriptive, or Phenomenal Geology,** which treats of the appearance, arrangement, and physical condition of the materials constituting the earth's structure. It embraces, to some extent, the same topics as Physical Geography.

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* "It is not easy to give an accurate and comprehensive definition of the science of geology. It is, indeed, not so much one science, as the application of all the physical sciences to the examination of the structure of the earth, the investigation of the processes concerned in the production of that structure, and the history of their action. That this large view of geology is not only a true but a necessary one, is shown by the fact, that it was not until considerable advances had been made in all the physical sciences which relate directly to the earth, that geology could begin to exist in any worthy form. It was not until the chemist was able to explain the nature of the mineral substances of which rocks are composed ; not till the geographer and meteorologist had explored the surface of the earth, and taught us the extent of land and water, and the powers of winds, currents, rains, glaciers, earthquakes and volcanoes ; not until the naturalist had classified, named, and described the greater part of existing animals and plants, and explained their anatomical structure, and the laws of their distribution in space ;—that the geologist could, with any chance of arriving at sure and definite results, commence his researches into the structure and composition of rocks and the causes which produced them, or utilize his discoveries of the remains of animals and plants that are inclosed in them. He could not until then discriminate with certainty between igneous and aqueous rocks, between living and extinct animals, and was, therefore, unable to lay down any one of the foundations on which his own science was to rest."—*Encyclopedia Britannica*, 8*th edition*, *vol.* xv.

(2.) **Dynamical or Physical Geology**, which considers the nature, action and origin of the forces or agencies by which the structure of the earth has been changed and modified.

(3.) **Paleontology** (from *παλαιος*, ancient, *οντα*, beings, and *λογος*, discourse) or **Organic Geology**, which restricts itself exclusively to a consideration of the remains of animals and plants found imbedded in the rocky structure of the earth—their organization and relations to tho races now living, and the laws which have regulated the distribution of life, both in space and time, upon the surface of our planet.

(4.) **Practical, or Economical Geology**, which treats of the applications of geological science to industrial or economic purposes, such as agriculture, architecture, civil engineering, mining, etc.

3. Geology at one period was regarded as a branch of mineralogy, but the connection of the two sciences extends only so far as the latter classifies and characterizes a large portion of the objects employed by geology as evidence of its statements.

Mineralogy may be defined to be that branch of natural science which treats of the forms, properties, chemical composition and distribution of the mineral substances that enter into the constitution of the earth.

All terrestrial matter that is not animal or vegetable, including air and water, is regarded as mineral.

CHAPTER I.

GENERAL RELATIONS, STRUCTURE, AND CONSTITUTION OF THE EARTH.

4. **Planetary Relations.**—The earth is one of the planetary bodies constituting the solar system, and performs an annual revolution about the sun, at a mean distance of 95,000,000 miles, in an orbit varying a little from that of a circle. It also completes a revolution daily, upon an axis, which is inclined 23°, 27′ to the plane of its orbit.

QUESTIONS.—Define geology? What general divisions of the subject are recognized? Define mineralogy? What proportion of terrestrial matter may be regarded as mineral?

A connection between the planetary relations of the earth and its external geological structure may not at first be readily apparent, but a brief consideration of a few facts will render this evident. For example, the distribution of light and heat and the alternation of seasons are entirely dependent upon the distance of the earth from the sun, upon the earth's periodic motions, and upon the inclination of its axis of rotation; and any change in these conditions would occasion a change in all meteorological agencies and phenomena, and consequently affect the distribution or even continuance of animal and vegetable life; furthermore, a change in the position of the earth's axis of rotation would necessarily involve a change in the entire surface configuration of the globe, inasmuch as the present distribution of land and sea would be altered, as well as the course of all rivers and the influence of the tides. In fact, it has been assumed by some authorities that changes of this character must be admitted, in order to account satisfactorily for the convulsions which geology demonstrates to have taken place in past ages upon the surface of our planet.*

5. **Figure of the Earth.**—The form of the earth is that of a sphere, flattened at the poles—technically, an oblate spheroid.

Measured from north to south—that is, from pole to pole—the diameter of the earth is 7899·1 miles; while, measured from east and west through the equator, the diameter is 7925·6 miles. The equatorial diameter thus exceeds the polar 26·5 miles, thereby giving to each hemisphere a compression of 13¼ miles. This difference in diametrical measurement is more than four times the height (29,000 feet) of the loftiest mountain upon the surface of the earth.

The form under which atoms of matter group themselves, in obedience to the law of their mutual attraction, and uninfluenced by any other force, is always that of a sphere; and such must have been the shape assumed by the

QUESTIONS.—Is there any connection between the planetary relations of the earth and its geological structure? What is the figure of the earth? What its dimensions? Under what circumstances will atoms of matter group themselves in the form of a sphere?

* The dependence of the tides, which are among the most permanent and important agents concerned in producing geological changes, upon the attractive force of the sun and moon is universally admitted; but the fact that all "water-power" (in the ordinary acceptation of the term) upon the earth's surface is, equally with the tides, the result of an extra terrestrial influence, is not so generally recognized. This will, however, be obvious, if we consider that the momentum, or power acquired by water in falling from a higher to a lower level through the action of gravity, is the exact measure of a force which originally lifted the water to the elevation from whence it falls, and that this primary lifting power is heat;—heat derived from the sun, which, in lines of invisible force, draws up the water as vapor from the surface of the sea to the height where, through condensation, it becomes specifically heavier than the atmosphere, and descends as rain, rivulets, water-falls, and rivers to its original location. "All the rivers run into the sea, yet is not the sea full; unto the place whence the rivers come thither they return again."

Numerous other facts of like character might be adduced illustrative of the extent to which a connection can be traced, either directly or indirectly, between the planetary relations of the earth and its external geological structure.

earth at the beginning, supposing its mass to have consisted of yielding, semi-fluid materials, and provided it remained at rest upon its axis. The moment, however, that rotation upon an axis commenced, its form must have changed from that of a sphere to a spheroid, in virtue of the centrifugal force generated, which exerts itself at right angles to the axis of rotation, and in proportion to the distance from that axis;—thereby producing a bulging of the earth's mass at that part of its surface where the distance from the axis is greatest, *i. e.*, at the equator.*

Although we may not be able to affirm positively that the entire earth ever was in a plastic or semi-fluid condition, yet, in connection with certain geological speculations, it is interesting to know that its figure is such as would necessarily arise from the rotation of a yielding mass around its own axis.

6. **Density of the Earth.**—The mean density of the earth is at least five times that of water† (or about one half that of silver); but the actual mean density of the rocky substances most common on its surface is not more than half as great, or about 2·5. Hence the density of the earth increases from the surface toward the center.

These facts have induced a supposition that the earth, in its interior, must be composed of materials differing in composition or condition from those which make up its external structure; since, with a correspondence throughout of composition, and the law of gravitation acting uniformly toward the

QUESTIONS.—Under what influences will a sphere become a spheroid? What is the density of the earth?

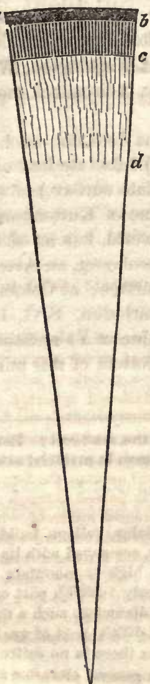
* An experiment strikingly illustrative of these facts may be performed as follows: oil will float upon the surface of water, but will sink to the bottom of strong alcohol; if, therefore, we take a portion of alcohol in a glass and drop into it a globule of olive oil, the spirit will float above, and the oil will assume the form of a flattened spheroid. If now we add a little water and mix it carefully with the spirit, without breaking the floating mass of oil, it will be seen to swim higher and present less flatness, and by continuing to carefully add water until the mixture and the oil correspond in specific gravity, we may at last bring the globule to the very center of the fluid, where, it will assume the form of a perfect sphere. If, under these circumstances, a slender wire is passed through the center of the oil globule and rotated, we have immediately a flattened spheroid, which will become more so as we increase the speed of rotation, until it spreads out into a sheet of oil, still held by the revolving wire. If the rate of revolution is still further increased, we have a very remarkable result—a ring of oil separates from the rest, which, although there is no apparent connection between it and its center, still moves at a uniform rate with it; thus giving a miniature representation of the phenomenon of the ring of Saturn.

† Distilled water, at a temperature of 60° Fahrenheit, is adopted as the standard of comparison.

The density of the earth is obtained by comparing the relative attracting power of particular mountains, or smaller masses of matter, with that of the whole globe, and by comparing the oscillations of a pendulum at the surface of the earth, with those of an equal pendulum at a depth below the surface, as in a mine. In this last case, the difference of the rates of the two pendulums would indicate the different force of gravitation at the two positions; and hence the density of the earth.

center, the density of all ordinary rocks, at a very inconsiderable depth, would, through compression, become so great as to give a mean density to the earth far exceeding that which its astronomical relations will admit of. Thus, for example, it has been calculated that air at a depth of thirty-four miles from the surface would become as heavy as water; water, at three hundred and sixty-two miles, as heavy as mercury; and that the density of limestone (marble) at the center of the earth would be one hundred and nineteen times greater than it is at the surface, with but one eighth of its ordinary bulk. To reconcile, therefore, the actual mean density of the earth with the action of the forces of attraction and gravitation, it has been suggested that the condensation of the central mass of the globe must be counteracted by some expansive influence, such as heat, or that it may consist of matter as attenuated as the lightest known gases. The *appreciable*, or *ponderable* crust of the earth, however, calculating from the astronomical phenomena of precession and nutation, can not be less than a fourth or fifth of the earth's radius; that is, it can not be much less than eight hundred miles.

FIG. 1.



7. **Crust of the Earth.**—In ordinary geological language, the expression "crust of the earth" is understood to refer to that portion only of the exterior of our planet which is accessible to human observation, or concerning which we are able to reason conclusively from observations made at or near the surface.

The thickness of such a superficial film or envelop is estimated by Lyell to be about ten miles, or $\frac{1}{400}$th part of the distance from the surface of the earth to the center. Other authorities, however, have supposed that we can, by the aid of geology, see as it were into the interior of the earth, as far as twenty or even thirty miles. In Fig. 1, a section of the earth, *a b*, approximately represents the superficial rock crust, and *a d* the appreciable or ponderable portion (required by astronomical calculations) which envelops the unknown interior.

8. **Surface Configuration.**—The surface configuration of the earth, as well

QUESTIONS.—What inferences have been drawn from the density of the earth? What is understood by the crust of the earth? What is the estimated thickness of the crust? What is the surface configuration of the earth?

beneath the ocean as on the dry land, is extremely irregular, being elevated into ridges and mountain chains, with intervening plains and valleys.

The mean height of all the solid parts of the earth's surface above the sea-level has been estimated by Humboldt at about 1,000 feet; that of all Europe, 671 feet; Asia, 1,132 feet; South America, 1,151 feet; North America, 748 feet.

The highest known mountains on the globe are Mounts Everest and Kunchinjinga, of the Himalaya Range, Central Asia, which attain an elevation respectively of 29,002 and 28,156 feet above the sea-level. The loftiest mountain in South America is Tupungato, one of the Chilean Andes (22,456 feet); in North America, Mount St. Elias, one of the Rocky Mountains, 17,900 feet, and Popocatepetl, Mexico (17,884 feet); in Europe, Mont Blanc (15,760 feet). The highest peaks of the Alleghany or Appalachian range, which extends throughout the Atlantic slope of the United States, are Clingman's Peak, Black mountains, N. C. (6,760 feet); Mount Washington, White mountains, N. H. (6,285 feet); Tahawas, or Mount Marcy, Adirondack mountains, N. Y. (5,467 feet).*

The greatest depth yet reached by man in excavations does not much exceed 2,000 feet (about one-third of a geographical mile) *below the level of the sea.* The absolute depth (*i. e.*, depth below the immediate surface,) of some excavations is, however, much greater. Thus, the mine of Kuttenburg, in Bohemia, which is believed to be the deepest in the world, has an *absolute* depth of 3,778 feet. At Mondorff, in the Duchy of Luxembourg, an Artesian well has been bored to a depth of 2,400 feet below the surface; at Columbus, Ohio, 2,340 feet; at Louisville, Ky., 2,086 feet; at Charleston, S. C., 1,145 feet. The deepest mine in America, viz.: the silver mine of Valenciana, in Mexico, has an absolute depth of 1,686 feet; but the bottom of this mine is more than 5,000 feet above the sea-level.

QUESTIONS.—What is the mean elevation of its surface above the sea-level? Enumerate the highest mountains? What depth has been reached by man in artificial excavations?

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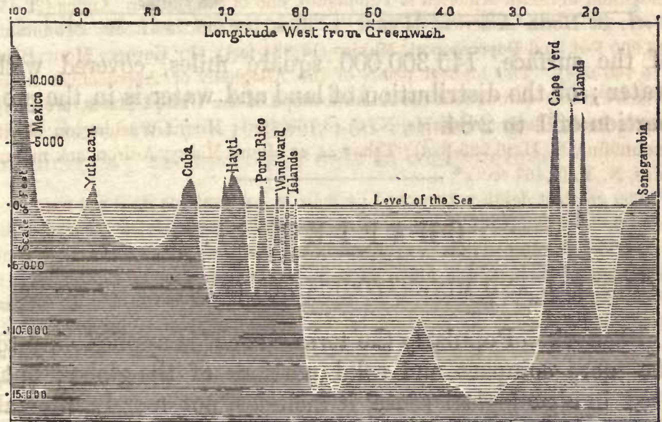
* "The inequalities on the earth's surface, arising from mountains, valleys, buildings etc., have been likened to the roughness on the rind of an orange, compared with its general mass; and the comparison is free from exaggeration. The highest mountain does not much exceed five miles in perpendicular elevation; this is only 1-1600th part of the earth's diameter. Consequently, on a globe of sixteen inches in diameter, such a mountain would be represented by a protuberance of not more than 1-100th part of an inch, which is about the thickness of ordinary drawing paper. Now, as there is no entire continent, or even any very extensive tract of land, known where the general elevation above the sea is any thing like half this quantity, it follows, that if we would construct a correct model of our earth, with its seas, continents, and mountains, on a globe sixteen inches in diameter, the whole of the land, with the exception of a few prominent points and ridges, must be compressed within the thickness of thin writing-paper, and the highest hill would be represented by the smallest visible grain of sand."—*Sir John Herschel.*

The depth of the sea has been generally supposed to correspond with the height of the land. Soundings, however, showing enormous depressions of the ocean-bed, at various points, have been reported, viz.: 49,800, 46,236, and 39,600 feet; but the accuracy of them is questionable. According to Commander Maury, the average depth of the Atlantic, for a distance of seventy-five to one hundred miles from the coasts of continents, is less than 6,000 feet: for a further distance of from 200 to 300 miles, the depth varies from 6,000 to 12,000 feet.

Fig. 2, designed by Com. Maury, U. S. N., represents the bed of the Atlantic ocean, as indicated by recent soundings and surveys, in a line extend-

FIG. 2.



ing southeasterly from Mexico to Africa. It is drawn to a scale, and represents the elevation of the land above the level of the sea, as well as the depth to which the ocean sinks below it.

While the great lakes of North America are elevated (one of them, Lake Superior, 596 feet) above the ocean, some of the inland seas of Asia are remarkably depressed below its level. Thus, the surface of the Caspian Sea is eighty-three and a half feet below the level of the Black Sea; that of the Lake of Tiberias, 466 feet below the Mediterranean; while the surface of the Dead Sea is 1,388 feet below the same, with a depth of water, in some places, of 300 fathoms (1,800 feet). Fig. 3 represents the respective levels of the Mediterranean and Dead Sea, with that of the adjacent country.

9. Distribution of Land and Water.—The surface of the earth has been estimated to contain about 196,800,000

QUESTION.—What is known respecting the depth of the sea? What is said of the elevation and depression of the beds of lakes? What is the area of the earth's surface square miles. Of this area the dry land is supposed to occupy about 51,500,000 square miles, leaving the remainder

FIG. 3.

of the surface, 145,300,000 square miles, covered with water; or the distribution of land and water is in the proportion of 1 to 2·84.

CHAPTER II.

CHEMICAL AND MINERALOGICAL COMPOSITION OF ROCKS.

10. **Rock.**—Popularly the term "*rock*" is applied only to the more compact and solid portions of the globe; but, used in a geological sense, it includes, not merely mineral masses which are hard and consolidated, as granite, limestone, etc., but also all natural accumulations of looser and less coherent materials, such as beds of sand, clay, gravel, etc.

11. **Chemical Composition of Rocks.**—Chemistry has established the existence of sixty-two* distinct forms or modifications of matter, each of which must, in relation to the present state of our knowledge, be considered as a "simple," or "elementary" substance.† Of these, but

QUESTIONS.—What is said of the distribution of land and water? In what sense does the geologist use the term rock? What is the number of the recognized elements?

* Sixty-five, according to some authorities.

† The term "*un*decomposed," in place of "elementary," better conveys the idea entertained by modern chemists in respect to these substances.

comparatively few enter into the composition of the crust of the globe, while many are so exceedingly rare that they are known only to chemists.

The names of the elementary substances which constitute the great mass of all the rocks, consolidated or unconsolidated, which are accessible to man, are as follows :—

12. **Non-Metallic Elements.** — OXYGEN, HYDROGEN, CHLORINE, CARBON, SULPHUR, PHOSPHORUS, and SILICON—7.

Metals of the Alkalies and Earths.—POTASSIUM, SODIUM, CALCIUM, MAGNESIUM, and ALUMINUM—5.

Metals Proper.—IRON and MANGANESE—2. Total 14.

Of these, two only, carbon and sulphur, are found pure as minerals ; the rest occur only in combination.

Oxygen is the most abundant of all the elementary substances. It constitutes at least one third part of the solid crust of the globe, and eight-ninths, by weight, of all the water upon its surface.*

Hydrogen, as a constituent of water, enters into the composition of many minerals and mineral strata, and forms part of almost every organic substance. *Chlorine* is abundantly present in common salt (chloride of sodium) of which it forms nearly seven-twelfths by weight: it also occurs in many other combinations.

Carbon is found pure in the diamond; is the chief constituent of all varieties of coal and of graphite (plumbago, black-lead), and, as an element of carbonic acid, forms nearly one-eighth part of carbonate of lime, (ordinary limestone and marble).

Sulphur occurs native as a volcanic product, and, in combination with a large number of metals, forming sulphurets (sulphides); in an oxydized condition, as sulphuric acid, it is still more widely diffused in combination with various earths, as the sulphates of lime, magnesia, baryta, etc. Nearly one third of the weight of sulphate of lime (gypsum, or plaster of Paris) is sulphur. *Phosphorus* exists in small quantities, but widely diffused, in the mineral kingdom, principally in combination with lime.

Silicon, in combination with oxygen forming silica, or silicic acid, is the

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QUESTIONS.—How many constitute the great mass of the rocks? Enumerate them?

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* One point in this connection is especially worthy of notice, as bearing on the important question of the former condition of our globe, namely, that about one half of all the ponderable matter of the earth's crust, taking into consideration oxygen, hydrogen, and carbonic acid, is capable of existing, or may be said to exist naturally, in a gaseous condition.

most abundant of all *solid* substances, and has been estimated to form forty-five per cent. of all the ponderable matter of the globe.

Aluminum, the metallic base of the earth alumina, is the characteristic constituent of all clays, and is also present in almost all other rocks. Alumina has been estimated to form ten per cent. of the crust of the globe.

Potassium, *sodium*, and *magnesium*, the metallic bases from whence are derived the salts of potash, soda, and magnesia, are also very widely disseminated. *Sodium*, united with chlorine, forms common salt; and magnesia, beside constituting an important part of some rocks, is an abundant constituent of sea-water.

Calcium, in combination with oxygen, forms the well-known mineral *lime*, which, in turn, united with carbonic acid, as carbonate of lime (ordinary limestone, marble), is estimated to constitute one seventh of the crust of the globe. Lime and magnesia are also diffused almost universally throughout the silicious rocks, in the form of silicates of lime and magnesia.

Of the metals, commonly so called, *iron* and *manganese* are the most widely diffused (as oxyds); and the former has been calculated to form at least two per cent. of the crust of the globe.

In addition to the above-named elementary substances, *fluorine*, *iodine*, *gold*, *arsenic*, and *titanium* may also be mentioned as having a very general distribution, but in very minute quantities.

13. **General Mineralogical Composition of Rocks.**— Nearly all the minerals which make up the great rock-masses constituting the crust of the globe have resulted from the chemical combination of two or more of the above enumerated simple substances. Most of the common minerals, furthermore, may be characterized as being either *silicious* or *calcareous*.

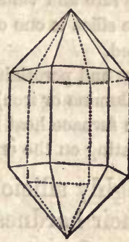
14. **Silicious Minerals** are those in which silica (silex, or silicic acid) predominates.

This substance, as a constituent of rocks, occurs under two forms, viz., as a pure or simple mineral, and as an acid united to mineral bases. When pure, or merely colored by small quantities of different metallic oxyds, it is generally termed "*quartz*," and as such occurs in amorphous, massive rock-masses, or veins—*common quartz*, and in crystals—*crystallized quartz*. The prevalent color of common quartz is white—often milk-white or gray; when pure, or nearly so, it is translucent, with a vitreous or glassy luster. It may have, however, almost every shade of color, and even a granular texture.

QUESTIONS.—What is said of their distribution and combinations? What is the general mineralogical composition of rocks? What minerals are termed silicious? What are the principal forms of silica?

Crystallized quartz, when transparent and colorless, is termed *rock-crystal.* The fundamental form of quartz crystals is a regular six-sided prism, terminated by six-sided pyramids; (See Fig. 4.) perfect specimens of this form, however, are rare, and the crystals usually met with are modifications of it. *Amethyst* is quartz colored purple by the presence of oxyd of manganese. *Agate* is a general name given to a semi-pellucid, uncrystallized variety of quartz, presenting various tints in the same specimen, the colors being delicately arranged in stripes or bands, or blended in clouds. When the colors and bands are not very numerous, but are arranged in flat, horizontal layers, the specimen is termed an *Onyx;* and when the colors are mixed irregularly, they are called "*Moss-agates.*" Agate of a pearly or smoky-gray color, is called *Chalcedony;* and specimens presenting a blood-red color, either uniformly distributed or in patches, are termed *carnelians,* and are much used in the less expensive kinds of jewelery. *Jasper* is the name given to highly compact, opaque varieties of quartz colored by iron; they admit of a high polish, and often present zones, or bands of color like agates. *Flint* is a massive, compact variety of Silica, of a gray, brown, or black color: its fracture is conchoidal, and it is often found in masses of grotesque and irregular shape. *Buhrstone* (mill-stone) is a variety of cellular flint, well adapted for grinding. *Opal, crysoprase,* and *bloodstone,* are other varieties of nearly pure silica. *Common sand* is usually composed of grains of silica; its ordinary yellow or brown color being due to the presence of oxyd of iron, or of organic matter. *Sandstone* is an aggregate of such grains cemented into a coherent mass.

FIG. 4



When silica plays the part of an acid and unites with other minerals, the resulting compounds are termed *silicates.* If we except carbonate and sulphate of lime, carbonate of magnesia, quartz, and coal, nearly all the mineral constituents of the great rock-masses of the globe are silicates.

Pure clay is a hydrated* silicate of alumina, but as commonly found, (common clay), it contains in addition variable proportions of silica (sand), iron, lime, magnesia, carbon, and the alkalies.

Any very finely divided mineral matter, however, which contains from ten to thirty per cent. of alumina, and is consequently "plastic," or capable of retaining its shape on being molded or pressed, would be usually called clay.

Rocks and minerals which contain a notable percentage of alumina or clay

QUESTIONS.—What are silicates? What is the composition of clay?

* Hydrated—containing a proportion of water in chemical combination.

emit, when breathed upon, a peculiar and distinctive odor (argillaceous odor), which is easily recognized.

Clays which are nearly free from oxyd of iron, carbonate of lime, or the alkalies, are termed "fire-clays," and being almost infusible, are used for the manufacture of fire-bricks, crucibles, etc. Such clays, however, are comparatively rare and valuable.

Pure silica is one of the most infusible substances with which we are acquainted.

Glass and porcelain are examples of *artificial silicates* (*i. e.*, of potassa, soda, lime, alumina or iron); but for the production of these compounds the most intense furnace heat is requisite, a fact which it is well to bear in mind when speculating on the origin and formation of certain rocks.

Highly silicious rocks and minerals may be recognized by their hardness, infusibility, and insolubility in ordinary acids. Quartz strikes fire with steel, is not scratched with a knife, but readily scratches glass and most other substances, except a few gems.

15. **Calcareous Minerals** are those in which lime predominates.

As a constituent of mineral masses, lime generally occurs, united with carbonic acid, as a *carbonate*, and in this condition it exhibits a great diversity of structure and appearance. The principal modifications of carbonate of lime, however, are the following: *chalk; earthy*, *granular*, *compact*, and *concretionary limestones; crystalline limestones*, or *crystalline marbles*, and *calcareous marls.* Carbonate of lime is also the principal constituent of the hard parts of corals, shells, etc., and consequently of the rock-masses formed of the remains of these organisms.

Any rock which contains at least half its weight of carbonate of lime may be properly termed a *limestone;* and the presence of other mineral matters commingled with the carbonate of lime is generally indicated by giving to the limestone a distinctive name. Thus, we have argillaceous (clayey) limestone; silicious; magnesian (containing magnesia); ferruginous (containing iron); bituminous; or, from the presence and decomposition of organic matter, *fetid* limestone.

The term *marble* is applied to those varieties of compact and crystalline limestones which are capable of being worked in all directions, and also of taking a good polish. It is an architectural rather than a geological term.

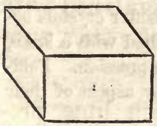
QUESTIONS.—What characteristic have aluminous rocks and minerals? When are clays available for fire-clays? What are examples of artificial silicates? What are the characteristic properties of highly silicious rocks? When are rocks and minerals termed calcareous? In what condition is lime found most abundantly? What are the principal modifications of carbonate of lime? When may a rock be termed limestone? What is marble?

Limestones which contain twenty per cent. and upward of carbonate of magnesia are called *magnesian limestones;* granular and crystalline varieties of magnesian limestone are termed *Dolomite* (from an eminent French geologist, Dolomieu).

Oolite (Gr. ωον, an egg, and λιθος, a stone) is the name applied to limestones made up more or less completely of small rounded particles like the eggs or roe of a fish (whence the name).*

Limestones, especially the marbles, exhibit every variety and shade of color—the coloring agents being, for the most part, metallic oxyds, and especially the oxyd of iron. Black limestones and marbles, however, owe their color, in great part, to the presence of carbonaceous matter, derived from the decomposition of animal or vegetable matter originally contained in the rock: when subjected to intense heat they become white.

FIG. 5.



Carbonate of lime is found in a greater variety of crystalline forms than any other known substance. Its primary form is a rhombohedron, as seen in "double refracting," or "Iceland spar"† (see Fig. 5); but of this figure over 650 modifications are known to mineralogists. The crystalline structure of limestone in rock-masses is best displayed in that variety of marble known as "statuary marble." Crystalized carbonate of lime is very often spoken of as "calc-spar," (*i. e.*, *calc*areous spar.)

The presence of carbonate of lime in a rock may be ascertained by applying to the surface a drop of any dilute acid (as sulphuric acid, or even vinegar), which has a stronger affinity for lime than carbonic acid has; the latter, being thus liberated, escapes in a gaseous form, and causes an effervescence in the drop of liquid.

Lime also occurs somewhat abundantly in nature in combination with sulphuric acid, forming *sulphate of lime*, or gypsum, and with silicic acid forming silicate of lime. Sulphate of lime may be distinguished from carbonate of lime by its softness, and by the absence of effervescence on the application of acids.

16. Specific Mineral Constituents of Rocks.—Considered specifically, the composition of the great rock-masses which constitute the crust of the globe is represented by an extremely small number of simple minerals—some eight

QUESTIONS.—What are magnesian limestones and dolomites? What is oolite? What is said of the color of limestones? What of the crystalline forms of carbonate of lime? How may the presence of carbonate of lime in a rock be ascertained?

* Oolites, or oolitic limestones, although common in the geological formations of Europe, are rarely met with in the United States.

† The term "spar" is applied in mineralogy to those crystals or minerals which break up into rhombs, cubes, plates, prisms, etc., with smooth, plane faces. Hence we have calc-spar, fel-spar, brown-spar, etc.

or nine—which are repeated over and over again in the different formations. They are, 1, quartz ; 2, feldspar ; 3, mica ; 4, hornblende ; 5, augite ; 6, carbonate of lime ; 7, talc ; 8, serpentine ; 9, oxyd of iron.*

As it is difficult to convey fully to the mind, by written descriptions, the physical characters of minerals, it is recommended to the student to obtain accurately-named specimens of the above-enumerated species, and to render himself thoroughly conversant with all their modifications—their characters in rock-masses being often very obscure. The following descriptions may, however, assist in their recognition.

Quartzite is a term applied to granular varieties of quartz, and to sandstones apparently converted by heat or chemical solvents into quartz.

Feldspar, as chiefly composed of silica, alumina, and potassa, is a softer mineral than quartz. It is found crystalline, generally of a reddish-white, or gray-color, with a vitreous luster inclining to pearly. The softer crystals occurring in granite are of feldspar, and admit of being scratched with a knife, when the quartz, from its extreme hardness, receives no impression. Feldspar crystals may be also recognized by the smooth, glassy aspect of their divisional planes.†

Mica. This mineral (so called from the Latin *mico*, I glisten) is distinguished by its brilliant, semi-metallic luster, and its ready division into extremely thin plates, or laminæ,‡ which are transparent or translucent, flexible and elastic.

QUESTIONS.—What are the principal minerals that make up the great rock-masses of the globe? What is quartzite? What is feldspar? Mica?

* The average composition of these minerals is represented in the following table:

MINERAL SPECIES.	Quartz, when pure.	Feldspar, common	Mica.	Hornblende.	Augite.	Talc.	Carbonate of lime, pure.	Serpentine.	Oxyd of iron, pure.
Silica	100·00	65·52	48·00	40 27	55·32	62·61	......	43.70	......
Alumina	......	17·61	34·25	16·36	0·43	......	......	2·76	......
Lime	......	0·94	0·13	13·80	23·01	......	55·93	0·42	......
Magnesia	......	......	......	13·38	16·99	32·51	......	39·96	......
Potassa	......	12·98	8·75	......	......	......	......	0·29	......
Soda	......	1·70	......	......	......	......	......	1·98	......
Oxyd of iron	......	0·80	4·50	15·34	2·16	......	......	10·03	100·00
Oxyd of manganese	......	......	0·50	......	1·59	......	......	0·90	......
Carbonic acid	......	......	......	......	......	......	43·58	......	......
Water	......	......	1·25	0·46	......	4·88	......	......	......
Fluorine	......	......	0·29	0·57	......	......	......	......	......

† The term "feldspar" properly applies to a group of allied minerals rather than to a single species. This group includes the following varieties: 1, common, or ordinary feldspar, in which the alkali is potash; 2, albite or soda-feldspar, in which the potash is replaced by soda; and 3, "Labradorite," or "Labrador feldspar," in which both soda and lime replace the potash. The last also differs from the two former in often having an irridescent appearance, and in its manner of fracture and cleavage.

‡ Mica is sometimes used as a substitute for glass (*i. e.*, in furnace doors, etc.) and according to Hauy is divisible into laminæ only 1-25,000th of an inch thick.

It is always present in true granite; is the principal constituent of a set of slaty rocks called mica-schists, or slates, and occurs also in minute scales in many sandstones, imparting to them a silvery appearance.

Hornblende, so named from its horny, glistening fracture (also from the German *blenden*, to dazzle), is a black, or dark-green mineral, softer than quartz or feldspar, and an abundant constituent of the massive crystalline rocks. It occurs massive, as hornblende rock, or with a slaty structure, as hornblende slate or schist.

Augite (pyroxene) is a blackish-green or greenish-gray mineral, allied to hornblende, but differing somewhat in crystalline form and chemical composition. It is the characteristic mineral constituent of rocks of an undoubted igneous origin, as trap, basalt, lava.

Talc is a very soft mineral, of a greenish color, a pearly luster and unctuous "feel." When pure, it occurs usually in foliated masses, easily separable into thin, translucent plates, which are flexible but not elastic, a characteristic which especially distinguishes it from mica. Talc is a silicate of magnesia, and enters largely into the composition of a variety of slaty rocks called "*talcose.*" *Steatite* (Gr. στεαρ, fat, or suet) is a compact variety of talc. From its greasy or soapy feel, it is also known as "soapstone," although this peculiarity belongs to most rocks which contain a considerable percentage of magnesia. "French chalk," "pot-stone," and "Rensselaerite," are varieties of steatite.

Chlorite is a greenish mineral, a silicate of magnesia and alumina, somewhat resembling talc.

Serpentine is a hydrated silicate of magnesia, with varying proportions of iron, manganese, alumina, lime, and sometimes chromium. It is generally of a variegated green color, and derives its name from the resemblance of its mottled colors to the skin of a serpent.

Oxyd of iron is present, in greater or less quantity, in almost all rocks, and often imparts to the minerals containing it a red, brown, or yellow color. It is the coloring agent of the red and brown sandstones.* Oxyd of iron also constitutes rock-masses, and sometimes entire mountains, as the "Iron-mountain" of Missouri.

QUESTIONS.—What is hornblende? Augite? Talc? Chlorite? Serpentine? What is said of the distribution of oxyd of iron? Are rocks in general made up of distinct mineral species?

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* Bricks and common pottery-ware owe their red color to the iron naturally contained in the clay of which they are formed—the iron, by the action of heat, being converted into the red oxyd of iron. Some varieties of clay, like that found near Milwaukie, Wis., contain little or no iron, and the bricks made from it are consequently of light yellow color.

The presence of iron in almost all rocks can be demonstrated by pulverizing a fragment, digesting it in weak hydrochloric or sulphuric acid, and adding to the filtered solution, diluted, a drop of solution of ferrocyanide of potash (yellow prussiate of potash); if the most minute quantity of iron is present, the solution will immediately assume a beautiful blue color.

A few of these minerals exist in a separate state, in so large masses as to be denominated "rock;" as quartz, carbonate of lime, serpentine, etc.; but, in general, the most common rocks are formed by the union of from two to four of them; as granite, for example, which is formed by the union of quartz, mica and feldspar. In rocks which have resulted from deposition, as sediment in water (sedimentary or stratified rocks), the simple minerals which enter into their composition are generally so much ground down and comminuted previous to their final deposition and consolidation, that the mass appears entirely homogeneous, as in the shales, slates, etc.

Other minerals forming rocks of small extent, or entering so largely into the composition of rocks as to modify their character, are the following:—sulphate of lime (gypsum), chloride of sodium (common salt), coal, bitumen, garnet, schorl, staurotide, epidote, pyrites (sulphuret of iron).

Water also constitutes a part of nearly all rocks; but in most cases its presence is simply mechanical, and is not essential to the chemical composition of the mineral substance. In a few minerals, however, it is an abundant chemical constituent, forming nearly twenty per cent. of sulphate of lime, twelve of serpentine and chlorite, and three or four of talc. A compound containing water in definite proportions is termed a *hydrate;* while a substance entirely free from water in combination is said to be *anhydrous.**

CHAPTER III.

ORIGIN AND GENERAL CLASSIFICATION OF THE MATERIALS CONSTITUTING THE CRUST OF THE EARTH.

17. All the rocks which make up the crust of the globe may, by reason of certain structural peculiarities, or by reference to differences in their mode of origin or formation, be divided into a few great general groups or classes.

A classification founded on differences in structural arrangement, and one that is most easily and generally recognized, divides all rocks into two classes, viz., Stratified and Unstratified Rocks.

Questions.—What minerals, other than those enumerated are found abundantly? To what extent does water enter into the composition of rocks? What is a hydrate? When is a substance said to be anhydrous? How are rocks classified? What two classes are generally recognized?

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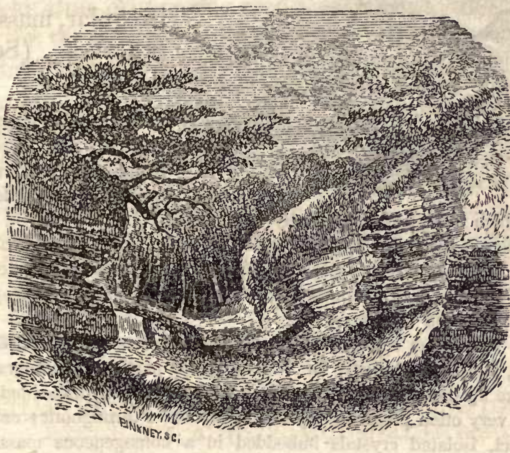
* "The presence of water in rocks is known by experience; since no stone is ever quarried which will not part with some water on being dried, either naturally in the air, or artificially."—*Jukes.*

18. **Stratified Rocks.**—Rocks are said to be stratified when they are completely and naturally divided, by nearly parallel planes, into beds or layers. (See Fig. 6.) These layers are technically termed strata (plural of the Latin *stratum*, strewn or spread out), and may vary in thickness from the fraction of an inch to many feet.

FIG. 6.



Masses or layers of one variety of rock, occuring in the midst of other strata, are said to be interstratified.

Lamination.—The same structure, which characterizes the stratified rocks in mass, may, in most instances, be observed in degree in each separate bed or stratum of the mass; inasmuch as the materials which enter into their composition are generally arranged in thin layers or laminæ, which may or may not be separable from each other. Such a structural arrangement is termed lamination.

FIG. 7.

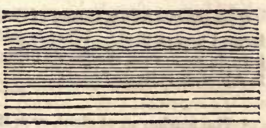


Fig. 7 represents some of the forms of lamination—waved, fine and coarse—observable in different strata.

QUESTIONS.—When are rocks said to be stratified? What is lamination?

Stratified rocks are estimated to occupy about nine-tenths of all the land surface of the earth.

19. **Unstratified Rocks.**—Rocks which do not exhibit in their structure any divisional arrangement of strata and laminæ, are called unstratified. Such rocks have, in general, an exceedingly irregular, massive appearance. (See Fig. 8.)*

FIG. 8.

20. Another classification, generally recognized, and by many geologists preferred to any other, is founded on the mode in which rocks have apparently originated.

That different rocks have had an entirely diverse origin must be obvious to even the most superficial observer: but the fact will appear more especially manifest if we minutely examine and compare well-characterized specimens of the most common varieties.

Thus in specimens selected generally from the class of unstratified rocks (as granite, trap, or porphyry, for example), the particles of mineral matter which make up the mass are internally compact, mutually imbedded or interlaced, and very often present a crystalline structure throughout; or else contain distinct, isolated crystals imbedded in a homogeneous mass. When broken, they tend to separate into irregular angular fragments. Now, it is a law of physics that matter can only assume a crystalline form when its particles are free to move and arrange themselves; and hence, whenever we find a crystal or a mineral particle that has an internal crystalline structure, we may feel assured that it has at some time been in a fluid, or nearly fluid condition; or, in other words, that it has been either dissolved or melted. And if this conclusion be true as regards individual crystals or particles, it must be also true of rocks which are made up of such crystals or particles.

QUESTIONS.—What is said of the distribution of the stratified rocks? When are rocks termed unstratified? What is said of the origin of rocks? What peculiarity of structure do some rock specimens present? What does the existence of a crystalline structure in minerals indicate?

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* The teacher or student, even if without access to a geological cabinet, will experience no difficulty in obtaining specimens of these two classes of rocks; granite, greenstone, and porphyry being illustrative of the unstratified rocks, and slates and sandstones of the stratified. Opportunity also should be taken by the learner to examine the characteristics of these rocks in place, or natural position.

Rocks may, however, present evidence of former fluidity or plasticity other than that afforded by the existence of a crystalline structure. Some do not differ materially in appearance from the products artificially formed in blast-furnaces, being compact and vitreous (glassy), or even porous and slag-like; while others seem to have been deposited in shapeless masses from solutions in water.

These considerations, therefore, have induced geologists to ascribe to many rocks a chemical origin, and also to divide rocks thus originating into two classes, viz., IGNEOUS ROCKS, or those which, in accordance with chemical laws, have consolidated from *fusion ;* and AQUEOUS ROCKS, or those which, under similar laws, have been deposited from *solution.*

21. If, however, we examine specimens of *other* varieties of rocks, we shall find that the mineral particles which enter into their composition, whether internally crystalline or internally compact, are not mutually imbedded and interlaced like those of the chemically formed rocks, but have evidently been brought together from different places, and adhere to each other in consequence of having been forced together by mechanical pressure, or because they are cemented together by some other substance. In rocks of this character, moreover, the particles are usually arranged in layers or strata, and are generally more or less rounded and smoothed externally, as if water-worn;—this latter appearance, in some instances, being especially obvious, inasmuch as the whole mass of the rock consists of pebbles or rounded fragments of other rocks, cemented in sand, which is also the result of an abrading process. In other cases, as, for example, in many slates, sandstones and limestones, the constituent particles of the successive layers appear to have been deposited as mud, and are too much comminuted to be separately discernible even with the aid of a lens.

From these considerations, therefore, it is evident that the origin of rocks thus constituted was mechanical ; or, in other words, the materials of which they are composed have been derived from other and older rocks, and have been transported to their present sites *mainly* through the agency of currents of water ; while their characteristic arrangement into layers or strata is obviously the result of

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QUESTIONS.—What other evidence is there of former fluidity or plasticity of mineral matter? Into what two classes may rocks of a chemical origin be divided? What is said of the structure of other varieties of rocks? What is the assumed origin of such rocks?

their having been strewed out in succession over the bottom of the lakes and seas in which they were deposited. They have hence been called SEDIMENTARY or AQUEOUS-MECHANICAL ROCKS, and very generally, also, in allusion to their structural arrangement, STRATIFIED ROCKS.

That the view entertained by geologists respecting the origin of the above-described rocks is correct, is further shown by the fact that earthy deposits characterized by the same horizontality of arrangement and the same water-worn form of their particles, are continually in the process of formation near the mouths of rivers or on the land during temporary inundations; for whenever a running stream charged with mud and sand has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment previously held in suspension by the motion of the water sinks by its own gravity to the bottom, the heavier particles first, while the finely comminuted matter settles more gradually, and is often floated to a great distance.* In this way layers of gravel, mud and sand, constituting strata, are thrown down upon one

FIG. 9.

another, as is represented in Fig. 9.† The same arrangement of sediment may also be observed in the dry bed of almost every pond, and even in little pools formed by a shower.

22. **Fossiliferous and Unfossiliferous Rocks.**—Rocks, according as they are characterized by the presence or absence of fossils, are further distinguished as FOSSILIFEROUS and UNFOSSILIFEROUS.

Fossil.—Any organic substance, the remains or product

QUESTIONS.—How have they been designated? What evidence is there that the assumed sedimentary origin of such rocks is correct? How may rocks be characterized by the presence or absence of fossils? What is a fossil?

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* The sediment brought down by the Amazon discolors the waters of the ocean at a distance of three hundred miles from its mouth; while much of that discharged by the Mississippi into the Gulf of Mexico is swept by the Gulf stream into the Atlantic.

† "The annual floods of the Nile in Egypt are well known, and the fertile deposits of mud which they leave on the plains. This mud is *stratified*, the thin layer thrown down in one season differing slightly in color from that of a previous year, and being separable from it."—*Lyell.*

of an animal or plant, imbedded in the earth by natural causes, or any recognizable impression or trace of such a substance, is called "a fossil" (Latin *fossus*, dug up).

In many instances the fossil remains of animals and plants occur in such abundance as to constitute almost the entire mass of some rocks;—immense masses of limestone, for example, appearing oftentimes to be wholly composed of shells or corals mineralized and cemented together; while coal, in all its varieties, is believed to be entirely the product of an extinct vegetation.

23. **Metamorphic Rocks.**—In addition to those varieties of rocks which present marked evidence of a distinctive igneous or aqueous origin, geologists recognize a third great class, which appear to have originated from other rocks by alteration. Rocks of this character are hence termed METAMORPHIC, or, literally, *transformed rocks* (Gr. *μετα*, change, *μορφή*, form).

Metamorphic rocks are usually more or less indurated and crystalline, contain few or no traces of fossils, and for the most part exhibit stratification; although this structure in them is often indistinct and sometimes entirely obliterated. The general theory of their origin is, that their constituent materials were originally deposited from water as sediment, but subsequently, through the action of heat, pressure, chemical solvents, or other agencies, were changed and altered. In some cases, where sedimentary strata containing fossils are in contact with rocks of undoubted igneous origin, the whole process of change (metamorphosis) can be clearly traced;—dark limestones, replete with shells and corals, for example, being converted into white crystalline marbles with every sign of an organic body completely obliterated.

Among the common rocks which are regarded as unmistakably metamorphic, may be mentioned those known as the crystalline limestones (statuary marble); "indurated clay," or "roofing slate;" and gneiss, which last resembles (and is popularly called) granite.

24. **Recapitulation.**—From the above considerations we may class all the rocks which constitute the crust of the globe as follows:—

According to their structural arrangement into STRATIFIED AND UNSTRATIFIED ROCKS.

QUESTIONS.—What are metamorphic rocks? What is the assumed origin of the metamorphic rocks?

According to the presence or absence of organic remains, into FOSSILIFEROUS AND UNFOSSILIFEROUS ROCKS.

And, *according to their origin or mode of formation, into* IGNEOUS, AQUEOUS and METAMORPHIC

The student, however, would do well to bear in mind that all classifications of this character are in the highest degree general, inasmuch as rocks of every variety may so intermingle and insensibly graduate into one another as to render it extremely difficult to decide what agency was most concerned in their formation. And it has not unfrequently happened in the history of geological science that rocks which have been pronounced by good observers to belong to one class, have, when subsequently seen under different circumstances, or when examined more thoroughly, been referred to an altogether different class.

Adopting the classification of Igneous, Aqueous and Metamorphic in the present work, as most in accordance with the established facts of geology and chemistry, and most convenient for reference and study, we may indicate the characteristic features of each division as follows:—

"The Igneous Rocks are almost entirely chemically formed rocks, but some of their varieties may have mechanical accompaniments." They are unstratified and unfossiliferous.

"The Aqueous Rocks are either chemical, mechanical, or organic; those of mechanical origin being by far the most abundant." They are for the most part stratified and fossiliferous.

The Metamorphic Rocks are all more or less changed and altered. In some the original structure and composition are still obvious; while in others they are entirely obscured, or even replaced by entirely different characters.

25. **Formation.**—The term *formation* is applied in geology to any portions of the earth's crust, of greater or less thickness, which were formed under the *same contemporary influence.*

A formation may include rocks of very diverse character and composition, when there is reason to suppose that they originated at nearly the same

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QUESTIONS.—Do rocks admit of a precise and definite classification? Give the characteristic features of the igneous, aqueous and metamorphic rocks. What is a formation in geology?

epoch. Thus we speak of stratified and unstratified, fresh-water and marine, aqueous and volcanic, carboniferous (*coal-bearing*) and metaliferous formations.

CHAPTER IV.

VARIETIES AND LITHOLOGICAL CHARACTERS OF THE IGNEOUS ROCKS.

26. By the lithological characters of rocks we understand their external aspect, mineralogical composition, texture,* and such other physical features as can be determined by the inspection of hand specimens.

27. Three classes of rocks, formed mainly by the action of heat, are recognized by geologists, viz., the VOLCANIC, TRAPPEAN, and GRANITIC.

According to such a classification, the term Volcanic is applied exclusively to the products of modern volcanoes, or to rocks formed through igneous agency within a comparatively recent period, at or near the surface of the earth. The terms Trappean and Granitic, on the other hand, are applied to classes of igneous rocks much older than the volcanic, and which are generally believed to have consolidated below the immediate surface of the earth, and consequently under pressure.

The Trappean and Granitic rocks, in reference to their supposed origin, have been also called Plutonic, from Pluto, the ruler of the inferior regions.

28. Rocks of igneous origin, with few exceptions, are composed of minerals which are silicates. These minerals are mainly silicates of alumina, of magnesia, and of

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QUESTIONS.—What is understood by the lithological characters of rocks? Into what classes have the igneous rocks been divided? What is said of the structure and chemical composition of the igneous rocks?

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* The *structure* of a rock refers to the manner in which it occurs in mass; its texture, on the contrary, refers to the manner in which its individual particles are internally arranged. Thus, granite has a massive *structure;* but its texture is crystalline, coarse or fine grained, hard and compact.

lime, with admixtures of silicates of potash, soda, iron and manganese.

The varieties of the mineral feldspar (silicate of alumina and potassa) constitute the basis of most igneous rocks; those in which no feldspar of any kind is present being very few and unimportant, even if they exist at all. After feldspar the varieties of hornblende and augite (silicates of magnesia and lime) hold the next most important place.

Igneous rocks exhibit great diversities of texture; some being crystalline and granular, others compact and stony, and others glassy or vitreous. These differences are generally referred to the diversity of circumstances under which the rocks in question have consolidated rather than to differences in their chemical composition; similar transformations being observed to take place in masses of silicates artificially fused (as in the manufacture of glass) and cooled under different conditions.

The terms "unstratified," "Plutonic," and "pyrogenous" are often used by geologists in describing rocks which have been formed by the action of heat, as synonymous with the term igneous.

SECTION I.

VOLCANIC ROCKS.

29. The volcanic rocks are the only igneous rocks whose formation we are at present able to witness.

In one sense, all the strictly igneous rocks are volcanic; that is, they have been formed through the agency of heat, in a manner similar to the products of existing volcanoes. For the sake of classification, however, the use of the term is restricted by geologists to those rocks which have been formed by the action of heat within a comparatively recent period, at or near the surface of the earth, in air, or in water.

A volcano (from Vulcanus, the God of fire) is an opening in the crust of the earth, from whence melted or heated rock, ashes, water, smoke, gases or vapors are discharged.

A volcano is usually a more or less perfectly conical hill or mountain, with a truncated apex, produced by the successive accumulations of ejected matter or by the elevation of a portion of the earth's crust. The vent or opening communicating with the interior of the earth (which in the first instance

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QUESTIONS.—What are the principal minerals which enter into their composition? What is said of the texture of the igneous rocks? What is the origin of the diversities of texture exhibited? What synonyms for the term "igneous" are often used? What peculiarity characterizes the volcanic rocks? To what rocks is the term volcanic restricted? What is a volcano?

must have been merely a fissure) in such cases assumes the form of an inverted cone, and is called a *crater*. Volcanic cones vary in height from 90 feet, to 23,900 feet (Aconcagua, Chili.)

A volcanic fissure or orifice which emits only smoke, gases, aqueous and corrosive vapors, is termed a SOLFATARA or FUMAROLE.

When volcanoes exist beneath the sea, as they not unfrequently do, they are termed *sub-aqueous* or *sub-marine*. Those which have exhibited no evidence of action since the commencement of the historic period are termed *extinct*, while those which are constantly or intermittingly in action are termed *active*.

FIG. 10.

The general name given to all melted rock matter ejected from volcanoes is *lava*.

Fig. 10 represents an ideal section of a volcano during an eruption; *a* is

QUESTIONS.—What is a solfatara? When are volcanoes said to be sub-marine? When active and extinct? What is lava?

the volcanic fissure, or channel, communicating with the interior of the earth filled with lava; *b*, the crater; *c*, the volcanic cloud of smoke and vapor above the crater; *d*, the spheroidal shape assumed by the smoke column; *e*, the shower of lava or dust falling from the volcanic cloud; *f*, falling scoriæ and ashes; *g*, lateral channel discharging lava at a point below the crater; *i*, lava stream, with smoke issing from *fumaroles*.

30. The mineral constituents of almost all volcanic rocks or lavas are mainly feldspar and augite. When the feldspar predominates the lavas are termed *trā'-chyte* or felspathic lavas; and when the augite is in excess, augitic lavas.

The trachytes are so called from the Greek word *τραχὺς*, rough, as they have commonly a rough, gritty feel to the finger.

Lavas assume nearly every variety of texture and color, according to the varying proportions of feldspar and augite which enter into their composition, and according to the slowness or rapidity with which the mass is cooled;—those which have cooled quickly being compact and glassy, while those which have cooled slowly and under pressure, tend to become stony and crystalline. Some varieties of trachyte at first sight resemble granite.

Obsidian, or volcanic glass, is the vitreous condition of a lava. It is of various shades of color, often velvet black, and can scarcely be distinguished from the product of a glass furnace. It was formerly used by the ancients as a material for mirrors. *Pumice* is the solidified froth or scum of molten rock matter; it has a pearly silky luster, a fibrous texture, and is often sufficiently light to float upon water. It is generally of a grayish-white color, and is extensively used as polishing material.

Scoriæ is the name given to all accumulations of dust, ashes, cinders and slaggy rock fragments discharged from volcanoes. *Volcanic tufa*, or *tuff* (ash) is the general name given to volcanic rocks of a soft, earthy and porous texture; it ordinarily consists of ashes and dust, mixed, it may be, with coarser fragments, blown from a volcanic focus. Materials of this character falling upon the land may become compacted into rock either by the pressure of their own weight, or in consequence of the percolation of water containing mineral matter in solution; if, on the contrary, they fall into the sea, they become subjected to the conditions under which all other mechanically formed aqueous rocks are produced, and may exhibit stratification and contain fossils.*

Among other substances occasionally ejected from volcanoes are fragments

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QUESTIONS.—What are the principal mineral constituents of lava? What two classes of lavas are recognized? What is said of the texture of lavas? What is obsidian? What is pumice? What are scoriæ? What are volcanic tufas?

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* The word "tuff," or "tufa," used alone, may signify any porous, vesicular rock; thus we say "calcareous-tufa," "trap-tufa," "volcanic tufa," etc.

of granite or other rocks, scarcely altered; also sulphur in a pure state; chlorides of sodium (common salt), potassium, iron, lead, copper, sulphate of lime (gypsum), sal-ammoniac, borax (borate of soda).

"Volcanic mud, which bubbles out of many fissures and openings (known as mud volcanoes), is a product of considerable magnitude in some regions; and jets of hot water (like the geysers of Iceland) and those of steam (like the *suffoni* of Italy) are not unfrequent volcanic phenomena."

The principal gaseous emanations of volcanoes are carbonic acid, sulphuretted hydrogen, sulphurous acid, hydrochloric acid, and sometimes carburetted hydrogen.

31. The products described in the preceding paragraphs may be found, to a greater or less extent, in almost all volcanic districts; and the mode in which they are discharged, their varying admixtures, and the different appearances they assume, according to the rapidity or slowness with which they have cooled, afford highly instructive lessons to the geologist. Here the explosive force of highly heated vapors and molten matter breaks through the solid crust of the earth, and uplifts or deranges rocks of anterior formation; there the lava penetrates every fissure, or issuing from some vent flows down the mountain side, filling up valleys, damming up river channels, creating crags and cliffs, and spreading over plains; here scoriæ and ashes are showered forth, borne abroad by the winds, and scattered over land and sea, sometimes burying cities and villages, as in the case of Pompeii and Herculaneum; there heated vapors are perpetually exhaling from rents and fissures, and incrusting their sides with mineral or metallic compounds. Repeated discharges from volcanic vents may give rise in time to mountains; or taking place under water, may be spread out over the bed of the ocean, and become overlaid by true sediments—thus producing alternations of igneous and aqueous rocks. The molten matter also cools unequally—here forming vitreous masses (obsidian), there porous pumice or rough earthy tufa; here granular trachytes, there highly compact crystalline rocks. And just as igneous forces are acting at the present day under the eye of the observer, in the production of volcanic rocks, so it is inferred they have acted in former ages of the world in the production of other varieties of igneous rocks (the trappean and granitic): with this difference, that many of the latter have been formed at great depths and under great pressure, and have subsequently undergone internal changes to which volcanic or sub-ærial igneous rocks have not been subjected.—PAGE.

32. **Surface Configuration of Volcanic Districts.**—In districts where volcanic eruptions have been frequent, and where the surface has not been exposed to great aqueous denudation, cones and craters, with vast beds of scoriaceous lavas and volcanic sands constitute the marked features of

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QUESTIONS.—What are occasional volcanic products? What are the principal gaseous emanations of volcanoes? What inferences and lessons do existing volcanic phenomena afford to geologists? What is said of the surface configuration of volcanic districts?

the scenery. Fig. 11 represents a view of a chain of extinct volcanic hills in Auvergne, Central France.

FIG. 11.

33. **Geographical Distribution.**—In the United States, east of the Rocky Mountains, volcanic rocks do not occur; but throughout this whole chain of mountains, and especially in its continuations, as the Cordilleras of Mexico and the Andes of South America, volcanic formations are abundant. They also occur in the West Indies, the Cape de Verde and Canary Islands, in France, Germany, Italy, in many districts of Asia, and in numerous islands of the Pacific and of the Polar Oceans. In the British Islands they are unknown.

34. **Industrial Products.**—In an industrial point of view, volcanic products are of considerable importance. Nearly all the *sulphur* of commerce is derived from volcanic districts, Sicily alone yielding nearly 100,000 tons yearly. Sulphur occurs in Sicily in beds of blue clay, and the excavations, in some instances, resemble quarries of yellow marble. *Pumice* is extensively used in the arts for dressing leather and for polishing and smoothing wood, metals, glass and marble. Large quantities of it are annually exported from the Lipari Islands, Mediterranean, the price being from $30 to $50 per ton, according to the quality. *Borax* (boracic acid and soda) may also be regarded as a volcanic product—the principal supply being afforded by the hot springs (lagoons) of Tuscany, which yield about 1,000 tons of crystallized boracic acid annually. Borax is also found in the waters of some of the hot springs of California. Volcanic rocks rarely contain available deposits of the metals, but yield many interesting simple minerals, more than one hundred different species having been noted among the lavas of Vesuvius alone; the proportion which they constitute of the whole mass, however, is inconsiderable.

SECTION II.

TRAPPEAN ROCKS.

35. The term "trap" (from the Swedish "*trappa*," a stair) was originally applied to certain igneous rocks, which,

QUESTIONS.—What of the distribution of volcanic rocks? What of the industrial products of volcanoes? What is the origin and application of the term "trap?"

occurring in great tabular masses of unequal extent, give to many hills a terraced or step-like appearance.

At present, however, the terms "trap" and "trappean" are used somewhat indefinitely and vaguely by geologists to designate any igneous rock which cannot be said to be distinctly granitic on the one hand, or absolutely volcanic on the other.

36. In texture and composition the trap-rocks are extremely diversified and varied—some being highly crystalline and compact, while others are cellular or soft and earthy. Their relations to the other rocks are also often intricate and deceptive. Sometimes they present themselves, as already stated, in tabular masses, which are not divided into strata; sometimes in shapeless heaps and irregular cones, forming chains of small hills; and very often, as veins or wall-like masses, they burst through and intersect rocks of every description, deranging their position and spreading over them in sheets of varied extent and thickness. Trap-rocks are also frequently found divided into columns of great regularity. The annexed figure represents a very characteristic appearance of trap bluffs or exposures.

37. Mineralogically considered, the trap-rocks are chiefly composed of feldspar, hornblende and augite, with varying admixtures of olivine (a greenish mineral, a silicate of magnesia and iron), quartz, clay, iron, etc. Their weathered and decomposing surfaces, owing to the presence of oxyd of iron, are generally of a rusty brown color.

38. In structure and arrangement the trap-rocks exhibit unmistakable evidence of igneous origin, and in a majority

QUESTIONS.—What is said of the structure and composition of the trap-rocks? What of their mineralogical composition? What of their origin?

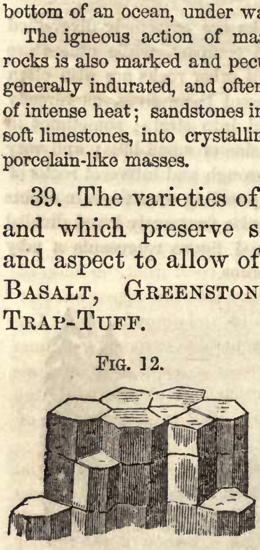
of instances, perhaps, the only distinction between them and the volcanic rocks which admit of recognition is, that the former are more ancient than the latter.

Some of them were evidently ejected after the manner of molten lava; some must have been scattered abroad as showers of volcanic dust and ashes; while others (*i. e.*, the highly crystalline and compact varieties) have undoubtedly consolidated under the enormous pressure of superincumbent strata, or at the bottom of an ocean, under water.

The igneous action of masses of trap upon the aqueous or sedimentary rocks is also marked and peculiar; the latter, at the points of contact, being generally indurated, and often greatly altered, as if subjected to the influence of intense heat; sandstones in some instances being converted into quartzites, soft limestones, into crystalline marbles, coal into coke, and clays into flinty, porcelain-like masses.

39. The varieties of trap which prevail most extensively and which preserve sufficient uniformity of composition and aspect to allow of general recognition, are as follows: BASALT, GREENSTONE, PORPHYRY, AMYGDALOID, and TRAP-TUFF.

FIG. 12.



The basalts are the hardest, most compact, and heaviest of the trap-rocks. They are usually of a black or greenish-black color, of a fine-grained texture, and very frequently exhibit a more or less columnar or prismatic structure—the columns or prisms having three, five, or more sides, regular and jointed. (See Fig. 12.)

Greenstone is a general designation for the hard, granular-crystalline varieties of trap. The term has reference to their usual greenish or blackish-green colors. Their weathered surfaces acquire a dull, dark-brown color, and are often covered with patches of white lichens. As compared with the basalts, the greenstones are less compact, more granular, exhibit more clearly their component crystals, and are usually massive or tabular in their structure.

Those varieties of greenstones and traps which are composed essentially of feldspar and augite have received the name of *dolerites* (Gr., δολεριτες, deceptive), from the difficulty of distinguishing their constituent minerals; while those composed chiefly of feldspar and hornblende, whose composition is less mistakable, have been called *diorites* (Gr., διωρος, a clear distinction).

The term *porphyry* (Gr., πορφυρα, purple) was originally applied to a reddish rock of igneous origin found in Egypt, and much used for ornamental

QUESTIONS.—What action has trap often exerted on other rocks which are in contact with it? What are the principal varieties of trap? Describe the basalts. What are the greenstones? What are dolerites and diorites? What is porphyry?

purposes. It is now, however, employed by geologists to designate any rock (whatever its color) which contains detached crystals imbedded in a compact base or matrix. (See Fig. 13.) Rocks thus constituted are very characteristic of the trap group, but do not belong exclusively to it.

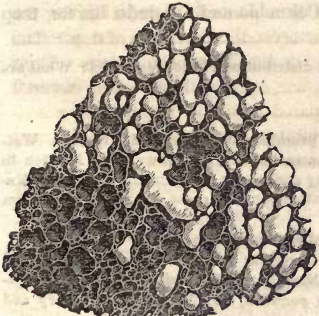
FIG. 13.

When porphyry is spoken of in general terms, the base is understood to be feldspar, with imbedded crystals of feldspar but when the base is some other mineral compound, as basalt, greenstone, granite, etc., the porphyry receives a distinctive name from the basic material; and thus we have basaltic porphyry, greenstone porphyry, porphyritic granite, etc., etc.

The term *amygdaloid* (Gr. *αμυγδαλεα*, an almond), is applied to certain rocks, especially abundant in the trap series, which contain small rounded, vesicular cavities partially or entirely filled with crystalline deposits of different minerals. These minerals, being of a different color from the mass of the rock in which they are imbedded, have somewhat the appearance of almonds in a cake, and hence the terms *amygdaloid* and *amygdaloidal.* The crystalline deposits found in amygdaloids are generally carbonate of lime (calcspar), agate, jasper, quartz, etc. Fig. 14 represents a specimen of vesicular lava, in one half of which the cavities or vesicles are empty, while the other part is amygdaloidal, *i. e.*, the cavities being filled with carbonate of lime, which appears as white kernels.

The *trap-tuffs* or *tufas* do not differ essentially from those of volcanic origin.

FIG. 14.



In addition to the general divisions of the trap rocks above described, different geological writers further recognize a great number of other varieties or sub-species. The following are the ones which the student will be most likely to meet with in his reading or collections:—

Clinkstones or *phonolites* differ little from the basalts in composition, but are less compact, and break up into slate-like fragments; when struck by the hammer, they emit a ringing metallic sound—whence the name. *Claystone* is an earthy, compact stone

QUESTION.—What is an amygdaloid? What is said of the trap-tuffs? What are some of the other varieties of the trap rocks?

of a purplish color, and having the aspect and texture of a baked or indurated clay. *Hornstone* (*petro-silex* or *rock-flint*) is a compact, highly silicious rock, with very much the aspect of a tough, massive flint; it has various colors and is often translucent. Other varieties of trap or porphyritic rocks are known as *melaphyre*, *aphanite*, *euphotide*, *diallage*, *diabase*, etc.

40. **Geographical Distribution.**—The geographical area occupied by the trap rocks is very extensive. In South America trachytic rocks, holding an intermediate place between the trappean and volcanic rocks, have an enormous development, and in the chain of the Andes, of which they form the summit, the beds are sometimes 18,000 feet in thickness, as at Chimborazo and the volcano Pinchincha. In the United States the trap rocks are mostly referred to the class of greenstones, and are extensively developed. In the Atlantic States three belts or ranges occur, which belong to the eastern slope of the Appalachian and Green Mountains, and are co-extensive with them. One belt, the eastern, begins in Rhode Island and extends entirely across the eastern part of Massachusetts into New Hampshire, and also encircles in part Massachusetts Bay.* The second belt runs up the valley of the Connecticut river and passes entirely across the States of Connecticut and Massachusetts, terminating at New Haven in the well-known "East" and "West Rock." The most prominent elevations of this range are Mt. Holyoke and Mt. Tom on opposite sides of the Connecticut river, near Northampton in Massachusetts. The third belt of trap or greenstone occupies a part of the valley of the Hudson River, appearing conspicuously and forming the bold continuous bluff, in the southern portion of the valley, termed the "Palisades."† This belt is prolonged through New Jersey, and may be traced, with a few interruptions, through Pennsylvania, Virginia, North and South Carolina, and into Georgia.‡ Trappean rocks are very abundant upon Lake Superior and mainly constitute the well-known promontory "Kewaunee Point" and also "Isle Royal." Upon the western slope of the Rocky Mountains, near the head waters of the Columbia and Colorado Rivers, trap

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Questions.—What is said of the geographical distribution of the trap rocks? What are their prominent features in the United States?

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* This belt, or rather area of greenstone, is prominently exhibited in Weston, Waltham, Lexington, Woburn and Wrentham in Massachusetts, and onward to Ipswich in New Hampshire. It also presents very striking and easily recognized features at Nahant, Salem, Marblehead, and at numerous points upon the coast of Maine and Nova Scotia.

† "This locality may be regarded as a typical representation of trap."—Emmons.

‡ This range of trap extends through New Jersey in nearly continuous ridges, and forms several conspicuous elevations between New York City and Newark. In Pennsylvania it is conspicuous in the north-eastern counties, *i. e.*, Burke, Montgomery and Chester. The "Coneaeaga Hills" of Pennsylvania are trap. In Virginia the trap range appears between Fredericksburg and Buckingham County, and pursues a southwest direction into Rockingham County, N. C., continuing to the Yadkin. Another branch begins near Oxford, Granville County, N. C., and extends into South Carolina, terminating apparently in the Chesterfield District.

rocks are probably developed to a greater extent than in any other portion of the North American Continent.

41. **Surface Configuration of Trap Districts.**—Districts abounding in trappean rocks exhibit a greater diversity of surface than is occasioned by the presence of almost any other geological formation—the characteristic features being long, low ranges of hills with a peculiar undulating outline, detached and isolated conical eminences, step-like ascents, abrupt crags, and often perpendicular walls of great height and length (*e. g.*, the Palisades of the Hudson)—the whole producing scenery extremely picturesque and beautiful. The soil, also, resulting from the decomposition of trap, as well as from most volcanic rocks, is generally remarkable for fertility, while the natural joints and fissures peculiar to rocks of this formation establish an effective drainage.

42. **Industrial Applications.**—Many of the varieties of trap afford very durable building materials, but the difficulty of dressing them into proper shape, combined with their dingy and unattractive colors, restricts their application to architectural purposes. Their hardness, however, renders them peculiarly fitted for the construction of roads and for "macadamizing." Basalt, artificially melted and cooled rapidly, is converted into a kind of obsidian (volcanic glass) undistinguishable by any external characters from that derived from volcanic districts. Such an artificial obsidian is now manufactured in Birmingham, England, and cast into ornamental blocks and moldings.

Rocks of trappean origin rarely afford available supplies of the metals. The wonderfully rich deposits of native copper in the vicinity of Lake Superior occur, however, in trap rocks, and are a notable exception to the rule. The amygdaloids and trap-tuffs abound in "*geodes*," or rounded nodules having internal cavities lined with crystals of quartz or amethyst, or concentric layers of agate, carnelian, chalcedony, or other minerals; and it is from this source that most of the above-named gems, made use of by lapidaries and jewelers, are obtained. In external appearance a geode is generally an irregular spherical mass of mineral matter, but exhibits a beautiful internal structure when fractured.

SECTION III.

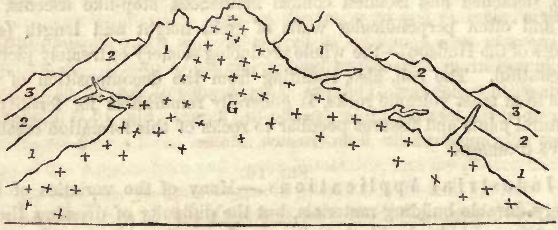
GRANITIC ROCKS.

43. This series of rocks derives its name from *granite*, its principal member. They are all highly crystalline, and *none* of their crystals are rounded or water-worn.

QUESTIONS.—What is the surface configuration of the trap districts? What are the industrial applications of the trap rocks and their associated minerals? What are "geodes?" What is the general character and position of the granitic rocks?

They occur, for the most part, in the crust of the earth, as mountain masses or veins, bursting through and pushing up the sedimentary rocks into inclined and unnatural positions. (See Fig. 15.)

Fig. 15.



44. **Typical or True Granite** is composed of three minerals—feldspar, quartz and mica—promiscuously intermixed, in the form of distinct grains or crystals.

The proportions of these three constituents vary indefinitely, with this limitation, that the feldspar is always an essential ingredient, and never forms less than a third, rarely less than a half of the mass, and generally a still larger proportion. Sometimes the mica, sometimes the quartz, becomes so minute as to be barely perceptible. The state of aggregation of the mass, also, varies greatly; some granites being very close and fine-grained, while others are largely and coarsely crystalline.

Masses of granite occur in Norway with feldspar crystals of a cubic foot, mica crystals of a square foot in dimensions, and the quartz in still more considerable masses—at one place twenty-one feet thick—extending between them. In other cases, granite of a uniform and extremely fine grain may be seen upon the sides of some mountains, covering acres of surface, without a crack or a seam.

The colors of granite are generally red, gray or white.

45. **Varieties of Granite.**—In addition to feldspar, quartz and mica, or in place of one or two of these ingredients, other minerals frequently occur in granite, giving rise to numerous varieties or sub-species. Of these the following are the most important:—

When hornblende replaces the mica found in true granite, the rock, although not essentially changed in character, is termed *Syenite*, from Syene, in Upper Egypt, where it was early known and quarried. When hornblende and mica are both found in the same variety of granite, the rock is termed *Syenitic*

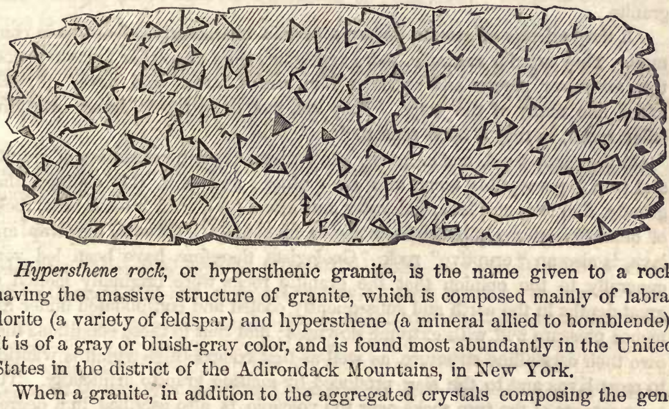
Questions.—What is the composition of true granite? What are the prevailing colors of granite? What constitutes varieties in granite? What is Syenite?

granite. Much of the so-called Massachusetts (Quincy) granite, famous for its architectural applications, is syenite,—the hornblende being frequently in very small proportion. Examples of this rock in construction may be seen in Bunker Hill Monument, the custom-house and court-house in Boston, the Merchants' Exchange and Astor House in New York City, and the custom-house in New Orleans.

When *talc* occurs in the place of mica, the admixture of feldspar, quartz and talc is called *Protogene*, or *talcose granite.*

Graphic granite is composed of flesh-colored or white feldspar, intermixed with thin and irregularly-shaped laminæ (plates) of quartz. A section across the ends of these laminæ exhibits the appearance of Arabic or hieroglyphic writing upon the feldspar tablet; hence the name. Fig. 16 is a fac-simile of a section of graphic granite from Goshen, Mass.

FIG. 16.



Hypersthene rock, or hypersthenic granite, is the name given to a rock having the massive structure of granite, which is composed mainly of labradorite (a variety of feldspar) and hypersthene (a mineral allied to hornblende). It is of a gray or bluish-gray color, and is found most abundantly in the United States in the district of the Adirondack Mountains, in New York.

When a granite, in addition to the aggregated crystals composing the general mass of the rock, contains large and distinct crystals of feldspar, it is

FIG. 17.

QUESTIONS.—What are examples of syenite in construction? What is protogene? What graphic granite? What hypersthene rock? When is granite termed porphyritic?

termed *porphyritic.* Fig. 17 represents a marked example of porphyritic granite from Cornwall, England, figured by Sir Charles Lyell. Fine specimens of porphyritic granite may be obtained in the vicinity of Lake Memphremagog, Vermont.

Beside the preceding, there are many other granitic compounds, in all of which feldspar, quartz, mica and hornblende are the principal ingredients, and talc, hypersthene, chlorite and schorl the chief modifying or accidental minerals. Sometimes half a dozen varieties of granite may be found in the same district, or even in a single quarry.

Origin of Granite.—The granites differ little in chemical composition from the trappean and volcanic rocks—silica, alumina, lime, magnesia, potassa, soda and oxyd of iron being common ingredients of all. These substances, combined in different proportions and under different circumstances of pressure, etc., may yield a porous lava, a compact trap, or a crystalline granite.

All the varieties of granite preserve certain characteristic features in common. They are, for example, more crystalline than any other igneous rocks; they are never porous and vesicular like recent lavas; and never amygdaloidal, like many of the traps. They are, moreover, rarely found overlying other rocks, as trap is often seen to do.

On the other hand, instances are cited where contiguous masses of granite and trap imperceptibly blend into each other; and it is also claimed, that granite, like trap and lava, indurates and alters (as if with intense heat) rocks of other formations with which it comes in contact. Granite, like trap and lava, is also an "eruptive" rock. Geologists, therefore, have been led very generally to the opinion that the granitic rocks were originally melted at great depths in the earth and subsequently cooled and consolidated under immense pressure and with extreme slowness; and that to these conditions they owe their crystalline structure, as well as that compactness which is wanting to most lavas and to the slag produced by melting granite artificially. The compactness of the trap rocks over the volcanic is also ascribed, in a degree, to similar conditions of formation.

This generally-received theory of the igneous origin of granite has, however, within a recent period, been questioned or disputed by not a few able chemists and geologists. Admitting that the mineral constituents of granite have been in a fluid or partially fluid state, they ascribe this result to the solvent action of chemical solutions, aided, it may be, by moderate degrees of temperature, rather than to fusion by intense heat. Some of the arguments which have been brought forward in support of this view are as follows:—

In granite quartz is the most recent mineral. This seems evident from the

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Questions.—What is said of the chemical composition of granite? In what do the granites especially differ from the traps and lavas? What is the generally received theory respecting the origin of granite? What other view is entertained? What are some of the facts opposed to the igneous theory?

circumstance that the quartz is found to occupy the space left by the other constituents of the rock, *i. e.*, mica, feldspar, etc., and also presents impressions of the crystals of the associated minerals without their edges or angles appearing in any way broken or rounded.* But quartz is much less fusible than either mica or feldspar, and consequently would have crystallized and consolidated first, had the whole mass of the rock been melted. That it has not so happened, is claimed to be entirely inconsistent with any hypothesis of igneous fusion.

Granite veins, not thicker than fine wire or ordinary writing-paper, in some instances traverse rocks of other formations for a considerable distance. The advocates of the igneous origin of granite suppose that these veins have been formed by the injection of molten mineral matter into fissures previously existing; the opponents of this theory, on the contrary, maintain that *gradual* solidification and cooling—conditions deemed essential to a crystalline structure—would, under such circumstances, be impossible. The occasional presence in granite of minerals containing a considerable proportion of water in combination, is also regarded as inconsistent with the supposition that the constituents of the rock have been subjected to the continued action of intense heat.

These and other similar arguments have, therefore, induced many geologists to entirely abandon the theory which ascribes to granite an *exclusively* igneous origin; while others—perhaps a majority—still regard the evidence in favor of the igneous theory as sufficiently satisfactory.†

Industrial Applications.—Granite holds the first rank among building stones for durability. The finer varieties are susceptible of a good polish, and retain it for a long time under all atmospheric influences; granite, moreover, does not readily become stained by vegetation, and when carved preserves its sharp edges longer than any other rock used for architectural purposes.‡ To crush a half inch cube of the best granite requires a pressure of 24,500 lbs.

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* This "order of succession" in the constituents of granite may be seen to advantage in the coarsely crystalline specimens.

† The author, although favoring the most recent views, has not thought it expedient, in an elementary text-book, to depart from the usual classification which assigns to granite a place among the igneous rocks. Whatever theory may finally prevail, the student in possession of the facts as above given can not well be led into error. Those desirous of further information will find a full exposition of the modern views respecting the origin of the crystalline rocks in Bischof's "Chemical Geology," English translation.

‡ The pedestal of the statue of Peter the Great, at St. Petersburg, consists of a single perfect block of granite from Finland, weighing 1280 tons; while a monolithic statue of red granite, on the site of ancient Memphis, sixty feet in height, has an estimated weight of 887 tons.

Granite is commonly sold, in the rough block, by the ton of fourteen cubic feet, or, if dressed, by the superficial foot of hammered surface.

Granitic rocks often contain veins of metalliferous ores, which are commonly found most productive near the line of contact between the granite and other formations. They are also the repositories of many interesting minerals and gems. The finest porcelain clays (kaolin) result from the decomposition of the highly feldspathic varieties of granite.

46. **Distribution of Granite.**—Granite is one of the most easily recognized and widely distributed of all rocks. It forms the principal mass or axis of most of the great mountain ranges of the globe, although it rarely reaches the most elevated summits;—Mt. Blanc in Switzerland being the highest known peak of granite.

In all the New England States granite is most abundant; the most celebrated quarries being at Quincy, Mass. (where the rock is a syenite), and upon the coast of Maine. Some of the quarries in the latter State are capable of furnishing perfect blocks of fine grained granite from thirty to sixty feet in length. Granites and syenites abound in the southern Highlands of the Hudson and along the shores of Delaware Bay. A granite obtained on Staten Island, and much used for paving in New York City, is remarkable for its density, a cubic foot of it weighing over 180 lbs.; while that of Quincy weighs only 165 lbs. In Virginia granite is not, comparatively speaking, abundant; the principal variety—occurring on the low ranges of the Blue Ridge—being composed mainly of quartz and feldspar. A ridge of granite forms the first waterfalls of the Rappahanock, James, Roanoke, Neuse, Tar and Cape Fear Rivers. In South Carolina and Upper Georgia the formation is finely developed, and at Abbeville, S. C., the rock can scarcely be distinguished from that at Quincy. The famous stone mountain of De Kalb Co., Ga., is a huge mass of granite rising almost perpendicularly several hundred feet above the surrounding country.

In the highlands of Wisconsin and Michigan, on the northern side of Lake Superior and Lake Huron, and between the Upper Mississippi and Lakes Superior and Michigan, granites and syenites abound.

Upon the Pacific coast granite is a constituent part of all the great mountain ranges of Oregon and California.

Questions.—What is said of the distribution of granite? What are some of its most famous quarries in the United States? What of its occurrence in the Southern States and at the West?

47. **Surface Configuration of Granitic Districts.**—The physical aspect of purely granitic districts is in general sombre and monotonous—hills with a heavy rounded outline and slightly undulating plains being the characteristic features. Partly from their elevated and exposed situation as mountain chains and table lands, and partly from the barren nature of their scanty soil, granitic areas also offer but few inducements for the agriculturist Some of the most barren and unfertile portions of New England are her granitic districts.

CHAPTER V.

VARIETIES AND LITHOLOGICAL CHARACTERS OF THE AQUEOUS ROCKS.

48. It is admitted by all geologists that the aqueous rocks have resulted, either directly or indirectly, from a disintegration and breaking down of the igneous rocks and a rearrangement of their particles; and that the agencies by which these results have been effected have been mechanical, chemical and organic.

The special action of each of these various forces will be considered hereafter in detail, but at present our attention is to be directed to results rather than causes. "We are compelled," says Mr. Jukes, "to look upon the *purely* igneous rocks as original productions. We can only speculate, and that very vaguely, on what was the conditions of the materials which compose them previously to their being placed in a molten or plastic state, in the positions where they subsequently consolidated. But in our examination of the aqueous rocks we can go a step further back, and learn, either accurately or approximately, whence the materials composing them were derived, and what was their previous condition."

49. **Aqueous Rocks Mechanically Formed.**—The agencies concerned in the production of these rocks are, moving water (including ice) and moving air.

All the earthy matters we see around us, the mud, the clay, the soil, the sand, the dust, the gravel and the rounded rocks and pebbles, are only so

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QUESTIONS.—What is the general surface configuration of granitic districts? In what manner have the aqueous rocks been formed? What mechanical agencies have been concerned in the formation of the aqueous rocks?

much raw material in the process of manipulation. They may be likened to the refuse and the chips of some vast manufactory. They are the building materials of the stratified, sedimentary rocks, which are being carried from the quarry to the place of construction. Every pebble, every grain of sand, every atom of mud is a fragment of a pre-existing rock, removed at some period of past time and destined ultimately to enter into the structure of some other rock in the future.—JUKES.

50. **Alluvium.**—This term (from the Latin *ad*, together, and *luere*, to wash) is usually understood to refer to matter washed or brought together by the *ordinary* operations of water.

The soil and sands of river banks, deposited from overflows, of plains which have been once the sites of lakes, or estuaries of the sea, and the sand and mud resulting from tidal action, are considered as alluvial.

Drift or Diluvium (Lat. *dis*, asunder, and *luere*, to wash) is the name given to accumulations of abraded materials—sand, clay, gravel and fragments of rocks—brought together or produced by the apparently violent action of water, or water and ice conjointly.

51. **Soil** is merely disintegrated and decomposed rock, containing a variable proportion of organic matter, the product of decomposed vegetable or animal substances.

The principal mineral constituents of soils are silica (sand), alumina, lime, magnesia and oxyd of iron; of these silica is the most abundant, and frequently forms nine tenths of the entire weight of the soil. Good arable soil, in addition, always contains small quantities of potash, soda and phosphoric acid.

The relative proportions of sand, clay and lime in soils give to them certain peculiar physical characters. A soil in which sand predominates is light and porous; an excess of clay, on the other hand, renders it heavy and retentive of moisture. The best soils are those in which the earthy constituents are so proportioned that the light, porous qualities of one are balanced by the close, retentive properties of the other.

The quantity of organic matter (humus) derived from the decomposition of animal or vegetable substances present in a soil essentially modifies its character. The *average* amount of organic matter contained in soils is about five

QUESTIONS—What is alluvium? What is drift or diluvium? What is a soil? What are the principal mineral constituents of soils? What gives to a soil its physical characteristics? What is said of the organic constituents of soils?

per cent. Fertile alluvial soils, or those deposited from water, are generally characterized by the presence of a much larger proportion, and in some peaty soils the amount may exceed seventy or eighty per cent.

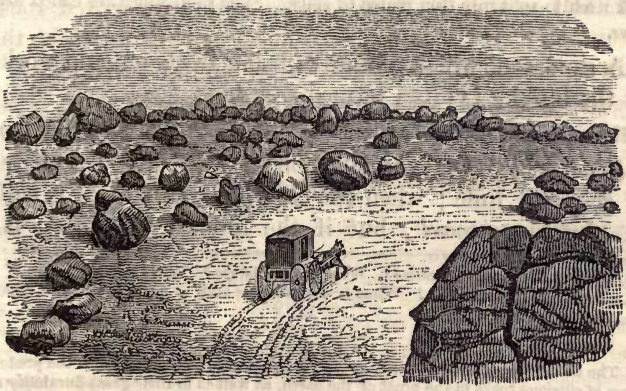
The presence of organic matter in a soil is easily proved by igniting a thoroughly dried portion and noting the loss of weight consequent upon the operation.

52. **Gravel** is the term applied to the water-worn fragments of rocks, when the pebbles or particles vary from the size of a pea to that of a hen's egg. It is generally composed of fragments of the harder and more silicious rocks —as these longest resist the process of attrition.

53. **Bowlders** are detached masses of rock, generally of a rounded form, scattered over the soil or distributed throughout the surface material. They are often of immense size and are not necessarily like the rocks which are contiguous or underlying.

Fig. 18 represents the appearance and distribution of bowlders at a locality on Cape Ann, Massachusetts.

FIG. 18.



54. **Conglomerates** are cemented masses of gravel and pebbles of all sizes ; in other words, consolidated gravel.

QUESTIONS.—How may the presence of organic matter in soils be determined? What is gravel? What are bowlders? What are conglomerates?

They are sometimes termed "pudding-stones," from the fancied resemblance of their pebbles to the fruit in a plum-pudding.

When the term "conglomerate" is used alone, we usually understand a mass of quartz pebbles united by a silicious sand or cement; but when the pebbles consist of trap, limestone, slate or other rock, the fact is denoted by calling them trappean, calcareous or slaty conglomerates, etc.*

55. **Breccias** are compacted masses of *irregular*, *angular* fragments; whereas in conglomerates the component pebbles are always rounded and water-worn.

56. **Sandstone** is simply consolidated sand, the particles being compacted by pressure, or held together by some cementing material.

Sandstones exhibit every variety of color. The red appearance of the sandstones of the valley of the Connecticut, of New Jersey, North Carolina, etc., is mainly due to the covering of each little grain with peroxyd of iron, which sometimes acts as a cement to the stone and binds its particles together. Flakes and spangles of mica occur so abundantly in some sandstones, and in such regular seams, as to cause the rock surfaces to glitter and the rock itself to split into thin plates or slabs. Such sandstones are called *micaceous.*

A sandstone which admits of being freely cut and worked by the builder is often termed *freestone.*

The composition of clay has been already noticed. (See § 14, page 19.)

57. **Marl** is a loose appellation for all friable compounds of clay and lime; when the clay predominates it is called an *aluminous marl;* but if the lime is in excess, it is

QUESTIONS.—What are breccias? What is a sandstone? What is the occasion of the red color of many sandstones? When is a sandstone said to be micaceous? What is freestone? What is marl?

* The abundance of silica in sand, gravel, conglomerates, etc., is due to the predominance of silicious rocks in the crust of the earth, as well as to their great durability and mode of fracture. Highly silicious minerals are not easily acted upon by water or any other common solvent, and are not, therefore, so easily disintegrated by chemical force as those which contain lime or other minerals. On the other hand, quartzose rocks, though very hard, are often rather brittle and tend to break into cubical masses rather than into plates or slabs. These masses are soon converted, by motion in water and the consequent rounding of their angles, into more or less globular pebbles, and are moved by the action of currents with comparative facility.—*Jukes.*

termed a *calcareous marl.* "*Shell-marl*" is the term applied to such varieties as contain abundant remains of shells.

58. **Loam** is a soft and friable mixture, containing much clay, sufficient sand to render the mass permeable by water and prevent plasticity, some iron, and a varying proportion of organic matter.

59. **Shale** (Ger. *schalen*, to peel or scale off) is a term applied to such argillaceous (clayey) rocks as split with facility into irregular plates or layers, in a direction parallel to each other and the original planes of deposition.

60. **Slate.**—This term is often applied to all hard rocks that can be readily split up. It should, however, be restricted to the highly compact and indurated argillaceous rocks, like roofing slate, which split with great regularity into thin, smooth plates, or layers.

In true slates the splitting or "cleavage" does not necessarily take place (as in shale) in lines parallel to the original planes of deposition, but it may be at right angles to them.

61. **Schist** is a term often used as synonymous with slate, but is properly limited to argillaceous rocks more highly indurated than slates or shales, often highly crystalline in texture, and which split either with the bedding or across it, but with much less facility and regularity than the slates.

In general, a rock described as "*schistose*" is understood to have an imperfect slaty structure, but the transitions from shale to slate, and from slate to schist are often so gradual as to be hardly discernible.

62. **Aqueous Rocks of Chemical or Organic Origin.**—Under this group are included most of the limestones (carbonate of lime), with the exception of some of the more highly crystalline varieties (statuary marble), which

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QUESTIONS.—What is loam? What is shale? What is slate? What is schist? When is a rock said to be schistose? What aqueous rocks may be especially referred to a chemical or organic origin?

are considered as metamorphic; the magnesian limestones; silicious sinter; infusorial earths; gypsum (sulphate of lime); rock-salt; coal in all its varieties, etc., etc.

Carbonate of lime is nearly insoluble in pure water (dissolving only to the extent of two grains to the gallon); but in waters charged with carbonic acid gas it dissolves freely. The waters of ordinary springs, rivers and lakes always contain some carbonic acid,* and in almost all of them carbonate of lime is retained in solution in variable proportions. In some springs it occasionally reaches the point of saturation, which is about 105 parts in 100,000. In the river Thames the quantity of carbonate of lime present has been estimated to be fifteen parts in 100,000 of water; in the Rhine, at Bonn, 9.46 parts in 100,000,†

Notwithstanding the immense amount of carbonate of lime continually carried into the ocean by land-drainage, the quantity found in sea-water is very small, and in most analyses of sea-water it is not mentioned at all.‡ This curious fact has been accounted for on the supposition that carbonate of lime is continually abstracted from sea-water by marine animals, for the formation of their shells and other hard parts of their structure.

When waters containing carbonate of lime in solution are agitated or heated, or even exposed continuously to the air, the carbonic acid, entirely or in part, escapes, and the lime is precipitated, forming incrustations, which may be often noticed in the channels of streams, or more commonly in water-pipes and on the sides of kettles and steam-boilers (the *fur*).

63. **Stalactites and Stalagmites.**—This action is beautifully illustrated in the formation of concretionary calcareous deposits in caverns, termed "stalactites" and "stalagmites."

Water charged with carbonate of lime and carbonic acid falls in drops from the roof and sides of the cavern; but each drop, before falling, remains suspended for a time, during which it loses, by evaporation, both water and carbonic acid gas, and its solvent power being thus diminished, a minute por-

QUESTIONS.—What is said of the presence of carbonate of lime in water? What is said of the presence of carbonate of lime in sea-water? When will carbonate of lime be precipitated from solutions? Describe the formation of stalactites and stalagmites.

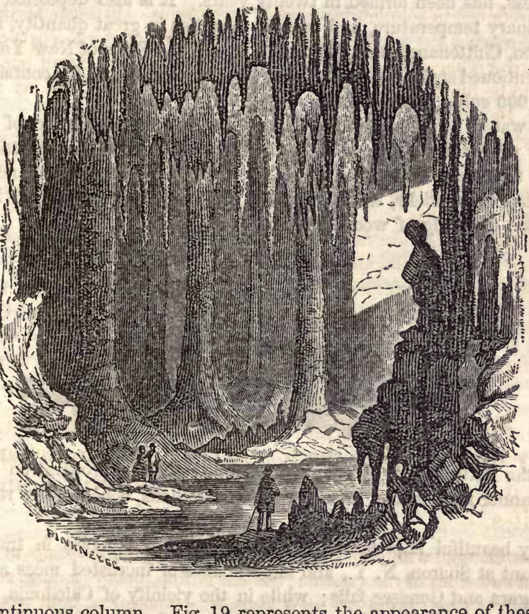
* Soils rich in organic matter contain much carbonic acid, and water, in percolating through them, is capable of absorbing it to the extent of about two thirds of its bulk. Rain-water and snow, also, acquire some carbonic acid from the atmosphere.

† Bischof calculated that the mean quantity of carbonate of lime carried into the sea by the Rhine is sufficient for the yearly formation of three hundred and thirty-two thousand millions of oyster-shells of the usual size.

‡ Other combinations of lime, *i. e.*, sulphate of lime, chloride of calcium, and the like, are always found in sea-water.

tion of solid carbonate of lime is deposited. The same drop also deposits another minute portion of calcareous matter on the spot upon which it falls, and as the drops collect on nearly the same spot for a long period of time, a dependent mass like an icicle is formed from the roof of the cavern—the stalactite; while another incrustation gradually rises up from the floor beneath—the *stalagmite*. In the process of time the two may meet, and thus

FIG. 19.



form a continuous column. Fig. 19 represents the appearance of these depositions in the Mammoth Cave of Kentucky. Vertical sheets of the same material may also be built up, as when the water drips from a long joint or fissure in the roof. The limestone thus formed is commonly white or pale yellow, often fibrous, and when thin, semi-transparent and crystalline.

Stalactites may also often be observed under vaults and arches, especially if the stone of which they are constructed is limestone.

64. **Calcareous Tufa, or Travertine** is a deposit analogous to stalactite, formed at the margins or bottoms of

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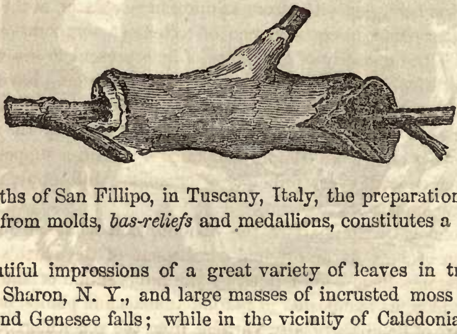
QUESTION.—What is calcareous tufa, or travertine?

springs or rivers, or wherever water holding carbonate of lime in solution is subjected to evaporation.

Travertine forms beds of limestone of considerable extent, which is often crystalline, and sufficiently compact to be used for architectural purposes. The Colosseum at Rome and the walls and temples at Pæstum are built of stone thus formed.* Thermal springs produce travertine most abundantly, and at a locality in the vicinity of Rome a layer of this rock, thirty feet in thickness, has been formed in twenty years. It is also deposited by springs of ordinary temperature, and in some localities in great quantity, as at New-Lebanon, Chittenango and Sharon Springs, in the State of New York. At the last-mentioned springs a mass of tufa has been formed, which contains upward of 200,000 cubic yards of rock.

The waters of some springs contain so large a proportion of calcareous matter when they first issue from the earth, and deposit it so readily on exposure to the air, that advantage is often taken of the circumstance to obtain incrustations of sticks, leaves, baskets, birds' nests, etc. Fig. 20 is a representation of a twig of wood thus incrusted.

FIG. 20.



At the Baths of San Fillipo, in Tuscany, Italy, the preparation of casts in this manner from molds, *bas-reliefs* and medallions, constitutes a regular business.

Very beautiful impressions of a great variety of leaves in travertine are abundant at Sharon, N. Y., and large masses of incrusted moss are common at Niagara and Genesee falls; while in the vicinity of Caledonia, Livingston Co., N. Y., the incrustations of organic structures are so abundant that they are used in the construction of walls and fences.

65. **Fresh-Water Limestones.**—This name has been given to a class of limestones which have evidently been deposited at the bottom of fresh-water lakes.

Some varieties resemble travertine in their appearance, but in general they

QUESTIONS.—Give some examples of its formation. What are the fresh-water limestones?

* The name "travertine" is derived from the river Tiber, and simply means "Tiber-stone."

appear to be the result of the deposition of a calcareous mud (the product of the disintegration of shells and the wear of previously existing limestones) mingled with clay and the detritus of other rocks. In some instances the proportion of clay present is sufficient to convert them into marls. Fresh-water limestones are usually rich in organic remains—shells, bones of animals and the leaves and stems of plants.

66. **Marine Limestones.**—Limestones of the class of travertines, tufas and fresh-water limestones constitute, however, but a very small proportion of the great deposits of carbonate of lime distributed throughout the earth's crust; and most of the calcareous rocks, from the abundant remains of marine animals, corals, shells, etc., contained in them, appear to have been formed beneath the waters of the ocean, and are, therefore, termed "marine limestones."

Geologists and chemists are not fully agreed as to the manner in which these immense deposits of marine limestones have originated. That carbonate of lime has been deposited from solution in sea-water, at the bottom of the ocean, like travertine, in consequence of extensive evaporation, is obviously improbable. The quantity of carbonate of lime present in sea-water is, moreover, comparatively small. Some geologists, therefore, have advocated a theory that lime is an organic product, and that the marine animals and plants, which secrete carbonate of lime abundantly, produce it by the agency of vitality from other and more simple substances. Such a supposition is, however, at variance with every principle of chemical philosophy, and at present has few or no supporters.

Other geological writers are of the opinion, that whatever may have been the condition of lime as an original constituent of the earth's crust, all the marine limestones have been formed by the intervention of the powers of organic life, which, as manifested in marine animals and plants, have abstracted the carbonate of lime, particle by particle, from the sea-water, and by solidifying it, have enabled it to form compact rock-masses.* This hypothesis finds

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QUESTIONS.—What evidence have we that the majority of the limestones are of marine origin? What theories of their origin have been adopted?

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* "When we consider the vast quantity of carbonate of lime which is daily and hourly being separated to form the solid parts of animals, and remember that the operation goes on in wide tracts of open water as well as on the sea-shore to a far greater degree than is possible on land; that every race of molluscs, crustaceans and zoophytes, inhabiting shells, or building coral reefs, or constructing other stony skeletons and dwelling-places, secretes a quantity of this material from the sea-water and renders it permanent in a solid form:—when we remember, too, that the quantity secreted by each individual during its brief existence is almost always greater in proportion as the animal is smaller and

strong support in the fact that nearly all the stratified limestones abound in the fossil remains of marine organisms, and in many instances the entire mass of rock over wide areas is *wholly* composed of corals and shells compacted together by a calcareous mud or cement derived from the waste of analogous materials.

Similar marine limestones, furthermore, are now in process of formation on an extensive scale in most tropical seas, which abound with shells and corals. In the vicinity of Florida, Hayti and the Bermudas, especially, the sea is loaded with fine calcareous matter, the product of the action of the waves on coral reefs and dead shells; and these fine particles of lime, acting as a cement between larger fragments of shells and corals, gradually produce hard, compact limestones. Recent investigations by Prof. Agassiz have shown, that in this way the whole of the southern portion of the peninsula of Florida, extending from the Atlantic to the Gulf of Mexico, and including the district known as the "Everglades," has been built up from the ocean.*

From these and similar facts and observations (which will be noticed more in detail hereafter), we are able to form tolerably accurate notions respecting the origin of many marine limestones—making allowance, at the same time, for the changes which they have undergone in texture since their formation and elevation above the ocean, from the pressure of overlying strata of other rocks—from the denuding and chemical action of rain-water and the atmosphere—or from the contiguity of rocks of an igneous origin.

Recent investigations, conducted by Mr. T. S. Hunt of the Canadian Geological Survey, have also rendered it probable that some of the marine limestones have had a direct chemical origin.†

67. **Magnesian Limestones** (*carbonates of lime and magnesia*) occur abundantly in the earth's crust. They are

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its life shorter, and at the same time that the number of individuals is then largest and the multiplication of the species most rapid, little astonishment will be felt at the vast accumulations thus made in the course of years, or the result thus produced upon the mass of solid matter in the earth's crust."—*Ansted.*

* On the coast of the Antilles these formations of the present ocean contain articles of pottery and other objects of human industry, and in Guadaloupe even human skeletons of the Carib tribes. In Hayti similar formations, called by the negroes Maçonnerie bon Dieu (God's Masonry) extend inland thirty miles, and rise to a height of upwards of a thousand feet above the present sea-level.

† Mr. Hunt has shown that the addition by degrees of dilute solutions of bi-carbonate of soda to liquids which, like sea-water, contain both salts of lime and magnesia, causes the separation and precipitation of the whole of the lime present as carbonate, and then gives rise to solutions of bi-carbonate of magnesia, which separates from concentrated solutions as a hydrous carbonate. The bi-carbonate of soda is, at the same time, converted into chloride of sodium (common salt). We have thus an explanation of several points which geologists have hitherto found difficulty in accounting for, viz., the production of some marine limestones, of the magnesian limestones (carbonates of lime and magnesia), and in part of sea-salt; the bi-carbonate of soda, the agent in producing these changes, being derived from the decomposition of feldspathic rocks and carried into the

supposed to have been formed through the chemical decomposition of the salts of lime and magnesia contained in sea-water and to have been deposited at the bottom of an ancient ocean.

Magnesia is one of the most abundant of the mineral constituents found in sea-water, but does not enter to any extent into the composition of the hard parts of marine animals—corals, shells, etc.

Magnesian limestones are very variable in their lithological characters. In general they are inferior in compactness and fineness of texture to pure carbonate of lime, and are commonly of a yellowish-brown or gray color, with very frequently a pearly luster. Some varieties are earthy and friable, while others admit of being split into long, thin slabs, which are sometimes flexible, and constitute the so-called "elastic marble."* Many magnesian limestones have also a curious concretionary structure.

Silicious Sinter.—This name (Ger. *sintern*, to drop) is given to aqueous deposits of silica, most frequently observed in the vicinity of thermal (warm) springs.

Thus at the Geysers, or hot springs of Iceland, a deposit about a mile in diameter and twelve feet thick occurs; and at the hot springs of the Azores elevations of silicious matter thirty feet in height have been formed.

68. **Infusorial Earth.**—Microscopic investigations have shown that many accumulations of stratified earths and rocks are almost wholly composed of the mineral structures—shells or skeletons—of minute animal or vegetable

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QUESTIONS.—What is said of the distribution and formation of the magnesian limestones? What of their character? What is silicious sinter? What is infusorial earth?

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sea by washings from the land. The decomposition of the feldspathic rocks has further resulted in the formation of clays and clay-slates.

The following analysis by Von Bibra shows the mineral constituents of the waters of the North Atlantic:

Solids in 100 parts of water	3.47 per cent.
Chloride of sodium (common salt) in 100 parts of solids . .	76.05
Chloride of magnesium " " " . .	9.00
Chloride of potassium " " " . .	4.00
Bromide of sodium " " " . .	1.15
Sulphate of lime (gypsum) " " " . .	4.60
Sulphate of magnesia (Epsom salts) " " " . .	5.20
Sulphate of potassa " " " . .	traces.

Carbonate of lime, fluorine, iron, silica, phosphoric acid, ammonia, baryta, strontia, manganese and iodine also exist to some extent in sea-water.

* The magnesian limestone found at New Ashford, Berkshire county, Mass., when sawed into slabs exhibits a very high degree of flexibility.

organisms, which, from the circumstance that similar forms are readily obtained from most stagnant infusions of vegetable matter, have been called *infusoria*.*

The composition of these shields or casings is frequently pure silica; but they may be composed of lime or even oxyd of iron—these substances being secreted by the organism from water holding silica, lime or oxyd of iron in solution.

The dimensions of the infusorial structures are so minute, that the greater portion require the aid of a microscope to establish the fact even of their existence; many complete individuals being less than 1-3000th of an inch in length. According to Ehrenberg (a German microscopist who has made this subject a speciality) 35,000 millions of some species would be requisite to occupy the space of a single cubic inch, and the late Prof. Bailey, of West Point, estimated the number of separate structures in a cubic inch of infusorial earth from Maidstone, Vermont, at 15,625,000,000.

Notwithstanding, however, the almost inconceivable minuteness of these organisms, the rock deposits formed and now forming of their remains are of great extent and thickness. At Richmond, Virginia, beds of silicious infusorial earth occur from twenty to fifty feet in thickness, and deposits of less magnitude may be found in almost all sections of the United States. In Germany beds a hundred miles in extent have been noticed, with a thickness, in some localities, of upward of sixty feet.

Fig. 21 is a magnified representation of some of the microscopic structures most common in the infusorial earths of Richmond, Va.†

QUESTIONS.—What is the composition of the so-called infusoria? What are their dimensions? What is said of their distribution?

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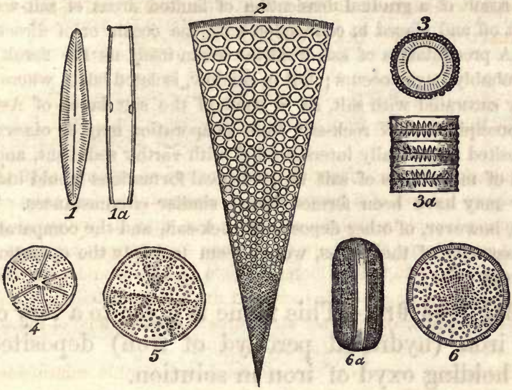
* The term *infusoria* was originally used as a general designation for a great variety of microscopic organisms, which were also regarded as animalcules (little animals). Recent investigations, however, have shown that many of the so-called "infusoria" are not animals, but microscopic plants belonging to the natural order Algæ;—as, for example the *diatomaceæ*, which are simply vegetable cells so covered with silica that they retain their structure permanently, and have thus been enabled to constitute geological deposits of great extent and thickness. According to the most recent zoological classification, the term *infusoria* is now applied only to certain forms of animalculæ which constitute the highest class of the *Protozoa*, which last is the name given to the first or *lowest* division of the animal kingdom. According to the latest zoological authorities, moreover, there are no fossil *infusoria*, but the microscopic organisms usually designated by this name include a variety of animal and vegetable species, *e. g.*, Foraminifera, Diatomaceæ, etc.

† Fig. 1 is termed a navicula (like a little boat); 1 *a*, a side view; 6 and 6 *a* represent curious saucer-shaped shells or discs, having surfaces elaborately ornamented with hexogonal spots disposed in curves, presenting some resemblance to the engine-turned case of a watch, as especially shown in Fig. 2, which is a small segment of a disc highly magnified. These discs vary in size from 1-100th to 1-1000th of an inch in diameter, and are named coscinodiscus (sieve-like disc). 3 and 3 *a* are jointed forms, called Gallionella; 4 and 5 are circular bodies with five or six lines radiating from the center like the spokes of a wheel, and hence termed Actinocylus.

FIG. 21.



69. **Sulphate of Lime** (*gypsum*) and **Rock-Salt** (chloride of sodium) both occur in sufficient abundance in numerous localities to merit the designation of rock-masses.

Gypsum is found under various conditions; sometimes as regular beds of considerable extent and thickness; sometimes as irregular concretionary masses, and not unfrequently in the form of veins or seams in other rocks. *Alabaster* (so called from the town Alabastron in Egypt) is a compact variety of gypsum. *Selenite* is a crystalline and often transparent variety.

Rock-salt commonly occurs in imperfectly crystalline, irregularly bedded masses, associated with various clays and marls, and very frequently with beds of gypsum, as if the salt and gypsum had both been deposited at nearly the same time and under the same circumstances. At Wurtemberg, Germany, beds of salt occur in limestone. In England bed-like masses of salt are often sixty to ninety feet thick, thinning out apparently in all directions, and thus assuming the form of large cakes. A deposit of rock-salt near Cracow, in Poland, is estimated to be 500 miles in length, twenty broad, and not less than 1,200 feet thick. As a mineral, rock-salt is sometimes perfectly pure and white, but in most cases it is obtained in the condition of an impure chloride of sodium, in masses of a dirty red color, and with little of that transparency and brilliancy which characterize the pure mineral.

70. **Origin of Sulphate of Lime and Rock-Salt.**—Sulphate of lime and rock-salt are generally believed to have been deposited from sea-

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QUESTIONS.—What is said of the distribution of sulphate of lime and rock-salt? What is gypsum? Under what circumstances does it occur? What are some of its varieties? In what condition is rock-salt found?

water, of which they are abundant constituents. This deposition may have been the result of a gradual dessication of limited areas of salt-water, alternately cut off and placed in connection with the ocean, or of direct chemical action. A precipitation of salt from the ocean itself, as the result of evaporation, probably never occurs; but in shallow, isolated lakes, where the water is entirely saturated with salt, as in some of the salt lakes of Asiatic Russia, the precipitation of rock-salt from evaporation may be observed. Salt thus deposited is generally interstratified with earthy sediment, and the like condition of many beds of salt in geological formations would indicate that the latter may have been formed under similar circumstances. The great thickness, however, of other deposits of rock-salt, and the comparative purity and homogeneity of their mass, would seem to imply the operation of more active forces.

71. **Bog Iron Ore.**—This name is given to a very common ore of iron (hydrated peroxyd of iron) deposited from waters holding oxyd of iron in solution.

Oxyd of iron is only slightly soluble in pure water, but waters which contain organic acids—the products of decomposing vegetable matter—dissolve out oxyd of iron freely from the earth and rocks with which it (the water) comes in contact. The iron which thus passes into solution is, after a time, by exposure to the air and a continuance of the decomposing action, precipitated from the water in an insoluble form, and in this way deposits of yellow, earthy oxyd of iron are formed, of varying extent and thickness. From the circumstance that such deposits are formed most frequently at the bottom of bogs and marshes, they have received the name of "bog iron ore." The iridescent film which may be often noticed on the surface of stagnant waters is composed of oxyd of iron passing from a state of solution. Many specimens of "bog iron ore," when examined under the microscope, will appear to be almost entirely composed of the shields of infusorial organisms.

72. **Hydrate of Manganese** is frequently deposited from shallow pools and lakes of fresh-water in the form of an earthy oxyd, technically called "*wad*," or "*wadd*."

The blackening of stones and pebbles in the beds of streams flowing over silicious rocks is in a great measure due to a thin incrustation of oxyd of manganese—a phenomenon which may be especially noticed in most of the mountain streams of New England.

73. **Coal**, which is essentially of organic origin, is a rock

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QUESTIONS.—What is said of the origin of sulphate of lime and rock-salt? What is bog iron ore? How is it formed? What is said of the distribution of manganese? What is coal?

generally familiar in its aspect and nature. It occurs in the earth in beds or seams, associated or interstratified with shales, indurated clays, limestones and earthy ores of iron.

Lignite, *bitumen*, *asphaltum* and the like, are mineral products of organic origin allied to coal. Their composition, character and distribution will be considered in a subsequent chapter.

CHAPTER VI.

VARIETIES AND LITHOLOGICAL CHARACTERS OF THE METAMORPHIC ROCKS.

74. The term "Metamorphic," when applied to rock masses, signifies, as has been already stated, that their original structure, texture and chemical condition, have undergone some internal change or metamorphosis.*

As there is, however, scarcely one of the infinite variety of accumulations of mineral matter constituting the earth's crust, which has not been changed to a greater or less degree since its formation, by chemical or mechanical

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QUESTIONS.—What is the signification of the term "metamorphic," as used in geology?

*** Professor Studer, a celebrated Swiss chemist and geologist (Edin. New Phil. Journ., Jan., 1848), defines metamorphism as follows:—"In its widest sense, mineral metamorphism means, every change of aggregation, structure, or chemical condition which rocks have undergone subsequently to their deposition and stratification, or the effects which have been produced by forces other than gravity and cohesion. There fall under this definition the discoloration of the surface of black limestone by the loss of carbon; the formation of brownish-red crusts on rocks of limestone, sandstone, many slate stones, granite, etc., by the decomposition of compounds of iron finely disseminated in the mass of the rock; the change in rocks consequent on the absorption of water; and the crumbling of many granite and porphyries into gravel, occasioned by the decomposition of the mica and feldspar. In its more limited sense, the term metamorphic is confined to those changes of the rock which are produced, directly or indirectly, by agencies seated in the interior of the earth. In many cases the mode of change may be explained by our physical or chemical theories, and may be viewed as the effect of temperature or of electro-chemical actions. Adjoining rocks, or connecting communications with the interior of the earth, also distinctly point out the seat from which the change proceeds. In many other cases the metamorphic process itself remains a mystery; and from the nature of the products alone do we conclude that such a metamorphic action has taken place."**

agencies, it is obvious that a classification, founded on such a characteristic, must of necessity be exceedingly general. In fact, by some authorities, metamorphism is not considered as affording a sufficient basis for the establishment of a classification, while the majority of geologists, who recognize it as such, are not fully agreed as to its limitations. Some geologists even consider granite and other highly crystalline and compact rocks, to which a direct igneous origin is usually assigned, as truly metamorphic, or, in other words, as sedimentary strata, altered under the influence of heated water, or water holding chemical agents in solution. These views, which derive strong support from the results of recent investigations, are not, however, adopted by *all* geologists, and in the present work we shall describe only those rocks as metamorphic which are *generally* believed to have been originally deposited as sediments, and to have acquired their present compact, crystalline, or semi-crystalline character through the subsequent action of various chemical or mechanical agencies.

Under such restrictions, the following rocks may be enumerated as belonging to the class metamorphic:—

CLAY, OR ARGILLACEOUS SLATE; QUARTZ ROCK, OR QUARTZITE; HORNBLENDE SCHIST; TALCOSE SCHIST; MICA SLATE, OR SCHIST; GNEISS; ALTERED, OR METAMORPHIC LIMESTONES; DOLOMITES, OR CRYSTALLINE MAGNESIAN LIMESTONES; SERPENTINE.

75. **Clay, or Argillaceous Slate** (common slate, as it is frequently designated) is an indurated, compact clay rock.

As a result of the metamorphic action to which it has been subjected, it has assumed a perfectly "fissile" or slaty structure, a peculiarity which renders some varieties especially valuable for roofing and flagging purposes. The finer sorts are also used for writing-slates and slate-pencils, and to some extent for hones and whetstones. The prevalent colors of clay slate are a dull blue, red, green, purple, gray and mottled. It passes, by insensible gradations, into hard, crystalline schists, containing quartz and mica, on the one hand, and on the other into dull, friable shales, or even into unconsolidated clay.*

Clay slates, containing sulphuret of iron (iron pyrites), tend to undergo decomposition on exposure to air and moisture; the sulphur of the sulphuret

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QUESTIONS.—What is said of a classification of rocks founded on such changes? What class of rocks are usually termed metamorphic? Enumerate them? What is clay slate?

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* According to some geologists, clay slate is the only rock to which the term slate properly applies; the other fissile argillaceous rocks being either shales or schist.

of iron uniting with oxygen to form sulphuric acid, which subsequently combines with the alumina of the clay to form sulphate of alumina. This latter product, which frequently appears on the surface as a white efflorescence, and may be obtained in solution by washing, is practically valuable in the arts for the manufacture of alum, and the slates capable of yielding it by decomposition are technically known as *alum slates*.

76. **Quartz Rock, or Quartzite,*** is a compact, fine-grained, but distinctly granular rock, very hard, frequently brittle, and often so divided by joints as to readily split in all directions.

Its colors, from the presence of oxyd of iron, are generally of some shade of yellow, passing into dull red or brown.

"When examined with a lens it may be seen to be made of grains, which appear sometimes as if they had been slightly fused together at their edges or surfaces, and sometimes as if embedded in a purely silicious cement. This cementation or semi-fusion of the grains shows at once that it is a sandstone which has been altered or indurated by the action either of heat alone or heat and water. It has been either *baked* or *steam-boiled*."—JUKES.

In some varieties of quartz rock, resulting from an intermixture with hornblende, talc, mica, or clay slate, the regular stratification is often apparent, but in other cases every trace of a mechanical structure seems wanting.

77. **Hornblende Schist** (hornblende rock) consists mainly of hornblende, with varying proportions of feldspar, quartz, mica, or talc. Its color is usually dark green.

78. **Talcose Schist.**—The characteristic and essential constituent of this rock is *talc*, associated with quartz, and sometimes with mica, feldspar, hornblende, and limestone. Its prevailing color, owing to the abundance of the talc, is a tint of green. When *chlorite* is found in the place of talc, the rock is termed a *chloritic schist*.

79. **Mica Schist** (mica slate) consists of alternate layers of mica and quartz, the mica predominating, and existing

QUESTIONS.—What is the characteristic of clay slate? What are alum slates? What is said of quartz rock, or quartzite? What are the characteristics of hornblende schist? What of talcose schist? What of mica schist?

* The student must carefully distinguish between pure vein quartz and the quartz rock, as here described. The former has a highly vitreous or flinty texture, is never granular, and, although sometimes occuring in large masses, it is more commonly noticed in the form of veins, or segregations in other rocks.

usually in the form of small particles. Its color is gray, with a shining, lustrous appearance.

Owing to the facility with which mica schist divides into large, smooth slabs, it is largely used for flagging purposes; and, at an extensively worked quarry at Bolton, Conn., smooth slabs of it, eight to twelve feet square, by one and a half to three inches thick, are very frequently obtained. Mica schist is one of the most common rocks of the metamorphic series, and in many localities abounds to such an extent in the minerals, garnet and staurotide, that the latter may be properly regarded as constituents of it.

80. **Gneiss**, in its purest and typical form, has the same component elements as granite: viz., quartz, feldspar and mica, with an occasional admixture of hornblende, all more or less crystalline. Unlike granite, however—which presents a confused aggregation of crystals—the constituent minerals of gneiss are arranged in parallel lines or layers; hence, it exhibits a marked laminated or stratified appearance, and by most geologists is considered as really stratified.

Sir Chas. Lyell designates gneiss as "stratified granite;" but some authorities are inclined to refer the peculiar laminated appearance of this rock to the circumstances under which it cooled from a state of fusion rather than to an original aqueous deposition of its particles.

Fig. 22 represents the appearance and structure of gneiss.

Fig. 22.

Some varieties of gneiss, by an indefinite transition, actually pass into granite; others, on the contrary, can scarcely be distinguished from mica schist, which last, through various gradations, may pass into talcose schist, and even into dull, earthy clay slate.

The contortions of the layers or strata of gneiss and mica-schist are, in some localities, most remarkable, and on a magnificent scale. (See Fig. 23.) "Imagination," says MacCulloch, "can scarcely conceive an intricacy of flex-

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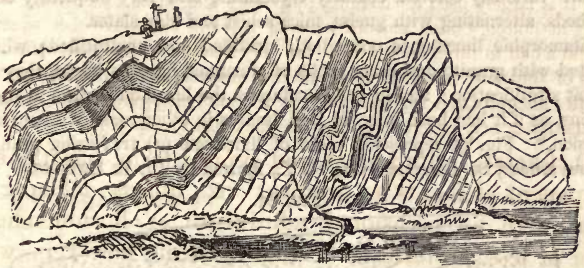
Questions.—Describe gneiss? What is said of the contortions of gneiss and mica slate.

ure of which a resemblance cannot be found in the gneiss of the western islands of Scotland." In other localities, however, the same rocks are distinguished for their regularity and evenness.

FIG. 23.



81. **Distribution of the above-described Metamorphic Rocks.**—The metamorphic rocks above-described are widely distributed, and constitute portions of most of the older mountain chains upon the surface of the globe—gneiss and mica slate being perhaps the most abundant members of the series. In the United States, these rocks, with few exceptions, form the White Hills of New Hampshire, the Green Mountains of Vermont and Western Massachusetts, and the Blue Ridge of the Southern States. They do not, however, occupy very great superficial areas, but are usually found compressed and tilted up at high angles (not unfrequently at right angles to the original plane of their deposition), thus producing rugged and abrupt scenery. They are everywhere associated with, and traversed by, rocks of an apparently igneous and eruptive origin, such as granite, syenite, and porphyry—which agencies would also appear to have been productive of metamorphism, upheavals and contortions.

The soils resulting from the decomposition of gneiss and mica slate are not unfruitful; but those resulting from the decomposition of clay slate are cold and clayey, and generally unproductive.

82. **Altered or Metamorphic Limestones.**—These limestones, which were formerly called "primitive" or "primary" limestones, are all highly compact and crystalline.*

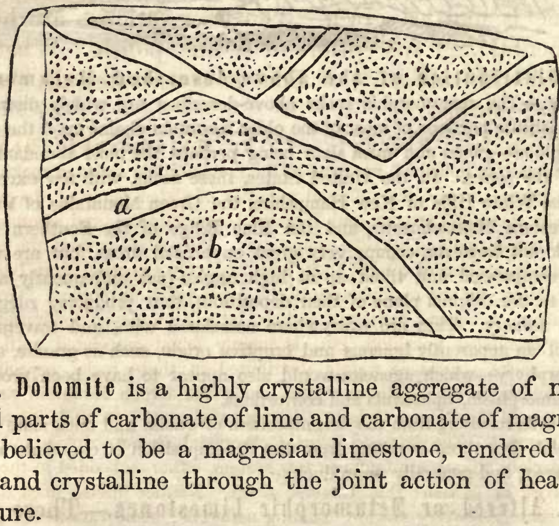
QUESTIONS.—What is said of the distribution of the above-described metamorphic rocks? What of their influence upon the surface and fertility of a country? What are the characteristics of the metamorphic limestones?

* The existence of a crystalline texture in limestones is in itself no proof of metamorphism, in the ordinary sense of the term, inasmuch as it is probable that some limestones were originally formed crystalline. Thus, many parts of a coral reef are, even now, crystalline internally. Carbonate of lime, deposited from solution, may also have a crystalline structure. The famous statuary marbles of Greece and Italy are metamorphic limestones.

"Some are pure white, fine-grained, and slightly translucent, and from their resemblance in color and texture to loaf-sugar are often termed "*saccharine*." Such limestones work freely in every direction, admit of fine polish, and furnish the finest marbles for statuary and architectural purposes. Other varieties are variously colored, coarsely crystalline, and very frequently occur in thin beds, alternating with gneiss, mica schist and clay slates.

Metamorphic limestones occur both stratified and unstratified; when associated with granite and other rocks of presumed igneous origin, they rarely exhibit stratification; and in some instances the limestone exists in the form of veins, as if it had been injected into fissures in other rocks while in a state of fusion.* Fig. 24 represents veins of limestone (*a*) traversing granite (*b*) at Gouverneur, St. Lawrence Co., N. Y., figured by Dr. E. EMMONS.

FIG. 24.



83. **Dolomite** is a highly crystalline aggregate of nearly equal parts of carbonate of lime and carbonate of magnesia. It is believed to be a magnesian limestone, rendered compact and crystalline through the joint action of heat and pressure.

Dolomite is usually white, but is also found of various colors. It is extensively used for the manufacture of lime and also as a building stone. No lime is more highly prized by masons than that made from the close, compact dolomite of Smithfield, R. I., and at Sing Sing, on the Hudson, N. Y. As a building stone, dolomite ranks among the best, possessing in a high degree

QUESTIONS.—What is dolomite? What are its characteristics and industrial uses?

* Experiments have proved that limestone (carbonate of lime), when subjected to pressure sufficient to prevent the escape of carbonic acid, may be entirely fused, and, on cooling, assumes different degrees of consolidation and crystallization, according to the pressure.

the properties of durability and ease in working. It forms a considerable part of the white marble used in the construction of the Capitol at Washington, and the Custom-houses in New York city, and Charleston, S. C., are also constructed of it.*

84. **Serpentine** (see §16) is usually classed among the igneous and eruptive rocks, but the most recent investigations seem to establish its position in the metamorphic series, as the product of a highly altered magnesian limestone. In the Canadian Geological Survey, serpentines have been traced to a gradual termination in unaltered beds of magnesian limestone. The predominant color of serpentine is mottled green. The finer varieties are highly ornamental and susceptible of a fine polish. When associated with carbonate of lime it constitutes the "*verde antique*" marble.

85. **Economic Products of the Metamorphic Rocks.**—The economic or industrial products of the metamorphic series of rocks in the United States embrace the different varieties of slates, many of the marbles (especially those of Vermont and Western Massachusetts), and abundant deposits of serpentine and steatite (soapstone). Pure silicious sand, the product of the decomposition of quartz rock, is extensively exported from Berkshire County, Mass., for the manufacture of the finest varieties of glass. Graphite, or plumbago, a natural variety of carbon, largely employed for writing-pencils, for crucibles, polishing, etc., is mainly found associated with metamorphic rocks. Gold is widely distributed in these rocks, especially in talcose schists, in the Southern States, along the Green Mountain range of Vermont, and throughout Canada; deposits of ores of iron and zinc are also not unfrequent. The diamond, beryl, rock-crystal, garnet, zircon, and many other precious stones, are found in this system, either embedded in the strata themselves, or in veins that traverse them. Neither gneiss, mica slate, or talcose slate, yield very elegant building materials; some varieties of gneiss, however, split with facility into huge blocks, and, being very durable, are extensively employed for massive constructions, as piers, breakwaters, etc.

QUESTIONS.—What is serpentine? What is *verde antique* marble? What are the economic products of the metamorphic rocks?

* In England dolomite has proved so excellent and durable a stone that a variety of it was selected by a government commission as the best material in the kingdom for constructing the new Houses of Parliament. The choir of Southwell Church, which was built of this variety of stone in the twelfth century, was found by the commissioners to be in so perfect a state that "the moldings and carved enrichments were as sharp as when first executed."

TABULAR CLASSIFICATION OF ROCKS.

86. The following table exhibits the principal varieties of rocks, arranged in accordance with the foregoing classification:

IGNEOUS ROCKS.

VOLCANIC.

TRACHYTIC LAVAS (*Trachytes*).	PUMICE.
AUGITIC LAVAS.	SCORIÆ.
OBSIDIAN.	VOLCANIC TUFF.

TRAPPEAN.

BASALT.	DIORITES.
GREENSTONE.	DOLERITES.
PORPHYRY.	AMYGDALOID.
CLAYSTONE.	TRAP TUFF.

GRANITIC.

GRANITE.	GRAPHIC GRANITE.
SYENITE.	PORPHYRITIC GRANITE.
HYPERSTHENE ROCK.	PROTOGENE.

AQUEOUS ROCKS.

MECHANICALLY FORMED.

ALLUVIUM.	SAND.
DRIFT, OR DILUVIUM.	CLAY, MUD.
SOIL.	SANDSTONE.
GRAVEL.	MARL.
CONGLOMERATE AND BRECCIA.	LOAM.
SHALE.	SLATE.

AQUEOUS ROCKS.

OF CHEMICAL OR ORGANIC ORIGIN.

STALACTITE AND STALAGMITE.	COAL, LIGNITE.
CALCAREOUS TUFA, OR TRAVERTINE.	SILICIOUS SINTER.
FRESH WATER LIMESTONES.	INFUSORIAL EARTHS.
MARINE LIMESTONES.	ROCK-SALT.
MAGNESIAN LIMESTONES.	GYPSUM (*Sulphate of Lime*).
BOG-IRON ORE.	HYDRATE OF MANGANESE (*Wadd*).

BITUMEN, ASPHALTUM.

METAMORPHIC ROCKS.

CLAY, OR ARGILLACEOUS SLATE.
QUARTZ ROCK, OR QUARTZITE.
HORNBLENDE SCHIST, OR HORNBLENDE ROCK.
METAMORPHIC OR ALTERED LIMESTONES.
TALCOSE SCHIST.
MICA SLATE, OR SCHIST.
GNEISS.
DOLOMITE.
SERPENTINE.

CHAPTER VII.

STRUCTURE, MECHANICAL DISPLACEMENT, AND RELATIONS OF ROCKS.

87. Having described the varieties and lithological characters of the principal rock-masses which enter into the composition of the crust of the globe, we come next to consider the actual state in which we find them; or, in other words, their *structure*, *position* and *mutual relations*, and also the disturbances to which they have been subjected.

This department of geology, which by some authors is termed "Petrology" (*the study of rock-masses*), is founded on observations which can be made only "in the field," and on an extensive scale.

88. **Stratification and Lamination.**—The aqueous rocks, *in general*, as has been already stated, are characterized by the arrangement of their constituent materials into *strata* and *laminæ;* the former designation being applied to indicate distinct beds, or wide, tabular masses of rock, completely and naturally separated from each other; while the latter refers to the more minute subdivisions or layers of which a bed is made up, and which may, or may not be separable. In short, the laminæ bear the same relation to a single bed or stratum that the latter does to a whole series of beds, or strata.

A careful examination of these beds or layers reveals at once their origin and the history of the rock formation of which they constitute a part. Thus, each little separate layer was obviously the result of a separate act of deposi-

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QUESTION.—What distinction do geologists make between stratification and lamination?

tion of earthy sediment from suspension in water—the interval of time between the successive acts of deposition being distinct, but not so far prolonged as to allow of the consolidation of one layer, before the next was deposited upon it. The whole set of laminæ, therefore, adhere together so as to form one bed, which now, as rock, may be quarried and lifted in single blocks.* The cause of the interruptions in the deposition of the sediment which have produced laminæ we may conceive to have been periodical floods, frequent changes in the force of currents, successive tides, or other like agencies, which, in some instances, renewed the supply of material, and in others deflected it, or suspended its settlement.

If, on the other hand, the interruptions between the acts of deposition were so far prolonged as to allow a mass of laminated material to consolidate to a greater or less extent, it is obvious that there would be a want of coherence between it (*i. e.*, the hardened material) and the sediment next deposited upon it ; and in this way the beds, which we call strata, would be formed with more distinct lines of separation between them than exists between successive laminæ.

The planes of lamination and of stratification, therefore, both mark interruptions in the act of sedimentary deposition; but the intervals between the formation of successive strata were undoubtedly considerably longer than between successive laminæ. In some instances, where the particles of the rock are fine-grained and homogeneous, it is exceedingly difficult to distinguish the planes of lamination from those of stratification. In such cases, the whole mass of the rock may have been deposited rapidly and without interruption; or the divisional structure may have been obliterated by subsequent pressure, or other metamorphic agencies.

Lamination is sometimes parallel with the planes of stratifications; some-

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QUESTIONS.—Explain the manner in which strata and laminæ have originated? Are the planes of lamination always parallel to those of stratification?

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* "In some shales the coherence between the laminæ is very slight, and they may be pulled asunder by the hand ; but in others it is more complete, and in some quite firm. In some laminated, fine-grained sandstones, it requires almost as much force to split them along the lines of lamination (or *with the grain*, to use a common term), as it does to break them across."—*Jukes.*

times inclined, and not unfrequently undulating and tortuous. Fig. 25 represents a case of very contorted lamination, figured by Prof. Hitchcock, in a stratum of gneiss, two or three feet in thickness.

FIG. 25.

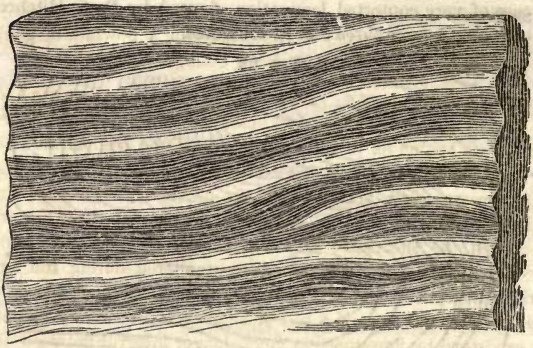
The varieties of lamination clearly indicate the circumstances under which the substance of a rock has been deposited as sediment, or the conditions to which it has been subjected subsequent to its deposition. Thus, *parallel laminæ* must be the result of quiet deposition upon a level surface. *Waved laminæ*, in many instances, are manifestly nothing but ripple or current marks, such as may be seen on the sands of the sea-shore when left dry by the tide, and at the bottom of any clear water where a current is moving over a sandy or muddy surface.* Magnificent examples of this rippled surface may be seen upon the sandstones and shales of the Connecticut River Valley. Fig. 26 illustrates their character. Similar undulating ridges and furrows may be also sometimes seen on the surface of drift snow and blown sand. *Oblique lamination* must generally have been the result of deposition upon a steep shore, where the materials were driven over the edge of an inclined plane.

Highly contorted lamination must have resulted from lateral and vertical

QUESTION.—What is said of the rippled surfaces of rocks?

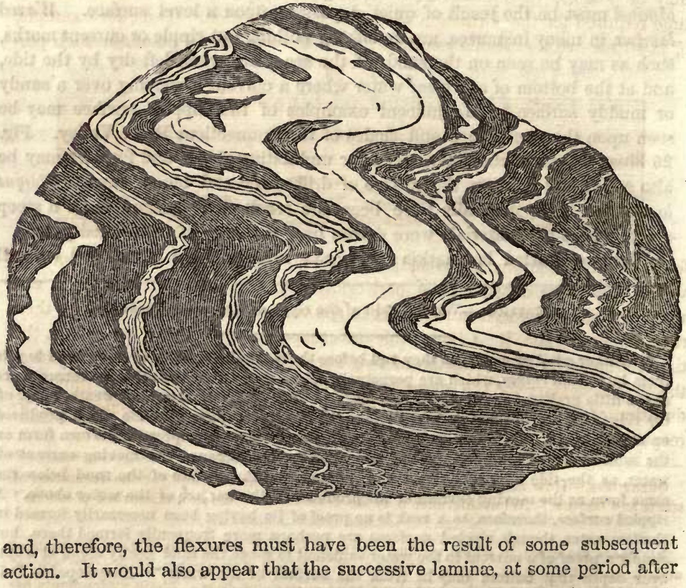
* "Either wind or water, as they roll before them the little grains of sand, tend to pile them into small ridges, which are perpetually advancing one on the other, in consequence of the little grains of sand being successively pushed up the windward or weather side of the ridge, and then rolling over and resting on the lee or sheltered side. It is produced on the sea-beach, not in consequence of the ripple of the wave impressing its own form on the sand below, which would be an impossibility, but because the moving current of water, as the tide advances or recedes, produces on the surface of the sand below the same form as the moving current of air produces on the surface of the water above. A rippled surface, therefore, to a rock is no proof of its having been necessarily formed in shallow water, though rippled surfaces are perhaps more frequently formed there, but simply a proof of a current in the water sufficient to move the sand gently along at whatever depth that bottom may be from the surface of the water."—*Encyclopedia Britannica*, 1859.

FIG. 26.



pressure. Thus, in the case represented by Fig. 25, it is clear that the laminæ could not have been deposited originally in the curved position represented;

FIG. 27.



and, therefore, the flexures must have been the result of some subsequent action. It would also appear that the successive laminæ, at some period after

QUESTION.—What must have been the cause of contorted lamination?

their deposition, must have been in a state so plastic as to admit of bending without breaking.

Fig. 27 represents an example of contortions in a bowlder of gneiss and hornblende schist in the cabinet of Amherst College.

89. **Comparative time required for the Formation of Strata and Laminæ.**—The thickness and cómposition of successive laminæ and strata enable us to form some idea of the comparative time required for their formation. Thus, if a series of beds have precisely the same character and composition, and if the planes of lamination and of stratification blend into one another, it is reasonable to suppose that the intervals of time between the successive depositions were comparatively short, and that the conditions of deposition remained unaltered during the formation of the series in question. If, on the contrary, the successive beds present entirely different characters—if a bed of shale is succeeded by one of sandstone, or sandstone by limestone—a much longer interval between the successive depositions may be properly inferred, since some time must have been required for changes to take place in the conditions of the neighborhood, sufficient to affect the character of the depositions.

When strata and laminæ enclose the remains of fossil animals or plants it may be possible to obtain, moreover, some conception even of the absolute time required for the formation of the rock in question. Thus, for example, if, in strata, we find shells (see Fig. 28), or the remains of plants in such per-

FIG. 28.

fectness and positions as to indicate beyond a doubt that the organisms of which they once constituted a part origiuated, lived to maturity, died, and were gradually inclosed in sediment in the very same localities in which their remains now exist, it is impossible to escape from the conclusion that the time requisite for the formation of two successive strata was *at least* equal to the time necessary for the organisms enveloped to attain maturity, and the duration of this period may be inferred by observing the development of corresponding living species.*

QUESTIONS.—How may we form an estimate of the time required for the formation of strata and laminæ? What inference may we draw from fossils in undisturbed positions?

* "There are cases in which we find on the surface of a bed of limestone the roots or attachments of a particular class of marine animals, called encrinites (see Fig. 29), which, when alive, were fixed to the rock by a solid calcareous base. These attachments belong to animals of all ages, and are in great numbers; and in a bed of clay or shale which

FIG. 29.

90. Position of the Stratified Rocks.—If we assume that the materials of which the stratified rocks are composed were originally deposited as sediment at the botton of seas, lakes, etc., the original position of strata must have necessarily been more or less nearly horizontal,* and in this condition we sometimes find them. In most cases, however, the beds and layers of the sedimentary rocks have been thrown, by the action of various disturbing forces, into inclined and irregular positions, and sometimes even on edge; thus producing extensive surface elevations and depressions.

Fig. 30 represents strata in different positions; A, horizontal; B, inclined; C, highly inclined, or on edge; D, thrown, or *tilted up*. Similar appearances

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QUESTIONS.—What must have been the natural position of the stratified rocks? In what position are they usually found?

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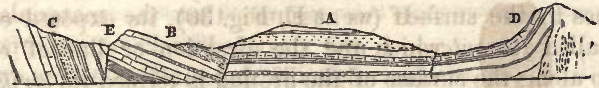
rests immediately on the limestones, there are found a multitude of the remains of the upper portions of these animals, likewise of all sizes and ages. Now, it is plain that in this case, after the limestone was formed, there was an interval during which the sea was quite clear and free from sediment, and, therefore, well adapted for the growth of these animals; and that they, after a time, settled, accordingly, on the limestone at the bottom of the sea, and grew and flourished there for a sufficient period to allow of successive generations arriving at maturity undisturbed before the time when a quantity of mud, having been carried into the water, was deposited upon them, and killed them, and at the same time buried their remains. Here, then, we have an interval of many years, if not of centuries, between the formation of two beds of clay and limestone, which rest directly one upon the other."—*Buckland's Bridgewater Treatise and Jukes' Manual of Geology.*

* The exceptions to the general rule—that strata were originally deposited in a more or less horizontal position—cannot extend very widely, or affect any very important rocks. Deposits now taking place have rarely an inclination greater than 10° over any considerable extent of surface, although under very favorable circumstances, as when sediment accumulates rapidly on steeply shelving coast-lines, strata may be formed with an inclination of from 15° to 30°.

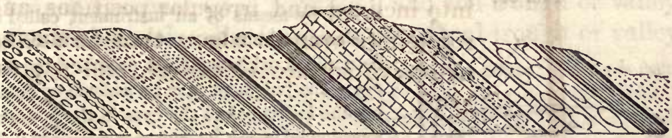
FIG. 30.



may be seen to advantage in almost all railway rock-cuttings, in ravines excavated by water, in sea-cliffs and in quarries.

Evidence in favor of the original horizontal deposition of inclined strata may sometimes be derived from the arrangement of the materials that enter into their composition. Thus, it is frequently observed that vertical or highly inclined strata contain pebbles with their longer axes in the plane of the strata. (See Fig. 31.) When these pebbles, however, were deposited, their

FIG. 31.



longer axes, in virtue of a well-known mechanical principle, would naturally assume a horizontal position (*i. e.*, the position of stable equilibrium); and, therefore, their present position must have resulted from a change in the position of the strata in which they are inclosed. The same thing may be also shown by the position of fossils. For example, in a geological formation in the south of England, known as the "Portland Dirt Bed," the remains of an ancient forest, which must have grown upon a comparatively level surface, are found imbedded in strata, inclined at a high angle. (See Fig. 32.)

FIG. 32.

91. **Dip.**—The angle or slope at which a stratum inclines to the horizon is called its *dip*.

Thus, in Fig. 31, the strata are represented as dipping at an angle of nearly 45° with the plane of the horizon.

Dip is reckoned from 0° to 90°; when the dip is 90° the strata are of course vertical.

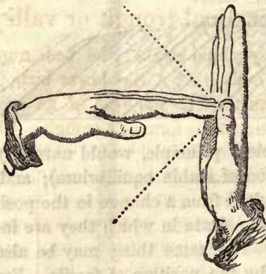
QUESTIONS.—What evidence do we find that inclined strata were originally horizonal? What is the "dip" of strata? How is it reckoned?

92. **Outcrop and Strike.**—When an inclined stratum comes to the surface (as at E, Fig. 30), its exposed edge is called its *outcrop ;* and the direction or line of outcrop along the surface of the ground is termed its *strike.*

The dip and strike are always at right angles to each other; so that if a stratum is found to dip either to the north or south, we may be sure that its strike or line of outcrop has an east and west direction.

"Dip and strike may be aptly illustrated by a row of houses running east and west; the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north and on the other to the south. A stratum which is horizontal or level in all directions has neither dip nor strike." —LYELL.

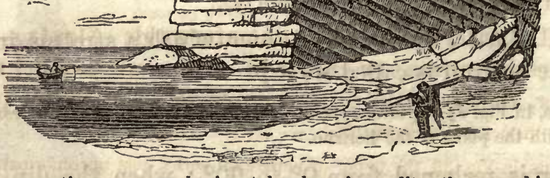
FIG. 33.



The dip of a stratum is sometimes ascertained by means of an instrument called a clinometer, but for most purposes it can be determined with sufficient accuracy by the eye. The judgment may be assisted by holding the hands before the eyes in the position represented in Fig. 33, and observing whether the planes of the inclined strata bisect the right angle at an angle of 45°, or whether the inclination be greater or less than that amount.

A good pocket compass will answer for finding the strike.

FIG. 34.



Strata sometimes appear horizontal, when, in reality, they are highly inclined. Thus, the strata in the sea-cliff (Fig 34), to an observer in front,

QUESTIONS.—What is understood by "outcrop" and "strike?" What relation do the dip and strike sustain to each other? How may dip and strike be illustrated? How may dip and strike be ascertained?

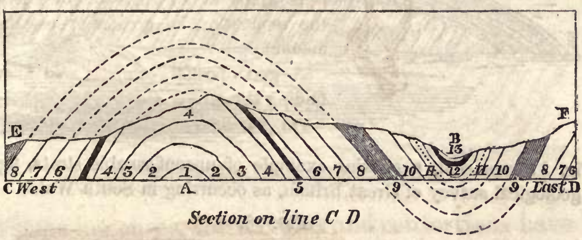
would seem to be horizontal, while a person on the side, facing a section at right angles to the strike of the strata would at once perceive that they have a high degree of inclination.

93. **Anticlinals and Synclinals.**—When strata dip in opposite directions from a ridge or line of elevation, like the roof of a house (as at A, Fig. 35), the ridge is said to be *anticlinal* (Gr. *αντι*, against, and *κλινω*, I bend), and the curve formed by the direction of the strata is termed an anticlinal curve.

On the other hand, when strata dip toward a common line of depression (as at B, Fig. 35), the axis or line is termed synclinal (*συν*, together), and the trough or valley, formed by such a dip, is called a synclinal trough or valley.

In Fig. 35, A represents anticlinal and B synclinal strata; the beds numbered 6, 7, 8 being repeated on each side of both. At A the lower beds, 1, 2, 3, 4, 5 are seen rising out from underneath them in the form of an arch. At B, the upper beds, 9 to 13, repose upon them in the form of a trough. The

FIG. 35.



Section on line C D

straight line, which may be supposed to run directly from the eye of the spectator, along the top of the ridge A, or the bottom of the trough B, is called the "axis" of the curve in each case.

94. **Conformable and Unconformable Strata.**—When successive strata, or groups of strata, are parallel to each other, they are said to be *conformable;* when not parallel, they are *unconformable.*

Thus, in Fig. 36, the upper or horizontal series rest unconformably on the highly inclined series beneath them, although the members of the horizontal and inclined series, considered separately, are conformable. The inference to

QUESTIONS.—What are anticlinals and synclinals? When are strata said to be conformable, and when unconformable?

FIG. 36.

to be deduced from a natural section like that shown in Fig. 36, is, that the lower strata were formed and tilted up before the upper and unconformable strata were deposited upon them.

FIG. 37.

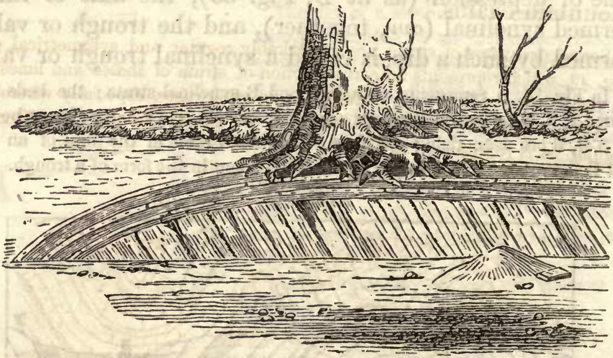


Fig. 37 represents a striking example of unconformable strata, figured in the geological survey of Great Britain, as occurring in South Wales.

FIG. 38.

It sometimes happens that in the interval between the deposition of two sets of beds, the inferior rock has had channels or hollows cut into it by currents of water, which irregularities have been subsequently filled up by a part of the bed next deposited.

QUESTION.—When are strata said to be conformable, and when unconformable?

Fig. 38 represents a case of this character, figured by Mr. Jukes, from the new red sandstone formation of England.

95. **Contortions.**—Strata which have been subjected to the action of extensive and powerful disturbing forces, rarely exhibit a uniform dip and strike over any considerable area, but are often bent and folded upon each other, or contorted in a very remarkable manner. These bendings and contortions of strata occur on every possible scale, "from mere little crumplings on the side of a bank, to curves, of which the radii are miles, and the nuclei are mountain chains."

Some curvatures of strata are remarkably regular and symmetrical, as in Fig. 39, which represents an actual section of strata of shales and limestones on the borders of Derbyshire, England; in other cases, especially where beds of soft material alternate with hard ones, the curvatures are exceedingly irregular, as is represented in Fig. 23.

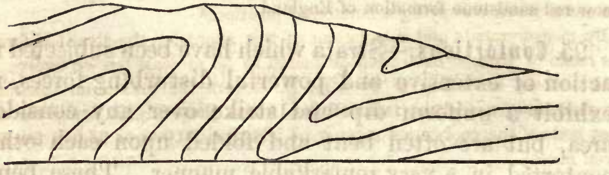
FIG. 39.

In some instances, the flexures and contortions have been sufficient to produce actual inversions in strata, so that beds, which were originally lowest in the series, are made to appear uppermost, and as of recent formation. (See Fig. 40.)

The agencies by which contortions and flexures may have been produced are numerous. Volcanic forces have, undoubtedly, in many instances operated from beneath, whereby the strata have been bent upward; on the other hand, the weight of superincumbent material would contribute to bend them downward; while the unequal elevation or depression of portions of the earth's crust might tend to subject adjoining strata to extreme lateral pressure.

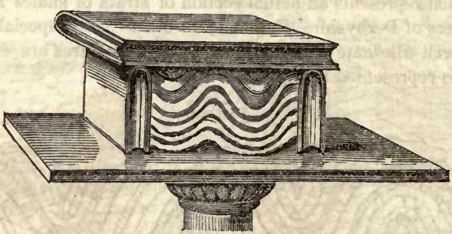
QUESTIONS.—What is said of the contortions of strata? Are strata ever found completely inverted? How have contortions of strata probably been produced

FIG. 40.



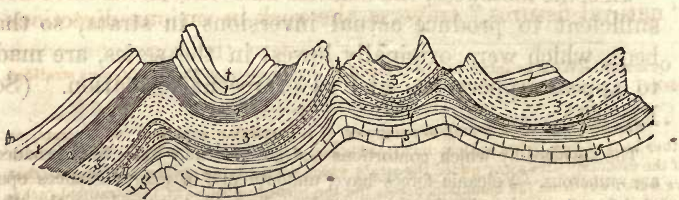
"We may illustrate the effects which lateral pressure may produce on flexible strata, by placing several pieces of differently colored cloths upon a table, and when they are spread out horizontally, covering them with a book. Then apply other books to each end, and force them toward each other. The folding of the cloths will exactly imitate those of bent strata" (see Fig. 41).—LYELL.

FIG. 41.



96. **Thickness of Strata.**—The displacements and curvatures of strata afford a ready means of calculating the thickness of different sedimentary deposits and also of determining the character of the crust of the globe to a depth

FIG. 42.



far beyond the skill of man to penetrate; since by measuring across the upturned edges of a series of strata (as in Fig. 42, which represents actual curvatures of strata in the Alps of Switzerland), we ascertain at once their thick-

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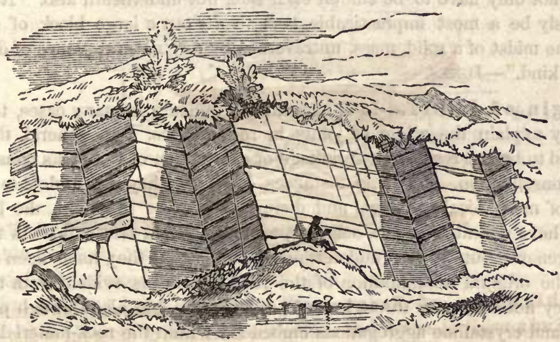
QUESTIONS.—How may the effects of lateral pressure on strata be illustrated? How do the displacements and curvatures of strata allow us to calculate their thickness?

ness, and also the depth to which they must have originally extended into the earth when occupying a horizontal position.*

By measurements and calculations of this character, the stratified fossiliferous rocks of Europe have been estimated to be at least ten or twelve miles thick; while, according to Prof. H. D. Rogers, the maximum thickness of the stratified fossiliferous rocks of the United States, lying below the uppermost beds of the coal series, can not be less than 30,000 or 35,000 feet (six to seven miles).

97. **Joints.**—In addition to the separation of rock-masses into beds and layers by planes of division, which were obviously the result of intervals in the acts of deposi-

FIG. 43.



tion of sediment, all rocks—stratified and unstratified—are traversed by other divisional planes called *joints*. These "natural fissures," traverse the rock in various directions

QUESTION.—What estimate has been made of the thickness of the fossiliferous stratified rocks?

* "Suppose we see a mountain composed of a particular substance, with strata, or other beds of rock, lying against its sloped sides, we, of course, infer that the substance of the mountain dips away under the strata which we see lying against it. Suppose that we walk away from the mountain, across the the turned-up edges of the stratified rocks, and that for many miles we continue to pass over other stratified rocks, all disposed the same way, till, by and by, we come to a place where we begin to cross the opposite edges of the same beds; after which, we pass over these rocks all in a reverse order, till we come to another mountain composed of similar materials to the first, and shelving away under the strata in the same way. We should then infer that the stratified rocks occupied a basin, formed by the rock of these two mountains, and by calculating the thickness right through these strata, could be able to say to what depth the rock of the mountain extended below."—*Vestiges of the Natural History of Creation.*

and separate it into blocks of various shapes and sizes, regular and irregular.

Fig. 43 represents joints in limestone. The planes of stratification are shown by the parallel lines dipping from the spectator and toward the left. The other lines are the ends of joint planes, which also form the smooth surfaces of the rock, nearly at right angles to each other, as shown by the projecting corners.—JUKES.

"Without natural joints the quarrying of stratified rocks would be very difficult, and that of unstratified rocks almost impossible. If beds of sandstone or limestone were undivided by natural joints, each block would have to be cut or split by artificial means, on every side, from the rest of the bed; but in rocks, such as granite and greenstone, which have no beds, the blocks would not only have to be cut on each side, but underneath also. It would obviously be a most impracticable task to *dig* out a large block of granite from the midst of a solid mass, untraversed by any natural planes of division of any kind."—JUKES.

Origin of Joints.—It is exceedingly difficult, in many cases, to satisfactorily explain the origin of joints in rock-masses. In general, they are believed to be the result of a shrinkage or contraction of the rocks consequent upon consolidation. In some instances, however, they are undoubtedly the result of mechanical upheaval and disturbance, while in others, the lines of fissure have definite compass-bearings, are arranged in sets, and seem to obey some general, but as yet undetermined law. That they have been formed since the original accumulation of the rock-material is evident from the fact that they not only pass through strata and laminæ, but also through pebbles, fossils, and crystalline aggregations embedded within the rock-material. One of the most striking examples of this action occurs in a conglomerate rock, at a well-known locality, "Purgatory," near Newport, R. I., where pebbles of various sizes and of the hardest material are as smoothly divided in given planes as if a succession of clean cuts had been made crosswise, with a sharp instrument, through the entire mass of the rock in which they are embedded.

98. **Faults, or Dislocations.**—When the continuity of strata has been broken in consequence of an upheaval, it sometimes happens that the beds on opposite sides of the fissure, or line of fracture, are left at very different levels —many feet, or many hundreds of feet above or below the parts with which they were once continuous. Such

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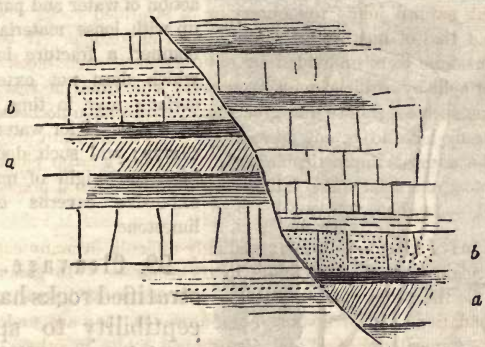
QUESTIONS.—In what manner are rocks divided by joints? How do joints assist the quarrying of rocks? What is said of their origin? What proof is there that joints have been formed since the accumulation of the rock-material? What are faults?

a displacement is termed a "*fault*," or "*dislocation*." (See Fig's 44, and 158.)

The interruptions occasioned by faults are a source of considerable difficulty in mines—especially in coal mines—since, when a fault is reached, it is almost impossible to decide whether the continuation of the mineral sought is above or below the level, or to the right or the left. In the great Newcastle

FIG. 44.



coal district of England, the upward or downward movement of strata has amounted to nearly 1,000 feet, so that the surface of the ground must have been originally affected to that extent—portions having either risen or sunk 1,000 feet above or below the rest. These projections or inequalities have been subsequently removed by denudation, and their former existence can now only be discovered by studying the internal structure of the underlying strata.

In some instances, the "fault-fissures" are mere planes of division, and not unfrequently the contiguous surfaces of the fault are found to be quite smooth and polished by the enormous friction that has taken place—an appearance termed by geologists "*slicken-side*." In other cases the fault-fissures are open, but most of the originally open fissures have been filled with angular, dispersed fragments from the adjoining rocks, or have become the repositories of minerals that have been subsequently introduced into them. These minerals are usually in a crystalline form, and commonly consist of quartz, calcareous spar, fluor spar, heavy spar (sulphate of barytes), together with ores of lead, copper, zinc, tin, iron, etc.

Fig. 45 represents a vein of lead (galena) embedded in calc spar, which fills a fissure in gneiss, at Rossie, St. Lawrence County, N. Y.—*Emmons' American Geology, p.* 133, *Part I.*

QUESTIONS.—How do faults occasion interruption in mining enterprises? How have many mineral veins originated?

FIG. 45.

Fissures containing ores of the metals are termed "mineral veins," or "lodes."

Many valleys, gorges, and ravines, were probably, in the first instance, merely fissures, or lines of fracture, which have subsequently been widened by the action of water and partially filled up with loose material. In like manner, a fracture in the rock which does not extend to the surface, may, in time, by serving as a channel for water, become a cavern; and such, doubtless, has been the origin of many of the extensive caverns existing in limestone.

99. **Cleavage.**—Some stratified rocks have a susceptibility to split into straight, parallel plates, which maintain a certain given direction over wide areas, and are independent of, and often not coincident with the planes of either stratification or lamination. Such a structure is called *cleavage*.

Cleavage structure is most common and most perfect in clay or argillaceous slate (common slate), though it is sometimes apparent in limestone and sandstones, and is always most perfect in the finest grained rocks.

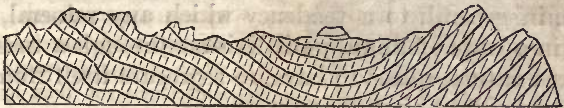
Cleavage planes are often inclined 30° or 40° to the planes of stratification and lamination, and not unfrequently the two sets of planes are at right angles

QUESTIONS.—What has been the origin of some valleys, ravines, and caverns? What is cleavage? In what rocks is cleavage most perfect?

to each other. In other instances, as may be often noticed in the finer slates of this country, the cleavage coincides with the original bedding or lamination.

Cleavage planes are remarkable for their almost perfect parallelism, no matter how much the strata and their laminæ may be disturbed and contorted. Fig. 46 represents a set of cleavage planes (figured by Prof. Sedgwick) crossing highly curved strata of slate in Wales.

FIG. 46.



Origin of Cleavage.—Geologists are not fully agreed as to the origin of cleavage. Some regard it as a kind of crystallization, induced in the particles of the rock by the action of heat or electro-chemical forces. This theory, which has been called the chemical, derives strong support from the fact that a kind of artificial cleavage can be produced by subjecting masses of moistened clay to the long-continued action of weak galvanic currents.

Another theory refers the origin of cleavage to a *mechanical compression* of the strata applied at right angles to the cleavage planes; and, in support of this view, Prof. Tyndall, of England, has experimentally shown that fine clay, or almost any impalpable material, as white-lead, wax, or even cheese, when subjected to pressure, and at the same time allowed to spread laterally, may become endowed with the property of cleaving, or splitting in lines, perpendicular to the direction of the pressure. Another fact, considered as confirmatory of the mechanical theory of cleavage, is, that fossils and other small bodies embedded in rocks possessing a cleavage structure, are not unfrequently distorted; being lengthened and pulled out, as it were, in the direction of the cleavage, and contracted in an opposite direction.

100. **Foliation.**—This name has been applied to a structure superinduced in some rocks subsequent to their original deposition, which imparts to them a tendency to split into plates or layers of different mineral composition, either coincident with the bedding or across it. Cleavage, on the contrary, implies only a tendency to split in a mass of the same composition.

The rocks in which a foliated structure, according to the above definition, is most apparent, are mica schist and gneiss—the former often separating into

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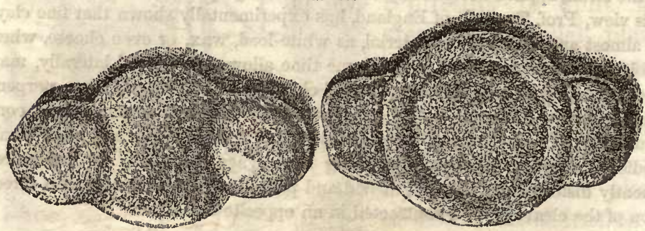
QUESTIONS.—What is said of the parallelism of the planes of cleavage? What is the supposed origin of cleavage? What is foliation? What rocks especially exhibit foliation?

distinct plates or layers of mica and quartz, and the latter into layers of mica, quartz, and feldspar.

101. Concretionary Structures.—Rocks are often pervaded by concretionary structures or masses, which differ to a greater or less extent in composition from the substance of the inclosing rock, and are usually of a spherical or cylindrical form. These structures appear to owe their origin, in general, to a tendency which any mineral, diffused in a state of minute subdivision through a mass of different nature, seems to have, to segregate itself from the mass, and collect about certain centers.

Claystones.—A well-known variety of these concretions occur in beds of clay, containing disseminated carbonate of lime, and are familiarly known by the name of "*claystones.*" They assume almost every variety of form; some being as smooth and symmetrical as if turned on a lathe, while others have not unfrequently a mimic resemblance to animals or artificial products. Fig. 47 represents some of the most common forms of these bodies.

FIG. 47.



According to popular credence claystones are the work of water, and are sometimes even regarded as artificial; but the true cause of their formation is, undoubtedly, the segregation and crystallizing influence of carbonate of lime. This mineral, originally disseminated through the mass of the clay in small quantities, tends to collect around some point, as a nucleus—as, for example, an organic body—and assume a crystalline form. The presence and contact of the inert, non-crystallizing particles of finely divided clay, however, obstructs, and in part prevents, this crystallizing tendency, and the result is an imperfect or semi-crystallization, producing globular or curve-surfaced solids, composed of a mixture of clay and carbonate of lime. Similar phenomena are often observed in laboratory processes, where the presence of

QUESTIONS.—What is said of the concretionary structure of rocks? What are claystones? What is the supposed origin of claystones?

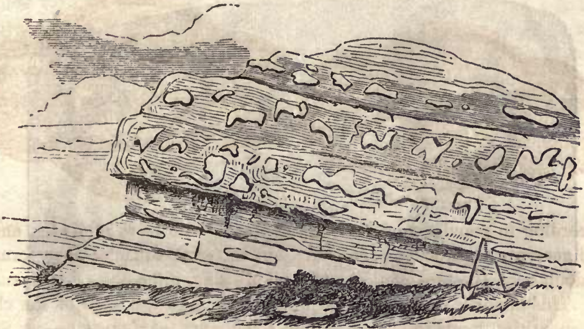
finely divided and diffused particles of foreign substances partially arrests the formation of crystals.*

In addition to the claystones described, a great variety of other concretionary structures are recognized. Iron pyrites (bi-sulphate of iron), and other ores of iron, are very frequently found disseminated in rocks in the form of rounded or nodular masses. The variety of iron ore known as "*hematite*" furnishes beautiful specimens of concretions, which have a minutely radiated structure at right angles to the mass. (See Fig. 48.)

FIG. 48.

Examples of concretionary structure abound also in limestones, especially in the magnesian limestone; the spherical masses varying in size from a mere globule to many feet in diameter. Fig. 49 represents the manner in which nodules of nearly pure silica (flint) are frequently distributed in beds of white chalk; and, before the introduction of the percussion-cap, such nodules, from the chalk beds of England and France, furnished the material for the manufacture of gun-flints.

FIG. 49.

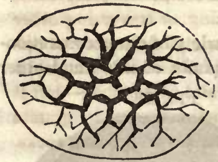


Septaria.—Some nodules or concretions, when broken open, are often found to be traversed by cracks in all directions, more or less filled up with

QUESTION.—What are other common forms of concretions?

* Most mineral substances refuse to crystallize in the presence of a large amount of impurities, but the force exerted by carbonate of lime in crystallizing is so energetic that it can form regular rhomboids, even when incorporated with fifty per cent. of its weight of sand. If the impurity exceeds this percentage the action of the crystallizing force will tend to produce spheroidal forms.

FIG. 50.

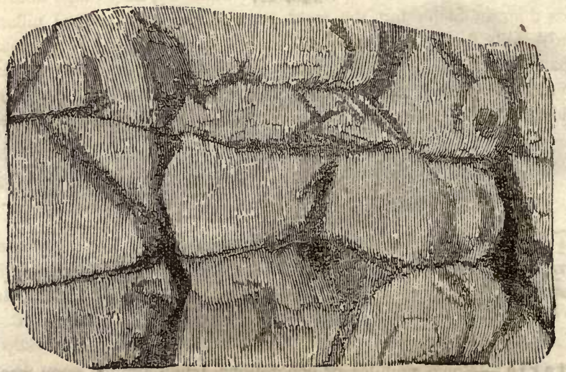


crystalline spar. (See Fig. 50.) Such nodules are termed *septaria* (Lat. Septum, *a division*), and, when cut and polished, frequently present a highly ornamental appearance. Some varieties of septaria—those composed of argillaceous limestone—furnish, when ground and pulverized, the finest hydraulic mortar, or "Roman cement."*

102. **Structure of the Igneous Rocks.**—One of the principal characteristics of the igneous rocks is a want of stratification—that is to say, their constituent ingredients do not exhibit any marks of arrangement such as might arise from suspension or drifting, nor any such proofs of mechanical action as worn and rounded pebbles or grains of sand. On the contrary, the igneous rocks are mostly crystalline rocks.

The granites, syenites, and porphyries have always a more or less jointed structure, which is sometimes sufficiently regular to impart an appearance of stratification. In general, however, the divisional joints of the granitoid

FIG. 51.



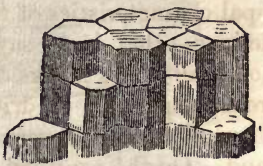
rocks are extremely irregular, and weathered vertical sections of these rocks, consequently, often seem composed of huge blocks, artificially fitted upon each other. Fig. 51 represents a jointed structure in granite.

QUESTIONS.—What are septaria? What is the principal characteristic of the igneous rocks?

* Most limestones which contain about twenty per cent. of clay (silicate of alumina) afford a lime which possesses the property, when made into mortar, of hardening under. Such mortars are termed hydraulic.

103. **Prismatic Structure.**—Certain igneous rocks, especially those which occur in thin sheets or wall-like masses overlying or traversing other rocks, are divided by a series of joints into a multitude of prismatic or columnar blocks, more or less regular. This structure is remarkably displayed in certain rocks belonging to the trap-group—basalt and greenstone—but it may also be occasionally observed in lavas, and sometimes even in granite or aqueous rocks, which are in close proximity to masses of igneous rocks. The sides of these prisms are sometimes regular and equal, producing hexagonal, pentagonal, or other forms; or they may be unequal and irregular, and give rise to uneven and wrinkled prisms.

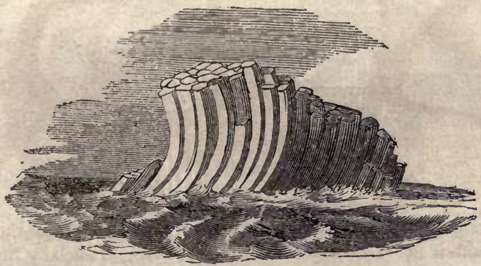
FIG. 52.



In columnar or prismatic basalt and greenstone, the prisms are often separated at intervals by other joints into short blocks (see Fig. 52), whose extremities are sometimes flat and sometimes curved into convex and concave surfaces, which fit into each other somewhat after the manner of a ball and socket joint. In other cases, the columns are simply continuous from the top to the bottom of the mass.

In length and diameter the columns vary exceedingly; McCulloch mentions some at the Isle of Sky, which are about 400 feet long; others have been noted as not exceeding an inch in length. In diameter, they range from nine feet to less than an inch; but the most regular and symmetrical pillars of basalt are usually from six to eighteen inches in diameter. In greenstone the prismatic structure is commonly on a larger scale than in basalt, and is generally more imperfect, and in some instances the columnar structure is most noticeable when the rock is viewed at a distance, as at the Palisades on

FIG. 53.



the Hudson. Usually the columns stand perpendicularly, and so closely compacted that, though perfectly separable, there is no perceptible space between them. (See Fig. 52.) Sometimes, however, they are curved (see Fig. 53),

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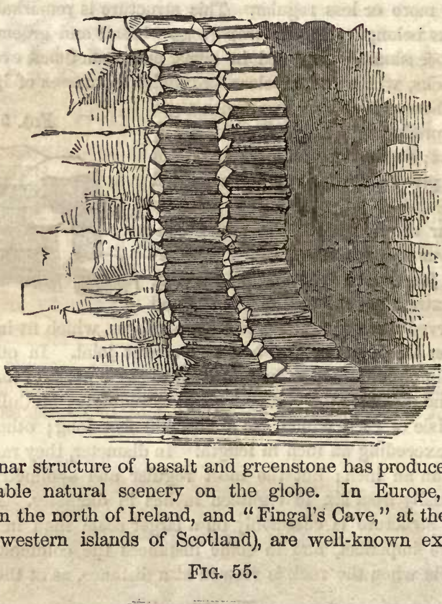
QUESTIONS.—What rocks have a prismatic or columnar structure? Describe the columnar forms of basalt and greenstone?

or even horizontal. Fig. 54 represents a basaltic vein divided into horizontal prisms, on the northwest shore of Lake Superior.

FIG. 54.

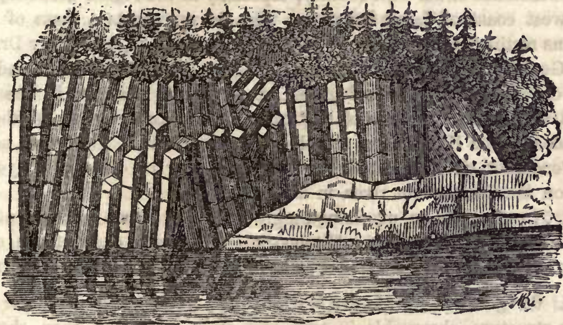


The columnar structure of basalt and greenstone has produced some of the most remarkable natural scenery on the globe. In Europe, the "Giants Causeway," in the north of Ireland, and "Fingal's Cave," at the Isle of Staffa (one of the western islands of Scotland), are well-known examples. The

FIG. 55.

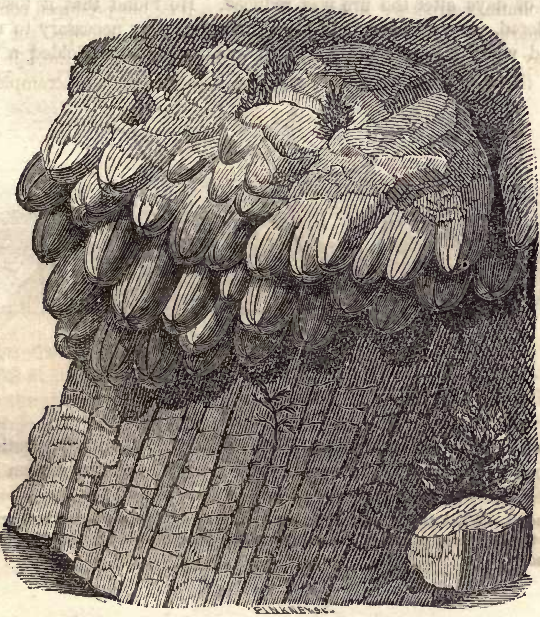
former consists of an irregular group of hundreds of thousands of pentagonal, jointed basaltic columns, varying from one to five feet in thickness, and from twenty to two hundred feet in height; the whole extending out into the sea

FIG. 56.



like an artificial causeway or landing. Fingal's Cave (see Fig. 55) is a natural cavern of great beauty, which has been produced by the degradation and re-

FIG. 57.



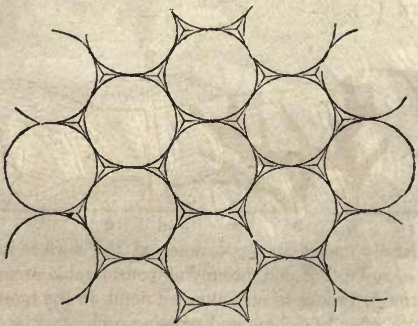
moval of basaltic columns by the action of the waves. The perpendicular pillars which inclose it are overlaid by a mass of the same rock, which is entirely wanting in prismatic arrangement.

Remarkable examples of the same structure occur also among the basalts and greenstones of our own country, especially in the region bordering on the northwest coast of Lake Superior. Fig. 56 represents a mass of basaltic columns resting on sedimentary strata from this locality, figured by Dr. Owen, U. S. Geologist. Greenstone columns (less regular than basalt), standing upright, or leaning only a few degrees, are also quite common in the United States, and constitute some of our most interesting scenery. Of these, the Palisades on the Hudson are a well-known example. They also occur on the Penobscot river, in Maine, and very perfectly on Mounts Holyoke and Tom, on the Connecticut river, in Massachusetts.

Fig. 57 represents an overhanging group of greenstone columns, at Mount Holyoke, figured by Professor Hitchcock. The lower ends of the columns have exfoliated in such a manner as to present a convex surface downward.

104. **Origin of Prismatic Structure.**—The prismatic or columnar structure, observable in trap and other rocks, has been shown, by experiment, to be due to the manner in which the rock cooled and consolidated from a state of fusion. Mr. Gregory Watt, of England, melted seven hundred weight of basalt in a blast furnace, and kept it in the furnace for a number of days after the fire was reduced. He found that it fused into a dark-colored, vitreous mass, with less heat than was necessary to melt pig-iron, and when cooled rapidly and in small quantities yielded a slag-like

FIG. 58.



glass, not differing in appearance from obsidian. When refrigeration, however, took place slowly, and considerable quantities of the molten material

QUESTIONS.—What are some remarkable examples of columnar basalt and greenstone? What is the supposed origin of the columnar structure in rocks? Describe Mr. Watt's experiment?

were concerned, the following results were noted: the mass returned to its original stony condition, and, during the process, small globules made their appearance, which gradually increased in size by the successive formation of external concentric coats, like those of an onion, so that, ultimately, a number of solid balls were formed, which continued to enlarge, until they pressed laterally against each other, and became converted into short, polygonal prisms. (See Fig. 58.) It was also evident that if many layers of these spheroids could have been formed in a mass of cooling basalt, one above the other, a long column of separate prisms would have resulted (as in Fig. 54) with the top and bottom of each joint flat, concave, or convex, according to variations in the amount and direction of the pressure at the ends of the columns. It has also been observed that the direction of the prisms or columns of basalt and greenstone is usually at right angles to the greatest extension of the mass, being vertical in a horizontal vein or bed, and horizontal in a vertical one, thus showing that the divisional structure commenced at the greatest cooling surface, and thence struck in toward the center of the mass.

105. Position of the Igneous Rocks and their relation to the Stratified Rocks.—The igneous (unstratified) rocks are found in the crust of the earth, under the following conditions: 1. As irregular masses underlying the stratified rocks (*a*, *a*, Fig. 59). 2. As veins crossing and dividing rocks of every description (*b*, *b*). 3. As irregular masses, disrupting (*e*), overlying (*d*), or intervening between strata (*c*).

FIG. 59.

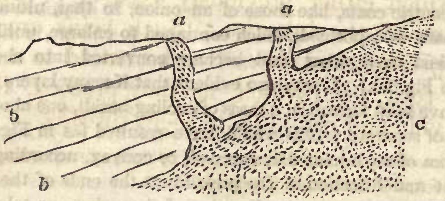
Granite generally makes its appearance at the surface in large irregular masses (as at *a* and *e*, Fig. 59), occupying considerable areas, and extending beneath the stratified rocks to an unknown depth in the interior of the earth. Veins of granite, often branching and crossing each other, sometimes proceed from these masses, and penetrate the adjoining rocks. These veins are, in some instances, miles in length.

Fig. 60 represents granite underlying and penetrating mica schists from a

QUESTIONS.—Under what conditions are the igneous rocks found in the crust of the earth? What is the general position of granite?

section in Cornwall, England; *a, a,* granite veins; *b, b,* mica schist; *c,* underlying mass of granite. Fig. 61 shows two exceedingly tortuous and small

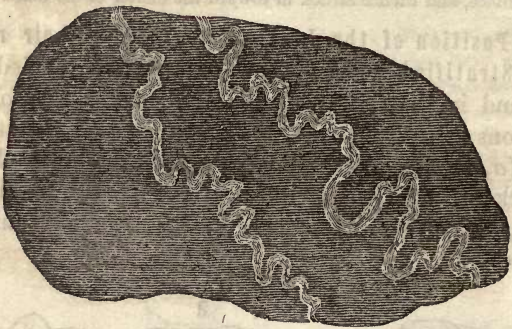
FIG. 60.



veins of granite (figured by Dr. Hitchcock), in limestone, at Colrain, Massachusetts.

The trappean and volcanic rocks do not, in general, possess the massive

FIG. 61.



structure of granite or occupy so continuous areas of the earth's surface.* They may be especially characterized as intrusive and overlying rocks.†

QUESTION.—What are the characteristics of the trappean and volcanic rocks?

* The largest area occupied by trap-rocks appears to be in India, where they are reported to cover an area of 200,000 square miles. In Europe, one of the most extensive developments of trap (basalt) occurs in the north of Ireland, and covers an area of country fifty miles long by thirty wide, to a depth of 300 or 400 feet. This locality includes the celebrated "Giant's Causeway." (See § 40.)

† According to Humboldt (Cosmos, vol. I.), "there is a special difference in the eruptive manifestations of the granitic rocks as contrasted with the trappean and volcanic. Thus, the latter appear as band-like streams, but by the confluence of several of them may cover an extensive area. Wherever it has been possible to trace basaltic eruptions they have generally been found to terminate in slender threads." Granatoid rocks, on the contrary, "with the exception of occasional veins, were probably not eruptive in a state of fusion, but merely in a softened condition—not from narrow fissures, but from long and widely extended gorges. They have been protruded, but have not flowed forth, and are found not in streams, but in extended masses."

106. **Veins.**—Veins of igneous rock are usually the result of the injection of liquid (molten ?) rock-matter into fissures, which either previously existed, or were formed at the time of the injection. Such veins are known as *veins of injection*, and can often be traced to a large mass of similar rock, from which, as they proceed, they generally subdivide and diminish to mere threads.

Fig. 62 represents an injection vein of porphyry traversing argillaceous slate, on the coast of Cornwall, England.

FIG. 62.

107. **Dike.**—This term is applied by geologists to wall-like masses of igneous rocks (generally trap, porphyry, or lava) which traverse other rocks, and appear to have been produced by the intrusion of melted rock-matter into rents and fissures.

Dikes are distinguished from veins by their greater magnitude, by the parallelism of their sides, by their not ramifying into smaller veins, and by the greater uniformity of their contents. When the matter of the dike is harder than the intersected strata, and the latter have been subjected to wear and degradation, the igneous mass frequently projects above the surface like a wall, and may be traced for miles across a country; hence the name from the Scotch "*dike*," a wall or fence.

QUESTIONS.—What is the assumed origin of veins of igneous rocks? What is a dike? How are dikes distinguished from veins?

Fig. 63 represents a characteristic appearance of a trap-dike *a*, entirely interrupting the continuity of the strata of the rock *c*; and *b*, a dyke which does not rise to the surface.

FIG. 63.

Dikes are met with from a few inches to more than a mile in thickness. In volcanic eruptions they may be seen in the process of formation, as deep rents and fissures filled with liquid lava. Fig. 64 represents dikes of modern lava traversing rocks in the vicinity of Mt. Etna.

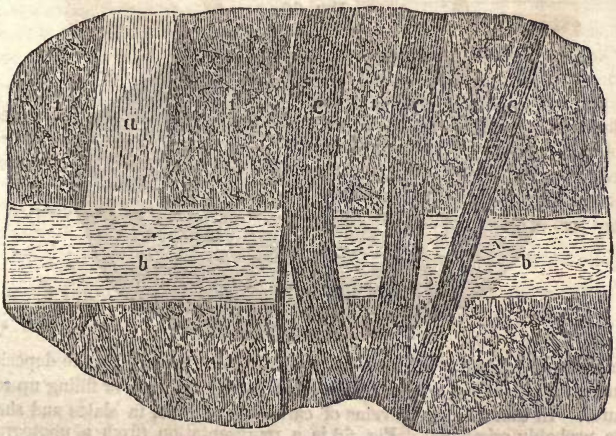
Very fine examples of trap-dikes may be found in all the trap districts of

FIG. 64.

New England; and on the coast of Massachusetts Bay—especially at Lynn, Marblehead, Beverly, Salem, Cohasset, and Nahant—the rocks are everywhere traversed with dikes of trap and porphyry. One dike, near Pulpit-Rock, at Nahant, is over thirty feet in width.*

Veins and dikes frequently intersect; and, in such cases, the one which cuts through the other must be regarded as the last erupted. In this way we are able to demonstrate the eruption of igneous rocks at several successive and distinct epochs. Fig. 65 represents an interesting example of dykes of trap and porphyry, erupted at four different periods, in the syenitic rocks of Cohasset, Massachusetts. The base of the rock 1 being syenite; *a* represents a dyke of porphyry ten feet in width; *b*, a dike of greenstone twenty feet wide; *c*, *c*, *c*, three smaller dykes of greenstone, of a darker color. In

FIG. 65.



this case we have, undisputably, the following record of events: *First*, the formation of the syenite; *second*, the syenite was rent, and the fissure filled with melted porphyry; *third*, the syenite was rent across the porphyry, and molten trap flowed up, forming a dike twenty feet wide; and, finally, three fissures were formed across the large dike, which were subsequently filled with trap of a somewhat different composition. In this example, furthermore, it will be observed that portions of the syenite are imbedded between

QUESTIONS.—What are some examples of remarkable dikes? How may we determine the relative age of intersecting veins and dikes?

* One of the most wonderful examples of a trap-dike exists in the coal fields of the north of England, and is known as the "Cookfield Fell Dike." It consists of a nearly vertical wall of trap, eighteen or twenty yards thick, which runs in a nearly straight line for a distance of about seventy miles. In one instance, where it crosses a bed of coal, the coal for a distance of eight yards from it is converted into a kind of cinder, while limestones, and other rocks in contact with it, appear as if they had been baked.

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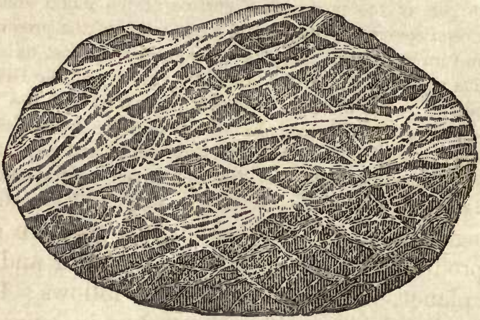
the smaller dikes upon the right of the engraving, and these imbedded masses masses present evidence of having been inclosed by the trap, while the latter was in a state of fusion.

108. **Veins of Segregation.**—In some instances veins are found entirely included or insulated in the rock, and cannot be traced to a connection with any larger mass of similar character. Such veins, in general, appear to have been formed of materials which have been separated or segregated by chemical action from the mass of the containing rock, and pass at their edges, by insensible gradations, into that rock. They are, hence, termed "*veins of segregation.*"

FIG. 66.



In other instances, veins have undoubtedly been formed by the deposition of mineral matter from aqueous solutions trickling through, or filling up rock-fissures. In this way many veins of carbonate of lime, in slates and shales, have probably originated. Fig. 66 is a representation (from a photograph) of veins of carbonate of lime in black slate, from the shores of Lake Champlain, Vt.

CHAPTER VIII.

GEOLOGICAL AGENCIES.

109. IF there is any one fact which the study of geology teaches more unmistakably than another, it is, that the matter composing the crust of the earth, from the time when it was first called into existence by the *fiat* of the

QUESTIONS.—What are veins of segregation? What one fact respecting the history of the earth does the study of geology especially teach?

Creator to the present, has been subjected to an endless cycle of mutations. There may have been periods of comparative rest and quiescence, but none of perfect stagnation and stability; so that the present condition and configuration of the earth's surface may be considered as the last result of a series of cosmical changes, which commenced with the dawn of creation, and are continuing on into the future.

"Had the exterior crust of the earth been subjected to no modifying causes, the world would have presented the same appearance now as at the time of its creation. The distribution of land and sea would have remained the same; there would have been the same surface arrangement of hill, valley, and plain, and the same unvarying aspects of animal and vegetable existence. Under such circumstances, geology, instead of striving to present a consecutive history of change and progress, would have been limited to a mere description of permanently enduring appearances. The case, however, is widely different." There is no part of the present land-surface of the globe which has not at some time been covered by the ocean, while much of the present sea-bottom has been in turn dry land. Many of the loftiest and most extensive ranges of mountains upon the globe—the Alps, the Andes, and the Himalayas—are of comparatively recent elevation (recent as compared with the White Mountains of New England, or the Appallachian chain of the Atlantic States); while the commencement of the existence of every animal and vegetable species at present found upon the earth was long subsequent to the existence of the myriad organisms, whose remains are now found fossil beneath its surface.

The agencies which have produced, and are still tending to produce, changes in the constitution and structure of our planet, may be classified as follows: 1. Igneous agencies, or such as manifest themselves in connection with some deep-seated source of heat in the interior of the globe. 2. Aqueous, or those arising from the action of water. 3. Atmospheric, or those operating through the medium of the atmosphere. 4. Organic, or those depending on animal and vegetable growth. 5. Chemical, or those resulting from the chemical action of substances on each other.

SECTION I.

IGNEOUS AGENCIES.

110. From what has been already said respecting the origin of certain rocks, the student must have inferred that geologists recognize heat as one of the great agencies which, in times past, have been active in determining

QUESTIONS.—What would have been the condition of the earth's surface had it remained unchanged? What are the agencies concerned in producing geological changes?

the constitution and structure of our planet. And no person at the present time can witness, or even read of, the eruption of a volcano, or, to choose a more familiar illustration, can observe the constant supply of heated waters that flow from the numerous warm springs of our own country, without being forcibly impressed with the idea that heat is *still* a most active element in the earth's crust, at no great distance beneath its surface. When examined in detail the evidence is much more conclusive.

111. **Temperature of the Earth.**—If we descend beneath the surface of the earth, and observe the temperature with a thermometer at different depths, it will be found that, at a certain depth, the thermometer remains stationary, and is uninfluenced by either the heat of summer or the cold of winter. This depth, called the "stratum of invariable temperature," ranges, in the temperate zones, at from fifty to ninety feet below the surface, according as the material passed through is rock, clay, sand, or water. Below this depth, the temperature increases as we descend, at the rate of *one degree of Fahrenheit for every fifty or sixty feet of descent.** Experiments made in various deep mines and artesian wells have invariably shown this to be the case in all quarters of the globe and in all kinds of rock.

Now, if this increase of heat toward the center goes on at the same rate that it does near the surface, the temperature, at a depth of 9000 feet (about one and three quarters miles), must equal that of boiling water, and, at the

QUESTIONS.—What influence has heat exerted upon the structure of the earth? What is the stratum of invariable temperature in the earth? What is its range?

* The following are some of the observations made most recently on this subject: In England observations have been made in the vertical shafts of two very deep coal mines, viz., at Monkwearmouth, which is 1800 feet deep, and Dunkinfield, which is upwards of 2000 feet deep, and in both cases the observations were made while the workmen were sinking the shafts, and with every precaution against the influence of any extraneous causes. The former gave an increase of 1° of Fahrenheit for every sixty feet of depth, and the latter 1° for about every seventy feet. The artesian well of Grenelle (Paris), is 1800 feet deep; observations made by Arago, during the boring, showed that the average increase of temperature in this was 1° for sixty feet. At Mordorff, Luxemburg, the depth of the artesian well is 2400 feet, and the increase in temperature 1° for every fifty-seven feet. At the artesian well of New Seltzwork, in Westphalia, the depth is 2100 feet, and the increase 1° for every fifty-five feet. At Louisville, Ky., the depth of au artesian well, finished in 1859, is 2086 feet deep, and the average increase is 1° for every sixty-seven feet below the first 90 feet from the surface. In the silver mine of Guanaxato, Mexico, 1713 feet deep, the increase is 1° for every forty-five feet. In the coal mines of Eastern Virginia, the average increase is about 1° for every sixty feet.

comparatively small depth of twenty-five or thirty miles, the heat is probably sufficient to reduce to fusion any material found upon the earth's surface.

It is also a fact of much significance that the waters of deep springs and wells (such as deep artesian wells), have always a high temperature. The water of the artesian well of Grenelle (Paris), 1,800 feet deep, has a constant temperature of 82° F., while the mean temperature of the air in the cellars of the Observatory at Paris is only 53° F. The water of the artesian well at Louisville, Ky.—2,086 feet deep—as it flows from the top, has a constant temperature of 76½° F., and of 82° F. at the bottom. This well discharges at the rate of 220 gallons per minute, consequently the source of the supply of heat to the water cannot be local or insignificant.

"As another result of direct observation, we may state that all igneous rocks proceed from below upward, coming out of the interior of the earth; and that whenever we are able to see the actual base of the aqueous rocks of any district, we find them reposing upon cooled igneous rocks, generally granite; and that, *ceteris paribus*, the lower the rocks or the deeper they have formerly been buried, the more marks do they bear of having been subjected to great heat."—JUKES.

From these and other facts, such as the existence of volcanoes, and the phenomena of earthquakes, which will be hereafter noticed, geologists have been led very generally to the conclusion that the solid or rocky crust of the earth forms but a comparatively thin film or shell, and that the great interior mass exists in a state of high incandescence or molten fluidity.*

The influence of such a heated interior upon the present surface temperature of the earth, is, however, insignificant, owing to the extreme slowness with which heat is transmitted by all earthy materials. Supposing the external rocky crust to have a thickness of thirty or forty miles, M. Fourier, of

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QUESTIONS.—In what manner does the temperature of the earth increase as we descend into it? What must be the result of a progressive increase of temperature? What is the general temperature of deep springs and wells? Give some illustrations? What appears to have been the source of the igneous rocks? What opinion is generally entertained by geologists respecting the condition of the interior of the earth? What effect would a heated interior produce at present upon the temperature of the earth's surface?

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* Geologists differ widely in their estimates of the thickness of the solid rock-crust of the earth. Some—perhaps a majority—are inclined to the belief that the most refractory rock-substances are in a state of complete fusion at a depth of twenty or thirty miles: others extend this limit to sixty or eighty miles. Mr. William Hopkins, of England, basing his conclusions on certain astronomical phenomena, and also on the fact that the temperature of the melting-point of most substances is much increased by great pressure, maintains that the minimum thickness of the *solid* external crust of the earth cannot be less than 800 miles, although the temperature may be at the same time intense.

France, has shown, by carefully conducted experiments and mathematical reasoning, that the excess of temperature at the surface of the earth from any possible supply of internal heat cannot exceed $\frac{1}{17}$th of a degree of Fahrenheit—an amount insufficient to melt a coating of ice ten feet thick upon the earth's surface in less than 100 years.*

It is, however, conceivable, that during the earlier geological epochs the crust of the earth might have been so thin (*i. e.*, before it thickened by cooling) as to allow of the communication of a large supply of heat from the interior to the surface, sufficient even to produce a tropical climate in extreme northern and southern latitudes. Such a supposition, furthermore, derives some support from the fact that recent geological investigations have proved, that the temperature of the Arctic regions was once sufficiently elevated to allow of the existence of animals and plants analogous to those which are now found only in the tropics.† It is not, however, probable that the temperature of the earth has sensibly diminished since the commencement of the historic period, or during the last 4,000 years.‡

QUESTIONS.—Is it conceivable that the surface temperature has been ever affected by the central heat of the earth? Is there any evidence on this point?

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* Earth and rock are among the very poorest conductors of heat. If we indicate the conducting power of gold (the best heat-conducting material) by 100, the figures 37.4 will express the relative conducting power of iron, 2.8 that of marble, and 1.1 that of clay. The non-conducting properties of "plaster of Paris" (gypsum) are so great that it is almost impossible to heat water in a tin vessel whose sides and bottom are thinly coated with this substance. In descriptions of volcanic eruptions we are often told of persons walking with impunity upon the cooled surface of lava streams, while a few inches below the surface the mass is still incandescent, or even fluid. In an eruption of Mount Etna, in 1819, a lava sheet was observed to be in motion, at the rate of three feet per day, nine months after its discharge from the crater.

† In Greenland, which is at present almost devoid of all vegetation, fossil trunks of trees have been found in the coal formation over three feet in diameter. The most abundant fossils collected by the parties engaged in the recent search for Sir John Franklin, from the rock formations of the extreme Arctic latitudes, were corals, and varieties of shells and plants of an eminently tropical character. (See Appendix to McClintock's Narrative, 1859.)

‡ From these old ages we have certainly no thermometric observations, but we have information regarding the distribution of certain cultivated plants, the vine, the olive, etc., which are very sensitive to changes of the mean annual temperature, and we find that these plants have the same limits of distribution that they had in the times of Abraham and Homer, from which we may infer backward the consistency of the climate. "As we may judge of the uniformity of temperature from the unaltered time of vibration of a pendulum, so we may also learn from the unaltered velocity of the earth the amount of stability in the mean temperature of our globe. This insight into the relations between the *length of the day* and the heat of the earth is the result of one of the most brilliant applications of the knowledge we possess of the movements of the heavens to the thermic condition of our planet. The rotary velocity of the earth depends on its volume; and since, by the gradual cooling of the mass by radiation, the axis of rotation would become shorter, the rotatory velocity would necessarily increase, and the length of the day diminish, with a decrease of the temperature. From a comparison of the secular inequalities in the motions of the moon, with the eclipses observed in ancient times, it

112. The hypothesis that the rock crust of the earth is only a comparatively thin shell or film, which has consolidated around a heated interior, furnishes a very plausible explanation of all those geological phenomena which appear to be either directly or indirectly the result of igneous agency; such as volcanic eruptions, thermal springs, earthquakes, and the upheaval or depression of extensive areas of the earth's surface. This theory, however, has been rejected by some very eminent geologists, who have suggested other explanations of the facts above referred to. Thus, some have supposed that the interior of the earth is composed, in part, of the metallic bases of the earths and alkalies—particularly potassium, sodium, and calcium—which combine energetically with oxygen whenever they are brought in contact with water, with the evolution of light and heat. If to these metals water should occasionally find access through fissures in the rock-crust of the earth, the heat generated might be sufficient to melt the surrounding mineral matters and produce volcanic and earthquake phenomena. Other chemical reactions, and the agency of electricity, have also been suggested as the cause of the internal heat of the earth, but none of these theories have thus far obtained general acceptation.

113. **Number and Distribution of Volcanoes.**—The number of active volcanoes on the globe is estimated at about 400.*

Of this number more than three-fourths occupy the islands or the shores of the Pacific Ocean. Thus, over seventy volcanoes exist on the islands of the Sunda Group (Java, Sumatra, etc.); seventy-four in Kamtschatka and on the Aleutian and Kurile Islands; twenty-three on the islands of Japan; thirty-four on the Moluccas and Phillippine Islands; fifty-four on the west coast of South America; forty-eight in Central America; and ten on the west coast of North America. Besides the volcanoes which thus fringe the Pacific, almost all the islands in the interior of this ocean, which attain a considerable height, are either of volcanic origin or are subject to volcanic eruptions—as the Sandwich, Friendly, Galapagos, and Ladrone Islands.

The Atlantic Ocean and Europe together number thirty-seven volcanoes; of these, ten are in the West India Islands, and five in Southern Europe and the Mediterranean. There is no certainty of the existence of any active volcano on the *continent* of Africa.

Questions.—Of what phenomena does this hypothesis furnish a ready explanation? Is the theory of a heated interior to the earth universally accepted? What is said of the number and distribution of volcanoes? Where are they mainly located?

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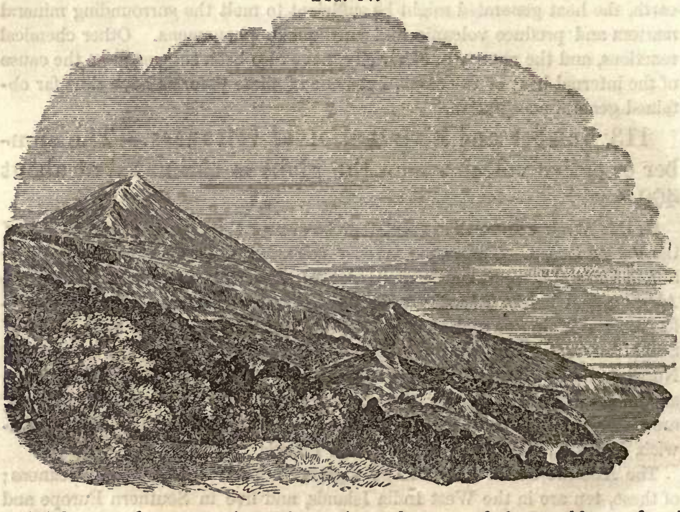
follows that since the time of Hipparchus, that is, for full 2,000 years, the length of the day has certainly not diminished by the 1-100th part of a second. The decrease of the mean heat of the globe during a period of 2,000 years has not, therefore, taking the extremest limits, diminished as much as 1-300th part of a degree of Fahrenheit."—*Humboldt.*

* This estimate includes all those which exhibit some evidence of having been in activity during the historic period. If, however, we class as active those only which have been in a state of eruption, within a comparatively recent period, the number is reduced to about 270.

The most extreme limit ever reached by man in the southern hemisphere also presents a wonderful example of volcanic fire. Sir James Ross, at a point on the coast of the great Antarctic continent, discovered in 1841 two immense volcanoes, the one extinct, called Mt. Terror; the other, discharging dense columns of black smoke, tinged with flame, called Mt. Erebus. The latter was estimated at no less than 12,000 feet above the level of the sea, and formed part of a stupendous chain of mountains belonging to the new continent, all of which were apparently volcanic.

The most active volcano in the territory of the United States is Mount St. Helens, on the Columbia River, in Oregon. In Mexico there are five active volcanoes; and notable examples also occur in the neighboring West Indian Islands, at Gaudaloupe, St. Vincent, and St. Christopher.

FIG. 67.



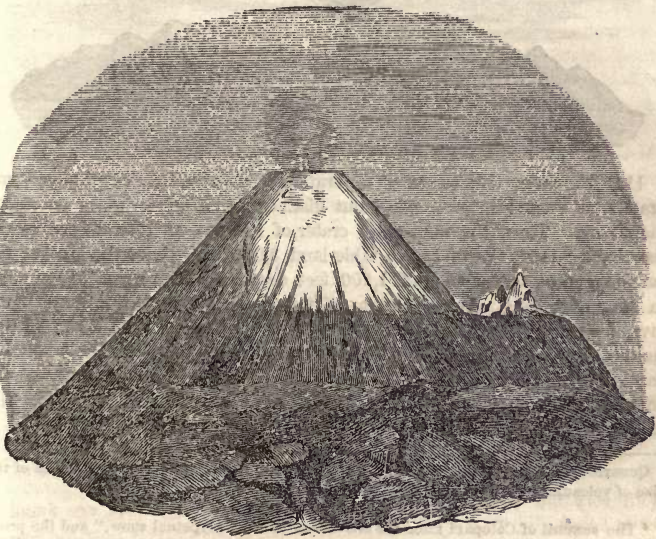
With very few exceptions, the active volcanoes of the world are found either in islands, or, if on continents, in situations comparatively near the sea-shore. Hence, it has been inferred that proximity to the sea, and the penetration of sea-water to the seat of igneous action, were essential for the production and continuance of volcanic phenomena. Humboldt, however, supposes that littoral (shore) situations only favor eruptions, by forming the margin of a deep sea basin, which, covered with water, offers less resistance to the subterranean fire than the interior continent covered with a greater weight of rock-strata.

QUESTIONS.—What volcanoes of note exist in or near the territory of the United States? What is said of the proximity of volcanoes to the sea-shore? What inferences have been drawn from this fact?

Volcanoes are rarely isolated, but on the contrary are almost always arranged in lines or bands, which generally coincide with extensive ranges of mountains.*

Such a linear arrangement, according to Humboldt, suggests the idea that volcanoes are merely vents, located above some far-extended subterranean crack or fissure in the crust of the earth, through which the molten matter of the interior escapes to the surface. The existence of these cracks, also, may be equally efficient in allowing water to find access to the interior, where, coming in contact with heated substances, great volumes of steam and gas would be evolved; and these in turn exerting an immense pressure, may be directly concerned in producing an eruption.

FIG. 68.



Of isolated volcanoes, disconnected with any other extensive elevation of the earth's surface, the "Peak of Teneriffe," 12,000 feet high, is one of the most marked examples. (See Fig. 67.)

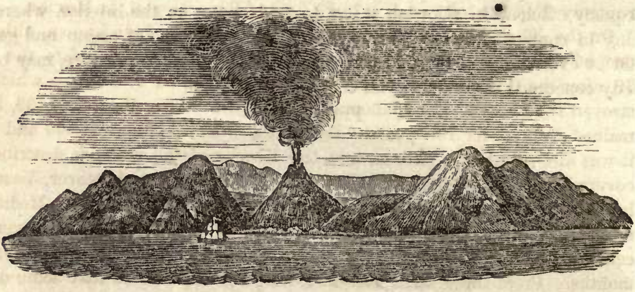
QUESTIONS.—What is said of the relations of volcanoes to each other? What does such a linear arrangement suggest? What is one of the most remarkable isolated volcanoes?

* Such a band or line of vents, for example, is presented by the volcanoes of America, those of the Andes and Rocky Mountains being connected by the Cordilleras of Mexico and Guatemala. Another remarkable line of volcanoes commences with Alaska, on the coast of Russian America, passes over the Aleutian Islands, thence into Kamtschatka, the Kurilian, Japanese, Phillippine, and Molucca Islands, then turning passes through Java and Sumatra, and finally terminates with the volcano of Barren Island, in the Bay of Bengal.

The loftiest volcano in the globe is Aconcagua (one of the Chilian Andes), which rises to the height of 23,900 feet. The most beautifully regular and symmetrical volcano is Cotopaxi, 19,070 feet. (See Fig. 68.)*

Other volcanoes exhibit no elevated cone whatever, but are mere accumulations or hills of loose materials. Fig. 69 is a representation of a low volcano on Barren Island, in the Bay of Bengal.

FIG. 69.



114. The proportionate size of the craters of volcanoes varies greatly; some craters, as Vesuvius, being small but distinct, while others are of enormous magnitude. Thus, the immediate crater of Kilauea, at Hawaii, one of the Sandwich Islands (located on a table-land 3,970 feet above the level of the sea), is a crescent-shaped gulf, 1,500 feet deep, and from seven to ten miles in circumference.† At the bottom of this crater are several lakes of liquid lava, which at times exceed two miles in circumference. At the great volcano of Pichincha, in South America—16,000 feet high—"the traveler," according to Humboldt, "may look down from the edge of the crater on the summits of mountains, which rise in the sulphureous atmosphere from the cavity beneath him."

QUESTIONS.—What is the loftiest? What the most symmetrical? What is said of the size of volcanic craters?

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* The summit of Cotopaxi rises far above the "line of perpetual snow," and the proximity of an eruption, according to Humboldt, is indicated "by a sudden fusion of the snow around the edges of the cone. Before the smoke is visible in the rarefied strata of air surrounding the summit and the opening of the crater, the walls of the cone are sometimes in a state of glowing heat, when the whole mountain presents an appearance of fearful and portentious blackness."

† "To give an idea of the capacity of this crater, the city of New York might be placed within it, and when at its bottom would hardly be noticed. All the usual ideas of volcanic craters are dissipated upon seeing it. There is no elevated cone, and no igneous matter or rocks ejected beyond the rim. The banks appear as if built of massive blocks, which are, in places, clothed with ferns, nourished by the issuing vapors. The bottom, in the daytime, looks like a heap of smoldering ruins, but at night the immense pools of cherry-red liquid lava, in a state of violent ebullition, illuminate the whole expanse, while an illuminated cloud hangs over the whole like a vast canopy."—*Narrative of the U. S. Exploring Expedition.*

115. **Frequency of Eruptions.**—Only a few volcanoes are in a state of *constant* activity, and the majority exhibit their powers only at distant intervals. The volcano of Stromboli, one of the Lipari islands, is a perpetually bubbling caldron of heated lava, and its operations were described by writers antecedent to the Christian era. The great volcano of Kilauea (which is the largest and most remarkable on the globe) is always active. Several volcanoes, in South and Central America, are also constantly burning; and, since the date of the Spanish Conquest, smoke has issued uninterruptedly from the lofty peak (17,000 feet) of Popocatepetl, in Mexico.

On the other hand, Vesuvius, which is one of the best known, although one of the smallest volcanoes,* is not recorded as active before the year 79, after the Christian era, when the famous eruption took place which destroyed the cities of Herculaneum and Pompeii. After the year 1139, it remained dormant for 168 years. During the interval between 1500 and 1631 it was also apparently extinct, and the interior of the crater is described as covered with shrubs and rich herbage. Of late years, however, Vesuvius has been exceedingly active. The volcano of Ischia, in the Mediterranean, is believed to have enjoyed an interval of rest for about seventeen centuries, or up to 1302, when an eruption broke forth, which lasted for two months. From these facts, therefore, it is not improbable that some of the volcanoes now regarded as extinct (like Chimborazo, in South America, or Mt. Ararat, in Eastern Asia), may at some future period exhibit intense activity.

The number of volcanic eruptions which take place in a century has been estimated at 2,000, or at the average rate of about twenty every year.

116. **Phenomena of an Eruption.**—The eruptions from those volcanoes, whose activity is intermittent, resemble each other so closely that the history of one is very much that of all; and this similarity is not limited to the external circumstances—namely, the explosion, the darkness, the torrents of lava, mud, or water, and the evolution of smoke and gases—but equally holds good in regard to the nature of the matter ejected from the interior of the mountain. Not only is the matter thrown out by volcanoes in the most distant parts of the world (with few exceptions) alike in form, but it is almost identical in chemical composition. We find that lava, scoriæ, ashes, and other products, proceed from all, or almost all volcanoes, and these products, when analyzed by the chemist, yield nearly the same ultimate elements.

QUESTIONS—Are the so-called "active volcanoes" always in a state of eruption? Mention some of the constantly active volcanoes? What is said of the eruptions of Vesuvius? What is the average annual number of volcanic eruptions? What is said of the similarity of volcanic eruptions?

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* The volcanoes of southern Europe, in the region of the Mediterranean, being surrounded by long-civilized communities, have been more closely observed and studied than any others on the globe; but the phenomena they exhibit are insignificant when compared with the operations of the mighty volcanoes of South America, or those of the Indian Archipelago.

Eruptions are generally preceded by loud, subterranean noises, and frequently by slight shocks of earthquakes. Fountains and springs dry up, and the air, pervaded by an unnatural stillness, seems close and oppressive. The sounds are described as being sometimes of the most awful description, and the noise, according to some writers, resembling discharges of heavy artillery, and awful roarings.* At the time when these sounds are issuing from beneath the ground, columns of dense smoke are seen to issue from the crater of the volcano. This smoke occasionally assumes a very singular appearance, and bears some resemblance to a tree, or an open umbrella. It sometimes overhangs so great an area as to produce total darkness in the neighborhood of the volcano, and is then accompanied by a fall of volcanic sand and ashes, which often attain a considerable depth.†

Succeeding the smoke, immense quantities of stones, of different sizes, mixed with ashes and sand, are now cast up from the mouth of the crater. In the eruption of Mt. Vesuvius, in 1779, a huge red column of liquid lava, mixed with stones, was projected to a height, according to Sir William Hamilton, of 10,000 feet; and the flames of Cotopaxi, according to Humboldt, have risen 2,700 feet above the crater.

The eruption generally soon reaches the point at which the molten lava begins to flow either over the crater or from lateral vents. It issues in a dark, sluggish stream, being sometimes of great breadth and depth, and always carrying destruction in its path.‡ Fig. 70 represents the appearance of a lava stream as it flows from the crater of Vesuvius.

QUESTION.—Describe the phenomena of an eruption.

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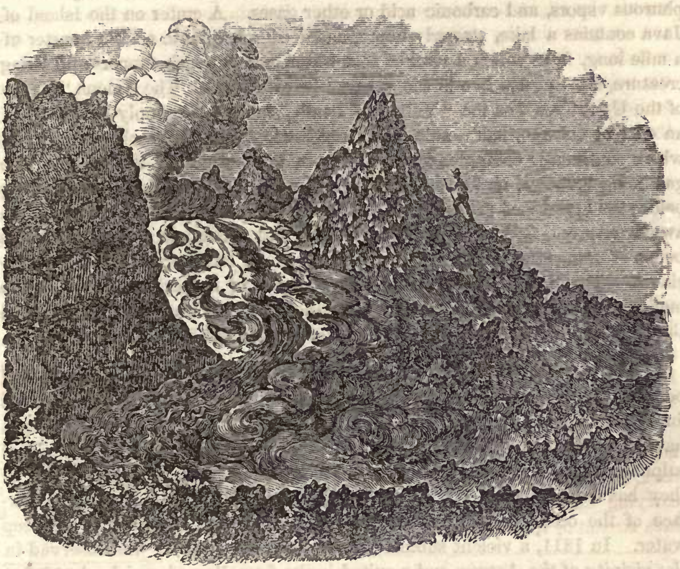
* Humboldt mentions that the ceilings in the palace at Portici, at the foot of Mt. Vesuvius, were cracked by the mere effect of the concussion of the air. On the occasion of an eruption of the volcano of Cozeguina, in Central America, the explosions are said to have been heard over an area of nearly 1,500 miles in diameter. During an eruption in Sumbawa, one of the Sundá Islands, the sounds were heard in Sumatra, at a distance of of 970 geographical miles, and at Ternate, in an opposite direction, at a distance of 720 miles.

† At the eruption of Cozeguina, in Central America, in 1835, the sand and ashes fell in such quantities in the immediate vicinity as to crush in the roofs of houses; ashes also fell at Leon, more than 100 miles distant, to the depth of several inches, and in Jamaica and Vera Cruz, comprising an area, in all, of 1,500 miles in diameter.—*Squier's Nicaragua.* It was by showers of this kind that the Italian cities of Pompeii and Herculaneum were buried in the year 79 of the Christian Era. In this case, however, the fine, loose materials appear to have been in part converted into mud by copious showers of rain, which resulted from the condensation of the vapors ejected from the volcano; and hence, as these cities are excavated, everything enveloped is found in a most perfect state of preservation—the pavements, with the carriage ruts in them, still distinct; the fresco-paintings on the walls almost as vivid as if just finished; the fabrics in the shops still showing their texture; bread retaining the stamp of the baker; and rolls of manuscript with the writing still legible.

‡ At an eruption of Mt. Etna, in 1792, it is mentioned that the liquid lava streams were often thirty feet high; and, when confined in narrow channels, they reached a height of 300 feet. Lava streams of the depth of 100 feet have repeatedly flowed from volcanoes in Iceland.

FIG. 70.



The progress of the lava is generally very slow; the rate of speed differing according as the lava-stream descends a more or less inclined surface. At the great eruption of Mauna Loa, Sandwich Islands, in 1859, a lava stream from an eighth to a half a mile in width, ran twenty-five miles in a single night, but did not reach the sea, forty miles distant from the crater, until eight days after the commencement of the eruption. Its speed at some points near the crater was estimated at thirty miles and upward per hour. It has been observed that lava, springing from a low source, is generally in a more liquid state than that from a more elevated crater; and that craters of low elevation throw out a much greater quantity of lava. The highest volcanoes of South America do not at present discharge any lava.

In the place of lava, torrents of mud, flowing with great violence, are sometimes the accompaniment of volcanic eruptions. Mud torrents, from Mt. Carguairazo, in South America, are said, on one occasion, to have covered a surface of about forty miles square; and similar streams, from Tunguragua, near Quito, S. A. (in 1797), filled valleys 1,000 feet wide to the depth of 600 feet.

From some volcanic fissures mud and steam are the principal products ejected. Very curious examples of this nature have been recently discovered in the Colorado Desert, on the eastern borders of California.

QUESTIONS.—**What is said of the progress and depth of lava streams? What other products besides lava are emitted from volcanic openings?**

Other volcanic fissures, or vents, are remarkable for the discharge of sulphurous vapors, and carbonic acid or other gases. A crater on the Island of Java contains a lake, strongly impregnated with sulphuric acid, a quarter of a mile long, from which a river of acid water issues, which supports no living creature, nor can fish live in the sea near its confluence. The famous "Valley of the Upas Tree," or the "Valley of Death," in Java, is simply the crater of an extinct volcano, half a mile in circumference, filled with carbonic acid gas, which continually emanates from fissures in the bottom of the valley. The gas being invisible, and entirely irrespirable, every living thing that descends below the margin of the valley is instantly suffocated; and as the same fate awaits any one that may go to the rescue, the ground is covered with the bones of numerous animals, and even men, that have approached the precincts. The deadly influence of this valley was formerly ascribed to the malignant properties of a peculiar vegetable production of the island, called the "upas tree," which especially flourishes in this locality.

117. Submarine Volcanoes.—Volcanic eruptions take place as well beneath the waters of the ocean as upon the land, although opportunities for observing such phenomena are not as frequent. The crews of vessels have, however, sometimes reported that they have seen in different places sulphurous smoke, flame, jets of water or of steam, rising up from the sea, or they have encountered islands, or reefs of rocks emerging above the surface of the ocean, where previously there was always supposed to be deep water. In 1811, a violent submarine eruption (see Fig. 71) was observed in the vicinity of the Azores, and resulted in the formation of an island 300 feet high, and a mile in circumference, which, after a time, disappeared. In 1814, a volcanic peak, 3,000 feet high, was protruded above the ocean, in the vicinity of the Aleutian Islands, east of Kamtschatka. In 1831, a volcanic island, called Graham's Island, one and a third miles in circumference, and about 200 feet high, rose in the Mediterranean, off the coast of Sicily. This island lasted about three years, when it was washed away, leaving an extensive shoal in its place. The water in this locality, previous to the eruption, was known to have been 600 feet deep.

118. One or two remarkable instances of volcanic eruptions may be briefly noticed. First, for duration and force we may refer to that which took place in the island of Sumbawa (one of the Sunda Islands lying east of Java), in the year 1815. It commenced on the 5th of April, and did not entirely cease until July. Its influence (*i. e.*, shocks, and the noise of the explosions) was perceptible over an area 1,800 miles in diameter, while within the range of its more immediate vicinity, embracing a space of 400 miles, its effects were most terrific. In Java, 300 miles distant, it seemed to be awfully present. The sky was overcast at noon-day with clouds of ashes, which the light of the sun was unable to penetrate, and fields, streets, and houses were covered

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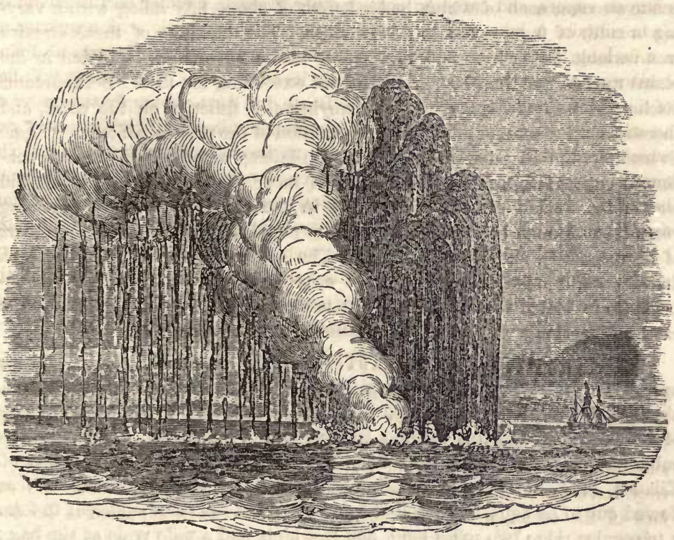
QUESTIONS.—Mention some examples? Do volcanic eruptions take place on the bed of the ocean? Mention some of the incidents attending such eruptions?

FIG. 71.



with ashes to the depth of several inches. At Sumbawa itself, immense columns of flame appeared to burst forth from the top of the volcano, Tombora, and in a short time the whole mountain appeared like a mass of liquid fire, which gradually extended in every direction. As the eruption continued, a darkness supervened, so profound as to obscure even the light of the flames; showers of stones and ashes fell continuously over the whole island; the sea rose twelve feet higher than it had ever been known to do before; and finally a whirlwind ensued, which tore up the largest trees, and carried them into the air, together with men horses, cattle, and whatever else came within its influence. Of 12,000 inhabitants in the vicinity only six are believed to have escaped, and of some entire villages not even a vestige remained.

In 1772, the Papandayang, one of the loftiest volcanic mountains in Java, after a short but severe eruption, suddenly fell in and disappeared in the earth, carrying with it about ninety square miles of territory. Forty villages were engulfed, or covered with ejected matter, at the same time, and nearly 3,000 persons perished.

Another eruption worthy of mention, in respect to the quantity of lava ejected, was that of one of the volcanoes of Iceland—the Skaptar Jokul—in the year 1783. This eruption commenced in May and lasted until the end of August, during the greater part of which time the sun was entirely hid by dense clouds of ashes and vapors, which extended even to England and

QUESTION.—What are some of the most remarkable volcanic eruptions on record?

Holland. The lava flowed from the volcano for ten weeks in two nearly opposite streams, each of which had a length of about fifty miles, with a varying breadth of from seven to fifteen miles. The thickness of these streams was variable, being from 500 to 600 feet in the narrow channels, but in the plains rarely more than 100, and often not exceeding ten feet. Both streams discharged into the sea, entirely destroying the fisheries on the coast, and thereby adding another misery to the condition of the poor inhabitants. Some rivers upon the island were heated to ebullition; others dried up; the condensed vapors fell in snow and torrents of rain; the whole country was laid waste; famine and disease ensued, and in the course of the two following years 9,000 human beings (one fifth of the population) and immense numbers of horses, cattle, and sheep perished. The scene of horror was closed by a dreadful earthquake. Previous to the eruption an ominous mildness of temperature indicated the approach of the volcanic fire toward the surface of the earth; a warning which has been observed in other eruptions.

119. **Force of Volcanic Action.**—The force exerted by volcanic agency is almost beyond computation. In the eruption of Skaptur Jokul, above described, it was estimated that there was discharged from the bowels of the earth, through this volcano, in the space of ten weeks, 60,000 millions cubic feet of molten matter, or forty millions of tuns. In an eruption of Kilauea, S. I., in 1840, Prof. Dana estimated the amount of matter that flowed out to be equal to 15,400,000,000 cubic feet—a mass sufficient to form a triangular ridge two miles long, 800 feet high, and a mile wide at the base.

The projectile force occasionally exerted in eruptions, may be judged of by the distance to which masses of rock have been thrown from the crater of volcanoes. Thus, Cotopaxi on one occasion threw a mass of rock, 109 cubic yards in volume, to a distance of nine miles; and the same volcano (which is 19,000 feet high) has projected material 6,000 feet above its summit. Vesuvius also (3,900 feet high) has also thrown scoria 4,000 feet above its summit.

The summit of Vesuvius is 3,900 feet above the sea-level. Now, to force a column of liquid lava, of the specific gravity of 2.8 (the comparative weight of compact marble), up the chimney of this volcano, to a height sufficient to cause the lava to flow over the crater, must require a pressure, at the base of the column, of at least 4,700 pounds to the square inch. In the case of Mauna Loa, Sandwich Islands, which is 13,600 feet high, the pressure requisite to effect the same result must be 16,500 pounds per square inch; and at Cotopaxi, 18,875 feet high, upward of 22,000 pounds.* But the chimney of a volcano, in all probability, extends to a very great depth—miles possibly—

QUESTIONS.—What is said of the force exerted by volcanic agencies? What proofs have we of the enormous power exerted?

* A better idea of the immensity of the power thus displayed may perhaps be gained by remembering that the pressure used in working high-pressure steam-engines does not ordinarily exceed sixty pounds per square inch of the piston.

below the sea level; and hence the figures above given must represent but a very small part of the actual force pressing upon the lava in its subterranean reservoir.

120. **Subterranean Connection of Volcanoes.**—It seems evident that there exists in many cases free communication under ground, between volcanoes at great distances from each other. Thus, according to Humboldt, all the lofty volcanoes in the vicinity of Quito, S. A., embracing Cotopaxi, Pichincha, and many others, are to be viewed as the openings of a single volcanic furnace—the subterranean fire sometimes breaking forth through one and sometimes through another of its chimneys.

An open, subterranean communication has also been inferred to exist between Etna and Vesuvius, in Southern Europe, since, when one of these volcanoes is active, the other, with all the smaller fissures in its vicinity, is generally notably quiet. In 1783, when a submarine volcano on the coast of Iceland ceased to eject matter, another immediately broke out 180 miles distant in the interior of the island. It therefore seems clear that however distinct the volcanoes of the same system may be at the surface of the earth, they are part of one general effect, produced by deep-seated subterranean causes.

121. **Extinct Volcanoes.**—Volcanic agency appears to have been more extensive—and possibly more active—in former ages of the world than at present; inasmuch as the remains of extinct volcanoes, craters, lava-streams, and accumulations of scoriæ and ashes occupy extensive areas of the earth's surface, which have exhibited no evidence of the action of subterranean fire during the historic period.

In southern and central France extinct volcanoes cover several thousand square miles of territory, the ancient craters and lava streams being every way distinct and characteristic. (See Fig. 11.) In southern Italy the craters of upwards of sixty extinct volcanoes can be recognized, some of them larger than Vesuvius. Extinct volcanoes also exist in Spain and Portugal, in Germany—along the Rhine—in Hungary, and throughout central and western Asia, and the whole peninsula of India. Mt. Ararat, in Armenia, is a huge extinct volcano. Striking marks of volcanic action also exist throughout Palestine and Asia Minor, especially in the vicinity of Mt. Sinai and the Dead Sea.*

In the southern plains of South America Mr. Darwin has described a vast deluge of lava which flowed in several streams from the Andes to a distance of over 100 miles, and of which the aggregate thickness at the extremity is not less than 130 feet. A large proportion of the lofty peaks of the Andes, of the Cordilleras in Mexico and California, and of the Rocky Mountains, must also be included in the class of extinct volcanoes.

QUESTIONS.—Is there any evidence of a subterranean connection between different volcanoes? What evidence have we of volcanic action in former epochs of the world's history? In what countries are the remains of extinct volcanoes especially noticeable?

* The destruction of the "Cities of the Plain," Sodom and Gomorrah, and the formation of the Dead Sea, is generally supposed by geologists to have been the result of volcanic action.

122. **Earthquakes** have been defined to be volcanoes without any vent; or, in other words, they are the result of the action of volcanic forces confined beneath the earth's surface.

As the accidental bursting of a powder magazine is more dreadful than the firing of the heaviest artillery, inasmuch as the one spreads all around and the other but in one direction, so earthquakes have ever inspired more terror and been more destructive of human life than volcanoes.

Earthquakes occur *not only* in all volcanic countries but in many districts which present no mark whatever of volcanic action and no trace of volcanic products.

123. **Earthquake Motions.**—The nature of the earthquake shock is that of waves propagated from a central point or focus.*

These waves sometimes manifest themselves as mere tremblings of the earth; at other times, the ground undulates like the sea. Occasionally a sudden upward motion is communicated to it, and when waves, advancing in opposite directions, cross each other, a rotary or whirling motion is produced. Earthquakes of the two latter kinds are the most destructive.

The undulations vary in height from an inch or two, to several feet. When their height is considerable very remarkable effects are produced. During the terrible earthquake which destroyed Calabria, in Southern Italy, in 1783, large tracts of land were conveyed from their original position to distances of more than half a mile. Humboldt mentions that, on one occasion, furniture was carried from one place and buried in another, and some persons were thrown across a river to a considerable height upon an opposite mountain.

The velocity of an earthquake's wave varies, according to the substance

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Questions.—What are earthquakes? Are earthquakes more to be apprehended than volcanic eruptions? Is the occurrence of earthquakes limited to volcanic districts? What is the nature of an earthquake shock? What is said of the height of the undulations? What of their effects?

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* "A powerful earthquake," says Mr. Darwin, "at once destroys the oldest associations; the world, the very emblem of all that is solid, has moved beneath our feet like a crust over a fluid: one second of time has conveyed to the mind a strange idea of insecurity, which hours of reflection would never have created."

"To man," says Humboldt, "the earthquake conveys an idea of some universal and unlimited danger. We may flee from the crater of a volcano in active eruption, or from a locality threatened by the approach of a lava stream; but in an earthquake, direct our flight whithersover we will, we still feel as though we trod upon the very focus of destruction. Every sound—the faintest motion in the air—arrests our attention, and we no longer trust the ground on which we stand. Animals, especially dogs and swine, participate in the same anxious disquietude; and even crocodiles, in the rivers of South America, which at other times are dumb, have been observed to quit the water and run, with loud cries, into the adjacent forests."

through which it is transmitted. Some strata carry it much further than others; and hence it will be felt along a particular line of country, where the stratum is more elastic, when it is not perceived at places much nearer its center. On the land the velocity of the wave has been estimated at from 40 to 140 miles per minute. Very frequently earthquakes originate in the bed of the ocean, and in such cases a wave is generated in the sea as well as the land. But the earth wave travels much faster than the ocean wave, and thus the destruction which the former commences on a coast the latter arrives to complete. The ocean wave, created by the great earthquake at Lisbon, in 1755, traveled to the West Indies at the rate of about eight miles per minute. In 1854, a wave, caused by an earthquake in Japan, traveled across the Pacific to the shores of California, in about twelve hours, or at the rate of about 600 miles per hour.

124. Earthquakes are generally preceded by loud, rumbling noises, and, in great convulsions, explosions like the discharges of artillery have been heard. At other times no sound whatever has been recognized.

125. **Duration of Earthquakes.**—The duration of an earthquake shock is seldom more than a minute; but successive shocks may succeed each other at intervals for a much longer period.

The great earthquakes at Lisbon, in 1755, which destroyed 60,000 persons, lasted but five minutes, and the first shock (which was the worst) but five or six seconds. In 1812 the city of Caracas, in South America, was leveled to the ground by three shocks, which occurred in the space of fifty seconds.

126. **Frequency of Earthquakes.**—In some countries earthquakes of greater or less intensity occur almost daily. At Lima, in Peru, an average of forty-five shocks may be expected yearly; and in Chili sixty-one have been noted in a single year, without including the slighter ones. The most destructive earthquakes have occurred on islands of the Indian Archipelago, Southern Asia; on the west coast of South America, and in Southern Europe, in the vicinity of the Mediterranean.

Single shocks are occasionally felt in the United States, east of the Rocky Mountains, but, with a few exceptions, their effects have been inconsiderable.* In Oregon and California earthquake shocks are not unfrequent.

QUESTIONS.—What is the velocity of earthquake waves? Do sounds precede the occurrence of earthquakes? What is said of the duration of earthquakes? What of their frequency? In what countries have the most destructive earthquakes occurred? Are earthquakes common in the territory of the United States?

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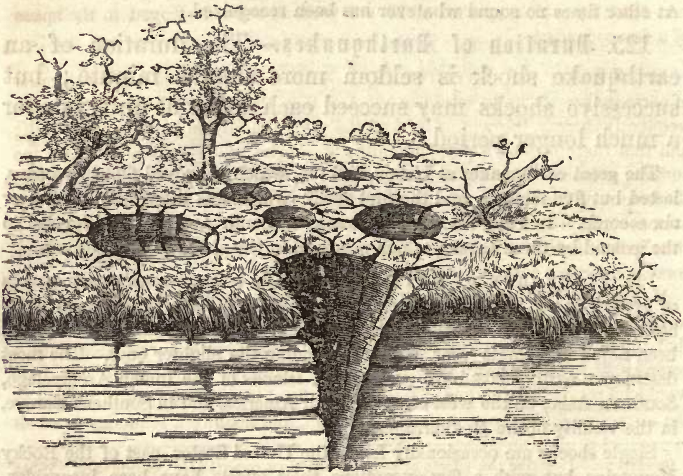
* In 1811-12, earthquake shocks, experienced in the vicinity of New Madrid, Missouri, caused the sinking of an area of country seventy-five miles long by thirty wide, to a depth of several feet. In some places the earth rose in great undulations. Lakes, twenty miles in extent, were formed, while others were drained. Extensive fissures in the earth opened, from which columns of water, gravel, and mud were ejected to a great height. New islands also appeared in the Mississippi. Some evidences of this earthquake are even now visible.

The total number of earthquakes recorded, from the commencement of the nineteenth century to the end of the year 1850, is 3,240; of this number fifty-three may be called great earthquakes, in which whole cities and towns were destroyed and many lives lost

127. **Remarkable Earthquakes.**—As illustrative of the effects of earthquakes, a few remarkable examples may be referred to

The most dreadful one on record is that, which in November, 1755, destroyed the city of Lisbon, in Portugal. The only warning the inhabitants received was a noise like subterranean thunder, which, without any considerable interval, was followed by a succession of shocks, which laid in ruins almost every building in the city, with a most incredible slaughter of the inhabitants (60,000). The bed of the river Tagus was in many places raised to the surface, and vessels on the river suddenly found themselves aground.

FIG. 72.



The waters of the river and the sea at first retreated, and then immediately rolled violently in upon the land, forming a wave over fifty feet in elevation. To complete the destruction, a large quay, upon which great numbers of people had assembled for security, suddenly sunk to such an unfathomable depth that not so much as one body ever afterwards appeared at the surface.

This earthquake also affords the best example on record of the extent of ground over which some of these great natural convulsions diffuse themselves;—its influence being felt over nearly 4,000,000 square miles of the earth's surface, and over one twelfth of its circumference. All the islands of the West Indies were agitated, and the sea around them rose to an unusual height; the shock was also perceptible throughout New England and the

Atlantic States. In Scotland, Sweden, and Norway the waters of lakes were observed to be in a state of commotion, and in many places springs temporarily disappeared. In the kingdom of Morocco upwards of 8,000 persons perished. It was also noticed that Vesuvius, which had shown signs of eruption previously, became tranquil at the time of this earthquake.

An earthquake which occurred in Calabria, Southern Italy, in 1783, was only equaled by that of Lisbon. It did not, however, extend like the latter, over so great an area of country, but the effects produced within a limited space were greater. Its duration was only two minutes, during which time it destroyed all the towns and villages within a circuit of twenty-two miles, and, directly or indirectly, the lives of about 100,000 of the inhabitants.* One singular phenomenon attending this earthquake was the formation, in the earth, of singular cavities, a few feet in diameter, and in the form of an inverted cone, through which a jet of water spouted. (See Fig. 72.)

A terrible earthquake also occurred in the kingdom of Naples, in December, 1857, by which upward of 20,000 persons were destroyed in the space of a few seconds.†

128. **Theory of Earthquakes.**—An examination of a great number of earthquakes seems to establish the fact that these convulsions occur more frequently during the winter half of the year than during the summer half; and that there is also a preponderance of shocks at the equinoxes and the summer solstice. Earthquake action also appears to be the greatest when the height of the column of mercury in the barometer is least (*i. e.*, when the atmospheric pressure is least), and when its range of oscillation is greatest—thus indicating that a variation in the pressure of the atmosphere may have some connection with the phenomenon.

M. Perrey, of France, who has tabulated about 7,000 earthquakes, inclines to the following theory respecting their origin: Starting with the supposition that the interior of the earth is in a liquid or melted state, surrounded with a comparatively thin crust; then the interior mass, being deprived of solidity, would be compelled to yield, like the superficial mass of the ocean waters to the attractive influence of the sun and moon, and acquire a tendency to swell

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QUESTIONS.—Describe the effects of some of the most remarkable earthquakes. What facts seem to be established respecting the occurrence of earthquakes? What theory has been proposed by M. Perrey, of France?

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* The peninsula of Calabria, where this earthquake occurred, forms the southern extremity of Italy, and is about sixty miles in length by about twenty in breadth. Through the center of the peninsula runs a chain of granite mountains, which is separated from the sea on its western side by a plain of recent strata, composed of very yielding material. The effect of the earthquake was to disconnect, throughout almost the whole length of this chain, the new from the ancient rock, leaving a chasm between them. One half of the peninsula, therefore, actually slid in the direction of the sea; and from this fact alone the change and destruction consequent may be inferred.

† It appears from reliable data that the kingdom of Naples, in the course of seventy-five years, or from 1783 to 1859, has lost, by earthquake agencies, at least 110,000 inhabitants, or more than 1,500 per year, out of an average population of 6,000,000.

out in the direction of the rays of these two bodies. This tendency, meeting with resistance from the rigidity of the solid crust, would occasion shocks and fractures in the latter. This theory is, however, opposed, *first*, on the ground that if tidal movements do take place in the interior of the earth their influence would be not only insignificant as compared with the total mass of the earth, but far within the elastic limits of the earth's materials; and, *secondly*, that the existence of a fluid interior to the earth is but an hypothesis.

On the other hand, no satisfactory hypothesis, explanatory of earthquake phenomena, has thus far been presented by any geologist who rejects the "internal heat theory."*

But whatever may be the ultimate cause of earthquakes and volcanoes, the supposition that they have a common origin is sustained by a great variety of evidence. Thus, it is said to be the general opinion at Naples and in Sicily, that earthquakes are not to be dreaded so long as smoke escapes freely from the craters of Vesuvius and Etna. The same feeling also prevails in the volcanic district of South America. It is stated by Humboldt that the volcano of Pasto, in South America, which for many months had uninterruptedly emitted a column of thick smoke, ceased to do so at the very moment that the province of Quito, 192 miles to the south, was convulsed by an earthquake. At the same hour that the town of Concepcion, in Chili, was destroyed by an earthquake, in 1835, a whole line of volcanoes, situated in the Andes, in the vicinity, instantaneously spouted out a dark column of smoke; and during the time that these eruptions lasted (all the subsequent year), the immediate neighborhood was entirely free from earthquakes.

129. **Thermal Springs.**—The phenomena of thermal springs are attributed to the same igneous agency as volcanoes and earthquakes.

Hot springs are found most commonly in the vicinity of volcanoes; but they also occur in countries which at present afford no evidence of volcanic

QUESTIONS.—What circumstances lead to the opinion that earthquakes and volcanoes have a common origin? To what are the phenomena of thermal springs attributed? Where do hot springs occur?

* Mr. Mallet, of England, who has made the study of earthquakes a specialty, and who entirely rejects the supposition that the interior of the earth is in a state of igneous fluidity, after noticing the circumstance, that the magnetism of the earth is in some way connected with the phenomena of spots upon the disc of the sun, says: "We find, then, that both sun and moon influence, with other and more occult forces than those which address sense and eye, our planet, and that these all incessantly modify the conditions and relations of every grain of matter in the inmost recesses of its nucleus. While every cosmical force is also found to be correlated to every other, all mutually convertible, and capable of appearing and disappearing, 'by measure, number, and weight,' as mere brute power or mechanical force, it is not too much, at least, to affirm the advancing probability that a distinctly (though irregularly) periodic phenomenon, such as earthquakes, will be found intimately related to them, possibly with no very long or intricate intermediate chain of causation." A similar theory has also been recently advocated by Dr. C. F. Winslow, of Boston, Mass.

activity. The majority of them, however, rise from rocks of a volcanic nature, from mountain chains, or from points of disruption in strata. But wherever their location, it requires no demonstration to prove that boiling water, continually issuing from the earth, must come from a depth where boiling heat continually exists. It is, furthermore, strong evidence of the connection between hot springs and volcanic phenomena, that earthquakes and volcanic eruptions are known to have affected the temperature of such springs. Thus, after the occurrence of an earthquake in the north of Spain, the temperature of a celebrated hot spring in the Pyrenees, was so much reduced as to be no longer of any value. In the year of the great earthquake at Lisbon, another spring among the Pyrenees rose 75° in temperature.

Hot springs are of all degrees of temperature, between that of the surrounding air and boiling water. They (with few exceptions) discharge at all times the same quantity of water, and their temperature remains constant. There is evidence to show that the temperature of some hot springs has not diminished during the last thousand years. The waters of thermal springs are frequently so charged with gases and mineral substances that they are termed "mineral waters;" as, for example, the Sulphur Springs of Virginia, of Bath in England, and Baden in Germany.

In the United States the most remarkable hot springs occur in Virginia, Arkansas, Oregon, California, and Territory of Utah. In Arkansas, upward of seventy have been enumerated, which range in temperature from 118° to 148° Fahrenheit.

Those of the Napa Valley, California, discovered in 1851, are thus described by Prof. Forrest Shepherd: "Within the space of a half mile square are from one to two hundred openings, through which the steam issues with violence, sending up columns of dense vapor to the height of 150 to 200 feet. The roar of the largest of these can be heard for a mile or more. Many of the openings work spasmodically, precisely like high-pressure engines, throwing out occasional jets of steam or volumes of hot, scalding water, some twenty or thirty feet high, endangering the lives of those who rashly venture too near. Numerous cones are formed by the accumulation of various mineral salts, and by deposits of sulphur crystals with earthy matter. Frequently the streams of boiling water mount up to the top of these cones with violent ebullition, giving to the cones an appearance of being immense boiling caldrons."

Of all hot springs, those of Iceland, known as the "Geysers" (raging fountains) are the most celebrated. They occur in a group of one hundred or more, in the vicinity of Mt. Hecla. The largest, termed the "Great Geyser," consists of a nearly circular basin, fifty feet in diameter, and about four feet deep. In the center is a well or tube, eight or ten feet in diameter, and seventy-five feet in perpendicular depth. Through this tube hot water, hold-

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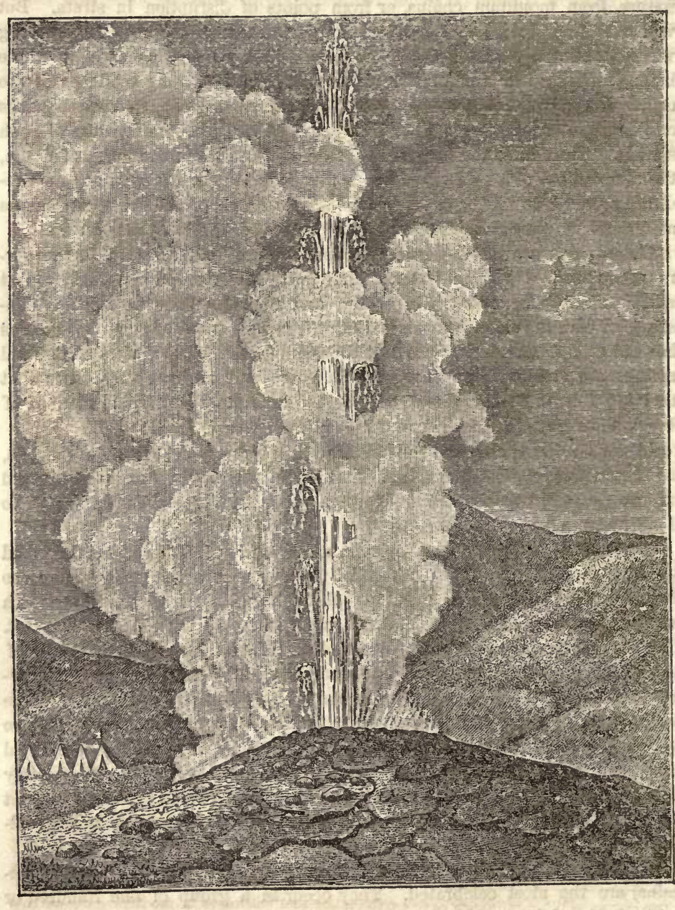
Questions.—Is there any evidence that hot springs are connected with the agencies that occasion volcanoes and earthquakes? Are hot springs found in the territories of the United States? Enumerate some of them? What are the most celebrated examples of hot springs?

FIG. 73.



ing silica in solution, is continually bubbling over into the basin, depositing silicious sinter at the bottom and round the cavity. When the basin is full, subterranean explosions, like the firing of distant cannon, are heard at intervals of some hours, accompanied with a tremulous motion of the ground. Louder explosions succeed; the water becomes agitated; steam escapes in large quantities, and, finally, a column of boiling water is thrown up with

QUESTION.—Describe the action of the Geysers.

great violence to the height of one or two hundred feet. After the water ceases to play, a column of steam, rushing up with amazing force and deafening explosion, terminates the eruption. Fig. 73 represents the Great Geyser of Iceland in action.

130. **Modifications of the Earth's Surface produced through Igneous Agencies.**—Earthquakes and volcanoes are powerful agents in producing modifications of the earth's surface.

During the earthquake in Chili, in 1822, the coast of South America, for upward of a hundred miles, was elevated from two to seven feet; while the whole area of territory permanently uplifted at the same time, was estimated at 100,000 square miles—an extent of country equal to one half the area of France, or about five-sixths of the area of the whole of Great Britain.*

In 1819, during an earthquake, near the mouth of the Indus, a tract of land, 2,000 square miles in area, was permanently depressed and converted into an inland sea; while another portion of country, fifty miles in length and several miles in width, was elevated at the same time to a nearly uniform height of ten feet. In 1692 the harbor and part of the town of Port Royal, in Jamaica, suddenly sunk, during an earthquake, to a depth of nearly fifty feet. Numerous other examples of a like character, occurring within the historic period, might also be cited.

131. **Gradual Elevations and Depressions.**—Another *apparent* manifestation of subterranean igneous agency is the *gradual* elevation or depression of portions of the earth's surface.

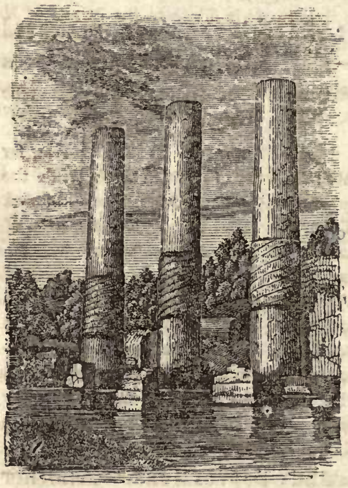
One of the most interesting local examples of this action is afforded by the remains of the temple of Jupiter Serapis, which was built on the shore of the Mediterranean, near Naples, about eighteen hundred years ago. Its ruins remained unnoticed until 1849, at which time three columns were discovered projecting a little above the surface of the ground, which, when excavated, were found to be composed of single blocks of marble forty feet high, resting upon a pavement or platform. (See Fig. 74.) The surfaces of these columns are smooth and uninjured, to an elevation of about twelve feet from the pedestal, where a band of perforations, made by a species of marine boring shell (*Lithodomos*), inhabiting the Mediterranean, commences and extends

QUESTIONS.—What influence have earthquakes and volcanoes in modifying the earth's surface? Give some examples. Do elevations and depressions of the earth's surface take place gradually? What is a remarkable local example?

* "If we suppose the elevation to have been only three feet on an average over this extent of territory, the mass of rock added to the continent of America by this earthquake, or, in other words, the mass of rock previously below the level of the sea, and afterward permanently above it, must have been equal to fifty-seven cubic miles in bulk, which would be sufficient to form a conical mountain two miles high, with a circumference at the base of nearly thirty-three miles."—*Lyell.*

to the height of nine feet, above which all traces of their ravages disappear. These perforations, many of which still contain shells, are so numerous and deep as to render it certain that the pillars were immersed in sea water at a time when their base and lower portions were protected by rubbish and sediment, and that the upper portions at the same time projected above the water, and were, consequently, placed beyond the reach of the *lithodomi*. The platform of the temple is now about one foot below high water mark, and the sea is 120 feet distant. The evidence, therefore, is conclusive that the columns were first depressed, and after remaining partially submerged in the sea for a considerable period were again elevated; thus incontestably proving that the relative level of land and sea in that part of the Mediterranean coast has changed more than once during the Christian era; and that each movement of subsidence and elevation, exceeding twenty feet, took place so gradually that the columns continued to maintain their upright position. At the present time the columns appear to be again subsiding, and a change in their position has been recognized within the last few years. The country in their immediate vicinity exhibits marked evidence of volcanic activity.

FIG. 74.



A gradual change in the relative level of land and sea has also been noticed on an extensive scale in regions not subject to the action of volcanoes and earthquakes.

Thus, in Sweden, for example, a line traverses the southern part of that kingdom from the Baltic to the Cattegat, to the north of which, even as far as the North Cape of Europe, there is evidence scarcely disputable that the land is gradually rising at the average rate of nearly four feet in a century; while, to the south of this line, there are similar proofs of a slow subsidence*.

QUESTION.—What is said of the elevation and depression of land now going on in Sweden?

* The gradual elevation of the northern portions of Sweden and Norway is proved by observations of marks cut in the rocks along the sea-coast; and also by the fact that numerous beds of shells, of the same species as those now inhabiting the Baltic, together with rocks covered with barnacles, are found at elevations of from 100 to 600 feet above the present sea-level. The subsidence of the coast of southern Sweden is also indicated by the circumstance that the streets of ancient seaport towns are now, in some instances, covered with water; and also by the record of measurements made during the last century.

On the other hand, the entire western coast of Greenland has, for the last two centuries, been gradually sinking, and the locations of the early European settlements are now entirely or in part submerged.

Evidence has also been collected, showing, beyond all question, that the eastern coast of South America, from the Rio de la Plata to the Straits of Magellan, a distance of 1,200 miles, has been raised in the most quiet manner, and within a comparatively recent period, to an elevation of from 100 to 140 feet in height; and that over wide areas of the Pacific and Indian oceans a part of the islands are at present rising, while others are slowly subsiding.

Evidences of similar changes may also be observed in various parts of the United States.

At Lubec, on the northern coast of Maine, barnacles (a species of marine shell) are found attached to rocks which are at present eighteen feet above high water. Beds of clay, sand, and gravel, containing numerous species of shells, now living upon the Atlantic coast, and presenting other evidence of being ancient sea-bottoms, are found in many localities in our country at heights varying from fifty to nearly 600 feet above the present sea-level: as at Montreal, 540 feet high; in the valley of Lake Champlain, 400 feet; and near Quebec, 200 feet.

The evidence of *subsidence* in other localities is almost equally striking. Thus, most persons at all familiar with shore life, must have observed at different points on the Atlantic coast the remains of logs, stumps, and roots submerged below the present tide level. These are generally regarded as the remains of trees, torn from their original places of growth by currents or by the wearing away of the shores, and deposited where they are found by the ordinary action of water. To any one who examines them carefully, however, it soon becomes evident that they grew upon the spots where they now are; inasmuch as their stumps remain upright, their roots are still fast in the earth, and in many cases the bark and small roots are still adherent. In protected situations upon the low, sloping shores of New Jersey and Long Island, areas embracing thousands of acres can be found, in which the bottoms of bays and marshes are as thickly set with the stumps of trees as the ground of any living forest. It is also stated by Dr. Emmons, Superintendent of the Geological Survey of North Carolina, that the bottoms of the sounds on that coast are everywhere so thickly studded with stumps of the common pine of the mainland, that it is necessary to remove them by gunpowder before a net can be drawn for fishing.

These and a multitude of other similar facts render it certain, that large portions of the solid crust of the globe, whether land or sea-bottom, are in a state of constant fluctuation as regards level. To such movements as these,

QUESTIONS.—What of the depression of Greenland? What of fluctuations of the earth's crust in South America and the Pacific? What evidence is there that similar changes have occurred in the United States? What is said of the existence of submarine forests on the Atlantic coast? What inference may we draw from these examples?

moreover, acting in times past, geologists ascribe the elevation of the whole of the present land-surface of the globe above the waters of the ocean. We say the whole of our present land-surface, because by far the greater portion of the dry land is now covered by, or made up of, rocks which must have been formed and consolidated on the bottom of the ocean; and of the remainder, where igneous rocks now prevail at the surface, we have every reason to believe that the greater part at least, if not the whole, was once covered by rocks of aqueous origin.

To such gradually acting forces we must ascribe not merely the elevation of all land, but also those diversities of the earth's surface which have resulted from unequal elevation, such as mountain-ranges, table-lands, valleys, and the depressions of the ocean, with many of the disturbances, fractures, and contortions of rock strata, which have been already noticed.*

Nor is the configuration and extent of the terrestrial surface alone affected by such movements; inasmuch as the generic distribution of animals and plants is governed in a great measure by altitude above the sea; and one may readily perceive, therefore, how gradual elevations of the land must also gradually change the character and distribution of the life upon its surface. As the sea-bottom, moreover, will also partake of the same fluctuations as the land, marine life, which is known to be more sensitive to physical changes than terrestrial, must also be sensibly influenced. Recent scientific investigations have shown that the sea-bottom, from the shore daily covered by the tides to the greatest depths to which life and organization extend, is divided into zones, each of which is characterized by its own peculiar sea-weed or shell-fish; and any derangement of these zones, therefore, whether sudden or gradual, must necessarily be followed by changes in their types of animal and vegetable life, and possibly by the extinction of whole races or families.

As to the cause of such fluctuation in the crust of the earth, geologists have not been able to furnish any entirely satisfactory explanation. Earthquakes have, in some instances, affected the level of limited districts; but this agency, when applied to the elevation of whole continents, seems altogether inadequate. The theory most generally favored is, that an explanation of the phenomenon in question is to be found in fluctuations of temperature in the heated interior of the earth. Thus, great accessions of heat, rising

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Questions.—What has probably been the condition of the greater portion of the earth's surface during some former period? What effect have gradual uprisings had upon the configuration of the earth's surface? What effect have such movements upon animal and vegetable life upon the earth? What has been ascertained in regard to the distribution of marine life? What causes have been assigned for fluctuations of the earth's crust?

*** The existence, in almost all quarters of the globe, of ancient sea-beaches, or coast-lines, at elevations varying from ten to several hundred feet above the present sea-level, affords us some indications of the extent of the changes which have been produced in the appearance and condition of the earth's surface by elevations within a comparatively recent period.**

nearer the surface in one part than another, would cause expansion of the rocks affected by it in every direction, and produce an outward bulging or elevation of the rocks, accompanied, it may be, by injection of molten matter among them; while, on the other hand, local refrigeration would tend to produce shrinkage and contraction of the rocks, and, consequently, depression.

Experiments made some years since, by officers of the Topographical Corps of U. S. Engineers, on the expansion of various rocks by heat, furnished data which proved, that if a mass of sandstone, a mile in thickness, should have its temperature raised 200° F., it would expand sufficiently to lift almost any amount of super-imposed rock ten feet above its former level. It would also appear that if a part of the earth's crust, 100 miles in thickness, and equally expansible, were to have its temperature raised 600° or 800°, it would probably produce an elevation of between two and three thousand feet, while the cooling of the same mass, subsequently, might cause the uplifted material to sink down again and resume its original position. In such an agency, therefore, we can find a plausible explanation of the gradual rise of land in Sweden, or South America, or the subsidence of Greenland, or of the bottom of the Pacific Ocean.

132. **Speculations concerning the Original Condition and Formation of our Globe.**—The theory of central heat, so generally adopted, extends no further back than the time when the *whole* globe was assumed to be in a state of complete fusion and incandescence. The mind, however, not willingly accepting any limit to its speculations, naturally seeks to know the origin of this vast accumulation of heat, or what was the condition of the matter constituting our planet at the commencement. In prosecuting the inquiry, the geologist finds little to assist him in the truths which belong especially to his own science, but must enter into the departments of astronomy and chemistry.

133. **Nebular Hypothesis.**—Modern science presents us with only one hypothesis which in a consistent and satisfactory manner attempts to reveal to us the condition of matter in what may be called the beginning. The outlines of this theory, and the evidence upon which it is based, may be briefly stated as follows:

Our solar system, of which the earth is a member, viewed superficially, presents to us the idea of a vast luminous body—the sun, occupying a central position, with a number of smaller, though various-sized bodies revolving at

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QUESTIONS.—What experiments have been made on the expansion of rocks by heat? To what extent does the theory of central heat extend? Does geology furnish in itself any evidence of the earliest condition of matter?

different distances about it; some of which, in turn, have smaller planets or satellites revolving about them. A closer examination, however, makes us acquainted with some very singular peculiarities in the structure of this so-called "solar system." Thus, in the first place, it is a very singular fact that the orbits of the planets are all nearly circular, and that their planes are nearly coincident with (or in the same line with) the plane of the sun's equator.

Next, it is not less remarkable that the motions of the planets around the sun, and the satellites around the planets, and finally, that the motions of all—sun, planets, and satellites—around their axes, should be only in one direction, viz., from west to east; that the periods of revolution grow shorter in the planets and satellites as their distances from their primary grow less: that the sun rotates on its axis in a shorter period than that employed in the revolution of any planet; and that every planet, accompanied by satellites, rotates on its axis in a less time than the period of revolution of any satellite. These peculiarities suggested to Laplace—the eminent French astronomer and mathematician—the idea that all the matter of the solar system was once a connected mass, endowed with a uniform motion in one direction. He further showed, that while this hypothesis and its deductions explained fully the peculiarities noticed, they were not accounted for by any other supposition; and also, that had the existing arrangement of the solar system been left to accident, the chances against the occurrence of the present organization would have been as four millions of millions to one.

Coincident with these investigations was the discovery, by astronomers, of the existence, in space, far removed from our system, of an immense number of objects, which, from their foggy, cloudy appearance have been called nebulæ;—some of vast extent and irregular outline, as that in the Sword of Orion, which is visible to the naked eye; others of shape more defined and regular; and others again in which small, bright nuclei, apparently condensed points, appear here and there over the surface. Ascending higher as it were in the scale of progress, we have next clusters of nuclei, with nebulous matter around them; and then what are called "nebulous stars," or luminous spherical objects—bright in the center and dull toward the extremities—existing, however, in every stage of concentration, from stars with ill-defined centers, to stars invested with only a slight burr or haziness. The figures in plate 75 represent some of these various forms of nebulæ, as seen through a telescope.

Upon these facts, mainly, has been built up the so-called "*nebular hypothesis*," which supposes that the various appearances we have described, represent the various conditions which suns, systems, and worlds pass through in their progress of formation; the cloudy nebulæ, representing matter in its original chaotic condition; the defined nebulæ, the first stage of condensation; and nucleated nebulæ, and the succession of nucleated stars, the more advanced

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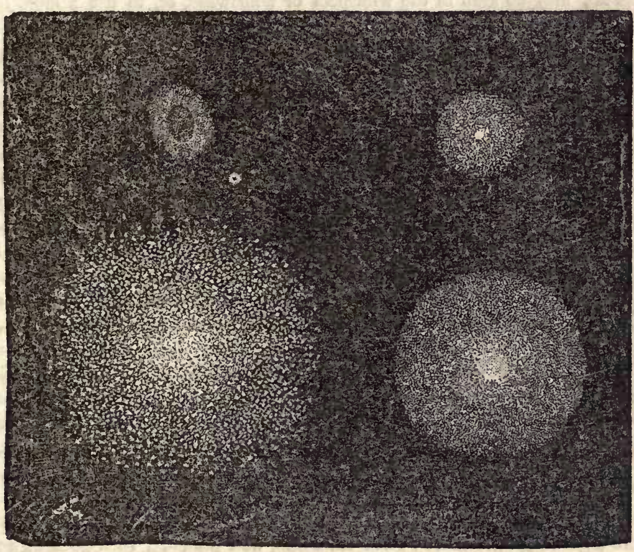
Questions.—Viewed superficially, what peculiarities are found in the structure of the solar system? What idea was suggested to Laplace by these peculiarities? What probability is there that they could have originated through accident?

and final stages;—just as a child, a boy, a youth, a middle-aged, and an old man, indicate the successive periods in the life of a human being.*

But whatever may be the physical condition of the nebulæ, the main features of the theory of Laplace curiously accord with the antecedent condition of our system as deduced from its present peculiarities; and it is accordingly

FIG. 75.



inferred that, in the "beginning," our solar system was an immense sphere of nebulous matter, filling all the space now occupied by the system, and extending even to a point far beyond the limits of the orbit of Neptune—a planet whose average distance from the sun is about three billions of miles.†

QUESTIONS.—What are the nebulæ? What is the hypothesis called that attempts an explanation of their appearances? What does this hypothesis assume was the former state of the solar system?

* It has been urged of late that the resolution of many of the nebulæ, under the powerful telescope of Lord Rosse, into stars, or, in other words, the proving that the misty condition of some of these bodies was due to distance rather than condition, was fatal to the assumptions of this theory; but this opinion is not generally entertained by astronomers, and the best authorities are now agreed, that even if all the nebulæ were resolved (which, as yet, is very far from being the case) the remaining evidence in favor of the hypothesis is almost incontrovertible.

† Astronomers, knowing the present mass and weight of the sun, planets, and satellites, have even been able to calculate the extent of expansion to which their material particles must have been subjected in order to fill up, uniformly, this enormous space, and it has

Assuming the existence of such a nebula in the first instance, the general attractive force resident in all matter would gradually cause its particles to approach each other, and thus, from the outset, the nebulous sphere must have commenced condensing and contracting. "It is, moreover, a well-known law of physics, that when fluid matter (gaseous or liquid) collects toward, or meets in a center, it establishes rotary motion. Every-day illustrations of this law may be seen in the whirlpool or whirlwind, or, to use a more humble illustration, in water sinking through the aperture of a funnel. Thus, rotation on an axis would commence, at first slow, but become quicker and quicker as the condensation increased." With the establishment of rotary motion, a tendency in the mass to throw off its outer portions would be generated, in consequence of the centrifugal force overpowering the central attraction; and it is accordingly supposed that masses of matter were, in fact, from time to time, torn away from the nebulous sphere, which detached portions afterward continued their courses separate from the main mass, but preserving a similar direction in their motion. Such detached masses, abandoned successively at different stages of the condensation, formed themselves into single planets, or like to the great original sphere, into planets with satellites and rings, until, finally, the principal mass condensed itself into the sun, which still occupies its original position as the center of the system, and as the largest body.

Simultaneously with the commencement of condensation in the nebulous matter, the force *heat* must have manifested itself, since it is a general law in physics that the condensation or compression of all matter, under all circumstances, evolves heat; and as condensation and refrigeration further progressed, by the radiation of heat into space, other forces—as chemical affinity, cohesion, etc.,—must have exerted an influence, until, at last, the constituent materials of our earth and the other planetary bodies, passed from a gaseous to a fluid or solid condition, and assumed their present forms and properties.

134. Such is a general outline of the only consistent and plausible theory by which modern science attempts to trace back the history of the formation of our earth, the sun, and its associate planets. It may also be remarked, that the suppositions of science involved in the nebular hypothesis are not antagonistic to the Mosaic account of creation. This will appear evident, if we remember that that which Moses names heaven is different from the blue

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QUESTIONS.—Assuming the existence of such a nebula, what changes would probably take place in it? In what manner was the solar system supposed to have been formed? What development of force must have accompanied condensation? Is the nebular theory antagonistic to the Mosaic accounts of creation?

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been found that the density of this hypothetical nebula must have been so small that all the matter included within three cubic miles would have weighed less than a single grain. Incredible as this statement may seem, there is some evidence tending to show that the matter constituting some comets exists in an equal state of tenuity.—*See Babinet's Researches on the Density and Mass of Comets;—Annual of Scientific Discovery for* 1858, *pp.* 361–364.

dome above us, and is synonymous with space; that the unformed earth was in a state of chaos and darkness, and that the separation of the waters of the great deep—which were afterward divided into waters above the firmament and waters below the firmament—resembles the process of condensation and consolidation by which the chaotic elements of the earth assumed form and arrangement.

The acceptance of this theory, moreover, can in no wise affect the inference that the universe is the work of a wise and omnipotent Creator. "Let it be assumed," says Dr. Whewell, "that the point to which it leads us is the ultimate boundary of physical science; that the furthest glimpse we can obtain of the material universe shows it to be occupied by a boundless abyss of attenuated, *self-luminous* matter (*i. e.*, the nebulæ); still we are left to inquire how space came to be thus occupied; and how matter came to be thus luminous; and if we establish, by physical proofs, that the first fact which we trace in the history of the universe is, 'that there was light,' we shall still be led, even by our natural reason, to suppose that before this could occur 'God said, Let there be light.'"

In addition to the support which the nebular hypothesis derives from the structural peculiarities of the solar system, and from the apparent condition of the nebulous bodies existing in space, various other facts strongly contribute to render its suppositions probable.

Thus, the substance of comets appears to be a kind of luminous matter, attenuated to a degree almost beyond conception—matter, possibly, in the condition of uncondensed nebulæ. According to M. Babinet's observations on the comet of Encke, and that of 1825, the density of the substance of these bodies could not be calculated at so high a quantity as that of our atmosphere, diminished by the enormous divisor, forty-five millions of billions. We may, therefore, regard it as certain, that bodies of a nebulous character still form a part of the solar system.

Again, it is found that the planets comprising the solar system exhibit gradations of density, those nearest the sun (which, by the nebular hypothesis, must have been thrown off last, and after the process of condensation had long continued) being much denser than those which are more distant; thus, Mercury, which is the nearest to the sun, the center, is the heaviest, being almost thrice as dense as the earth; while the density of Jupiter, which is far removed, is not more than one-third that of our planet; and Saturn, which is still more remote, is but little more than one-eighth as dense, or about as light as cork.

The spheroidal form which the earth now presents (see § 5., p. 11)—en-

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QUESTIONS.—Have we any evidence that matter analogous to the nebulæ still forms part of the solar system? Does the density of the several planets accord with the nebular hypothesis?

larged at the equator and flattened at the poles—is also precisely that which would necessarily arise from the rotation of a globular mass of yielding materials on its own axis. The same peculiarity of structure, moreover, is found in all the other planets; and in the planet Jupiter is especially manifest—its equatorial diameter exceeding the polar by more than six thousand miles. But if the earth and the other planets were originally fluid, the fluidity must have been the result of igneous action; for since the solid matter of the globe is many times heavier than water, the solution of its mineral constituents in such a solvent would be impossible.

135. To a mind unaccustomed to scientific inquiry, the proposition that our planet once existed in a gaseous state may seem somewhat difficult of conception; but this difficulty will seem less formidable, if we remember that at least one-half of all the ponderable matter of the globe, so far as it has been subjected to our examination, is made up of elements—oxygen, hydrogen, nitrogen, etc., which readily assume, or may be said to exist naturally,—in a gaseous condition; while the remaining more solid forms of matter may all be vaporized through the agency of heat.

Furthermore, the transition of the constituents of the earth, according to the nebular hypothesis, from a state of gas or vapor to a fluid or solid condition, furnishes in itself a ready explanation of the origin of the heat which is supposed to have formerly pervaded the whole mass of our planet, and which now appears to exist in its interior; inasmuch as a degree of heat sufficient to meet all the requirements of the case would be evolved by the act of condensation. It is also a fact worthy of note, that the sun, according to the generally received theory, is even now in a state of igneous fusion, or in such a condition of intense heat as the earth is supposed to have been, after condensing from a gaseous to a fluid condition.*

It will thus be seen that the hypothesis of a nebulous origin of our planet contains within itself all the conditions requisite for the succeeding changes to which it appears to have been subjected; it being considered that the globe first passed from a gaseous to a fluid condition, and that, subsequently, as the varied processes of condensation, refrigeration (through radiation of heat), and rotation proceeded, a thin crust cooled and solidified upon the

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Questions.—What inference has been deduced from the spheroidal form of the earth? Is there anything in the constitution of terrestrial matter that renders its existence in a gaseous state impossible? Does the nebular hypothesis afford any explanation of the internal heat of the earth. What is the theoretical condition of the sun at present? Assuming the nebulous origin of our planet, what have been the succession of changes to which it has been subjected?

*** According to Mr. Helmholtz, a German physicist, it has been calculated that, if the sun were diminished by condensation to the extent of only one ten-thousandth of its present diameter, sufficient heat would be generated by the act to compensate for the total emission for 2,100 years. But, according to measurements of the French physicist, Poullet, the quantity of heat emitted from the entire surface of the sun, *per hour*, is equal to that which a layer of the densest coal, ten feet thick, extending over its whole surface, would give out by its combustion.**

molten fluid surface.* As the temperature of the exterior still further diminished, this crust thickened; the existence of air and water became possible upon it; contraction, involving both subsidence and elevation of parts of the crust, gave configuration to the surface and established the divisions of land and water; and, finally, as the conditions became favorable, the first forms of animal and vegetable life were called into existence by the Creator, and the world became the home of living, organized structures. It is at this point that geology, leaving the domain of theory and speculation, commences to gather facts and reliable evidence concerning terrestrial phenomena, and becomes entitled to rank, in a measure, with the exact sciences; and it is from this point also that the history and chronology of the stratified or aqueous rocks admit of determination.

136. **Geology of other Worlds.**—As has been already stated, the other planets and satellites, belonging to the solar system, appear to have been formed by the same agencies as the earth. There is also good reason to believe that they are composed of essentially the same materials. Thus, the masses of earthy or metallic matter, known as meteorites, which from time to time fall to the earth through the atmosphere, and are now generally believed to have been derived from some one of the planetary bodies, contain no elementary substances before unknown to us, although the conditions of their combination are somewhat unusual.†

The planets which most nearly resemble our earth in physical condition are probably Venus and Mars. Upon the surface of both of these, mountain peaks and ranges are believed to exist; while upon the surface of the latter astronomers have fancied they could recognize the presence of an atmosphere, as well as the existence of seas and the outline of continents.

Concerning the physical condition of the moon, the nearest of the heavenly bodies, we have more definite information, and as the result of telescopic investigation we are enabled to affirm, with almost entire certainty, that our satellite has been the theater of most intense volcanic action. Its surface, in

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QUESTIONS.—What information do we possess respecting the geology of other worlds? What planets probably most resemble our earth?

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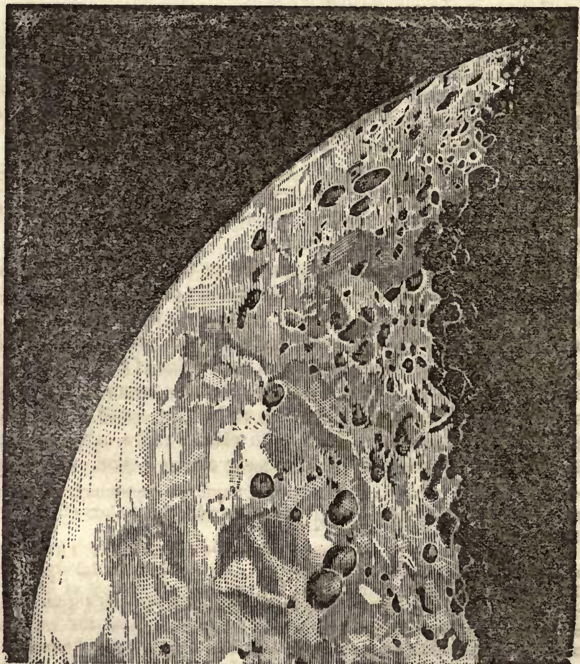
* Assuming that the earth was once entirely in a state of igneous fluidity, the cooling and solidification of its exterior must have been exceedingly gradual at first, and still slower after the formation of a crust, owing to the slowness with which earthy materials conduct heat. And if the residuum of this heat, furthermore, now pervades the central portions of the earth, it has most probably reached a fixed point in temperature, at which it will remain forever, as the thickness and non-conducting properties of the present crust would seem to absolutely prevent its diminution.

† Many of the meteorites which fall to the earth from the interplanetary spaces have little or no oxygen in their composition, and in this respect are unlike the generality of compound substances, which make up the crust of our globe. Hence, the inference has been drawn, that in some of the planetary masses of the solar system, from whence meteorites were undoubtedly derived, oxygen does not exist at all, or in much smaller proportions than upon the earth. Many meteorites contain, and some are entirely composed of, metallic iron and nickel; while upon the earth these elements are rarely, if ever, found, except in combination with other substances.

fact, is like that which we may conceive would be presented by our earth, had its exterior, (since it cooled and consolidated) remained unaltered by the action of the atmosphere, water, or organic life, inasmuch as none of these agencies are probably in existence upon the moon. As seen with a powerful telescope, the surface of the moon exhibits extensive ranges of mountains and isolated peaks of extreme steepness and distinctness of outline; some of which rise to elevations of from 7,000 to 10,000 feet above the general level. But the most remarkable feature of the lunar scenery is the existence of immense cup-shaped cavities or depressions, some of which extend beneath the gen-

FIG. 76.



eral surface to a depth of 10,000 to 17,000 feet, and exceed twenty miles in diameter. "The number of these cavities," says Prof. Mitchell, "is beyond credibility; and in case we admit them to be the extinct craters of once active volcanoes, we are forced to the conclusion that convulsions, such as the earth is a stranger to, have shaken the outer crust of our satellite into a hideousness of form unknown in any region of our planet. That these con-

QUESTION.—What is the structure of the moon?

vulsions are of different ages is also clearly manifest, from the fact that their outlines very often overlap one another, and thus the oldest and newest formations are distinctly traceable. Very often the interior of these cavities will exhibit a uniformly shaded surface, and in the center a conical mountain will lift itself far above this level plain. So sharp and positive, moreover, is the outline of these extraordinary objects that we cannot but feel that some sudden bursting forth might even occur while under telescopic examination." Fig. 76 represents the appearance of the moon's surface, as seen through a telescope, during the second quarter.

SECTION II.

AQUEOUS AND ATMOSPHERIC AGENCIES.

137. The aqueous and atmospheric agencies most prominently concerned in producing geological changes, are *rains, and the gases and moisture of the atmosphere, winds, ice, and snow, springs, rivers, waves, tides, and oceanic currents.*

The operation of water, acting mechanically, is, under all circumstances, to wear down the higher portions of the earth's crust, and transport the materials to lower localities—an action which obviously tends to reduce the whole surface to a smooth and uniform level. On the other hand, the operations of igneous agents—volcanoes, earthquakes, etc.—by breaking up and elevating the crust of the earth, tend to counteract the equalizing action of water and to produce that diversity of surface which is indispensable to variety in both the vegetable and animal kingdoms. These two forces, therefore—the aqueous and the igneous—may be considered as antagonistic to each other, and to them may be ascribed the principal modifications which have taken place, and are still taking place, in the crust of the globe.

138. **Rains, and the Gases and Moisture of the Atmosphere.**—"All rain falling upon land, and either running over its surface or draining through its interior, is constantly abrading and carrying off particles of pre-existing rock, in the shape of mud and sand. From the gutters and the ditches, from the rills, the streams, and the brooks, these materials for the building of mechanically formed rocks are almost unceasingly carried into the rivers, and by them transported to the beds of lakes and seas. Rain, soaking into the ground and issuing as springs on steep slopes or precipices, sometimes exerts also a more wholesale destructive power, by gradually loosening and undermining very considerable masses of ground, and thus

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Questions.—What are the prominent aqueous and atmospheric agencies concerned in producing geological changes? What are the relative effects of igneous and aqueous action? What is the mechanical effect of rains on the earth's surface?

causing them to be launched forward down the slope, producing what are called land-slips or slides."

In the year 1806, after a rainy season, a mountain in Switzerland, known as the Rossberg, was undermined, and a mass of eighty million cubic yards of earth and rock precipitated into the adjacent valley, forming hills 200 feet high, and burying several villages with their inhabitants. Some remarkable land-slides have also occurred in the United States. In 1826, one near the "Notch" of the White Mountains destroyed an entire family. In 1836, a mass of clay and earth, estimated to weigh 200,000 tons, slid from a hill 227 feet high, in the rear of the city of Troy, N. Y., destroying both life and property.

The fall of rain varies in different countries, and of course will be attended with proportional results. In the United States the average annual fall is about thirty-seven inches; while in tropical countries it is upward of 200 inches. In Guiana, S. A., twenty-one inches have been known to fall in a single day. Accustomed to the gentle rains of our own latitude, we can hardly form an estimate of the changes produced by such sudden and enormous falls on the surface-soil and river-courses of tropical countries.

Water also effects the destruction and disintegration of rocks by its solvent properties. Pure water alone dissolves more or less of almost every variety of rock; but when the water contains carbonic acid (as it generally does), or alkaline substances, its solvent action is much more energetic.

The atmosphere, partly by its gases and partly by the moisture always diffused through it, also exerts a wasting or *weathering* in all rocks—softening, loosening, and crumbling down their constituent particles, to be more readily borne away by currents of wind and water.

"Carbonic acid acts specially on all rocks containing lime; oxygen rusts or oxydizes those impregnated with iron; moisture insinuates itself everywhere; and thus, in a few years, the hardest rock exhibits a weathered or wasted surface. Particle after particle is loosened; film after film falls away; a new surface is exposed to new waste; and in the course of ages the boldest mountain-mass yields to the silent, imperceptible agent."

QUESTIONS.—How does the fall of rain vary? What is said of the solvent action of water? What action is exerted by the atmosphere on rocks?

139. **Action of Winds.**—Winds occasionally modify the surface of the earth by transporting or drifting loose materials from one locality and accumulating them in another. Such accumulations are often termed *sub-œrial*, in contradistinction to those formed under water, and hence spoken of as aqueous or sub-aqueous.

The sandy tracts, so frequent along our sea and lake shores, and known as sand-drift, or sand-dunes (dune being the Saxon word for a mound), are the results of wind agency—the wind carrying the dry sand left by the tides forward and landward beyond the reach of the waters; while the land breezes do not possess sufficient power to force it back. In this way hills of drift sand are formed, which sometimes attain an elevation of 200 or 300 feet. Such hills have been described as advancing on the low shores of France, in the Bay of Biscay, at the rate of sixty and seventy feet per annum, overwhelming fields, forests, and villages in their progress. Similar accumulations take place upon the shores of Cornwall, in England, and at various points on the coast of the United States, especially on Cape Cod and Nantucket, where the interposition of the National Government has been necessary to prevent the threatened destruction of harbors and villages.

Nor is it along coasts only that such changes are taking place. In the interior of great, dry continents, there are vast spaces covered with sand hills, which are shifted and carried about by the winds in the same manner as sand-banks are removed or deposited by the agency of water. The stories of caravans, being overwhelmed by moving columns of sand on the African deserts are familiar, as is also the fact that large tracts of land in the valley of the Nile, which in the days of the Pharaohs were highly fertile, and the sites of cities and temples, are now buried to a great depth by the accumulations of sand blown in from the Lybian Desert

140. **Action of Ice and Snow.**—When the rain or moisture, which penetrates the fissures and interstices of rocks, freezes, its conversion into ice is accompanied by an expansion which exercises an almost irresistible mechanical force; the effect of this action is to force asunder large masses of rock and destroy the cohesion of their constituent particles.

Thus, in all latitudes ana altitudes where frost occurs, vast waste is every season effected. The student may note the effects of frost on every plowed field, and on every cliff and railway-cutting around him; how it breaks up

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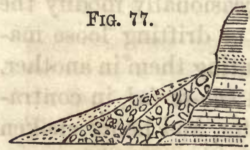
Questions.—What is said of the effect of winds? What is the origin of the sandy tracts along the sea-coast? What are some instances of remarkable accumulations of sand? What is the effect of freezing water on rocks?

FIG. 77.



c b a

and pulverizes the soil, cuts away the cliff, and leaves, every winter, at its base, a sloping mass —in geological language a *talus* or slope of crumbling fragments."

Fig. 77 represents a cliff, at the base of which is a talus, composed of angular fragments, *a;* finer particles, *b;* and an external layer of mud, *c*.*

141. **Glaciers** (Fr., *glace, ice*).—In mountain districts, elevated above the line of perpetual frost, the snows are ever accumulating, inasmuch as the temperature does not rise sufficiently for any considerable proportion to be melted and flow down. These accumulations, in valleys or other favorable situations on the sides of the mountains, often become converted, through the immense pressure of the superincumbent material, into compact ice, and form what are called glaciers, or, in French, *mers de glace* (seas of ice).†

"The common form of a glacier," says Prof. Forbes, speaking of the glaciers among the Alps of Switzerland, "is a river of ice filling a valley and pouring down its mass into other valleys yet lower. It is not a frozen ocean, but a frozen torrent, whose origin or fountain is in the ramifications of the higher valleys and gorges which descend among mountains covered with perpetual snow." Fig. 78 represents a view of the glacier of Viesch, and Fig. 79 that of Zermatt, both in Switzerland; the latter (as shown in the figure) being formed by the union of two glaciers.

Glaciers occur, in Europe, among the Alps, the Pyrenees,

QUESTIONS.—What are familiar examples? What is a talus? What are glaciers? What is the common form of a glacier?

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* The effect of frost in destroying rocks is very marked in the polar regions and on high mountains. Mr. Scoresby, in his work on the Arctic Regions, says of the rocks of Spitzbergen, "they appeared solid at a distance, but on examination were found so full of fractures in every direction that it was with difficulty that a specimen of five or six pounds in a solid mass could be obtained. Cliffs of a thousand feet were found fissured in every direction, and toward the sea-edge, stones, weighing more than two or three ounces each could not be obtained." Darwin makes the same observation on Terra del Fuego. Here, he says, he often observed that where the rock was covered with snow, its surface was shivered in an extraordinary manner into small angular fragments.

† It was formerly the opinion that in the formation of a glacier the snow was converted into ice by alternations of melting and freezing; but recent investigations have shown that this phenomenon is due solely to immense pressure. There is every reason to believe, also, that the interior of a glacier is comparatively unaffected by changes in the external temperature.—*See Annual Scientific Discovery.* 1860, *pp.* 297.

FIG. 78.

the mountains of Norway and Iceland, and on the coast of Spitzbergen; in Asia, among the Himalaya, Caucasus, and Altai Mountains; in Patagonia, South America, and within both the frigid zones.

Glaciers have been chiefly studied in the Alps, where the climate is sufficiently moderate to allow of their careful and detailed examination with comparative convenience. Along the central part of the Alps, from Mont

FIG. 79.

Blanc to the frontiers of Tyrol, there are estimated to be not less than 400 glaciers, some of which fill valleys twenty miles long, by three or four in width, to a depth of 600 feet. In the Himalaya Mountains, glaciers exist upon a most gigantic scale, one of which, on the slope of Kunchinjinga (one of the highest peaks), is said to present at its termination a vertical wall of ice 14,000 feet high. It is, however, in high Arctic latitudes, where the line of perpetual snow comes down to the sea level, that the glaciers attain their

QUESTIONS.—Where do glaciers occur? Where have they been chiefly studied? What is said of the extent of some glaciers?

greatest development. Thus, they were seen by Dr. Kane, in 1855, apparently forming a deep, unbroken sea of ice over the whole interior of Central Greenland, and sloping gently toward the coast, where immense masses were constantly being detached, and "floating off to be lost in the temperatures of other regions."

142. **Motion of Glaciers.**—"Although apparently solid and stationary, glaciers really move slowly down the valley or sides of the mountains, and carry with them, either on their surface, frozen into their mass, or grinding and rubbing along the bottom, all the fragments, large and small, from blocks many tons in weight down to the finest sand and mud, that rain and ice, and the friction of the moving glacier itself, detach from the adjacent rocks."

The rate of movement differs in different glaciers, and in different parts of the same glacier. Portions of some glaciers in the Alps have been observed to move, during the summer, at the rate of three or four feet per day; but in general, the advance of glaciers is very slow, and can only be correctly estimated by observations extended over a considerable period. The glacier of Aar, in Switzerland, which has been very carefully studied, appears to have moved 16,000 feet in forty-four years, or at the average rate of 375 feet annually. The motion of glaciers is always continuous and not by jerks and starts.

With respect to the cause of the motion of glaciers different views are entertained. Some believe it to be due to a slight degree of plasticity, *a sort of semi-fluidity*, in the ice mass, by which it is enabled actually to float down the declivity by the action of gravity, just as a viscous substance, such as partially melted pitch, would flow. Another theory, advocated by Agassiz, refers the onward movement to the force arising from the expansion of water freezing in the fissures and pores of the ice, into which, during the warm season, it is constantly infiltrating; and, more recently, Prof. Tyndel and other geologists of England claim to have proved, that the motion of glaciers is the result of a minute, almost molecular, fracture and re-cementation (regelation, as it is called) of the ice particles, which move as if they were sand, continually thawing and re-freezing.*

A glacier descends toward the base of the mountain until the heat melts it away. It usually terminates in a vertical wall, which marks the thickness of the ice at its extremity, and, in the Alps, is often from 60 to 100 feet high. During the summer, currents of water, formed from superficial thaws, flow over the surface of the glacier, and, falling into fissures and chasms

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Questions.—Where do glaciers attain their greatest development? Are glaciers fixed and stationary? What is said of their rate of movement? What is supposed to be the cause of the motion of glaciers? How far does a glacier descend down a mountain slope?

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* Few topics in geology have excited more interest and discussion than the phenomena of the structure and movements of glaciers; and in some instances investigators—Saussure, Agassiz, Desor, and others—have devoted years to their study, and have lived continuously, for months, in rude huts erected upon the moving ice-surface.

which extend across it, issue as a single stream from a sort of vault or cavern at its termination. Such streams, from the glaciers of the Alps, constitute the source of supply of some of the principal rivers of Europe.

The terminus of a glacier, however, varies somewhat with the seasons, being lower in winter than in summer. In cold seasons it sometimes invades the habitable valleys of Switzerland, and irresistibly and imperceptibly advances upon and destroys the cottages and farms of the peasantry. "The

FIG. 80.

green forests slowly disappear before it, and the growing wheat almost feels its icy touch before the soil is lifted by the ruthless plowshare. When, after such an advance, a warm summer succeeds, and the glacier retreats to its former bounds, the surface it covered is found to be changed into a dreary waste of loose rocks and stones. These have originally fallen upon the glacier, and have been borne down and deposited by its melting."

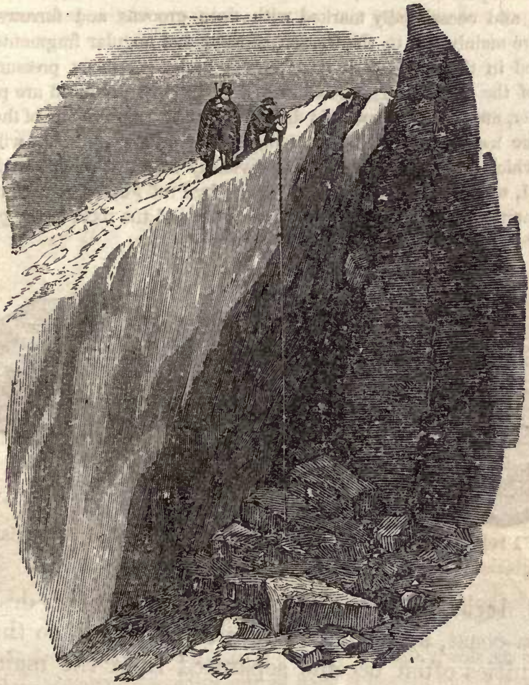
The confused heaps or ridges of rock fragments, mud, and sand, which a glacier pushes before it, or carries upon its surface, have received the name of *moraines*.

Fig. 78 gives a clear idea of the nature of these accumulations of detritus,

QUESTIONS.—What is its usual termination? Does a glacier ever invade habitable valleys? What is the condition of the ground temporarily covered by a glacier? What name has been given to the heaps of stone and earth accumulated by glaciers?

and the manner in which they collect in long lines upon the surface of the glacier, in the direction of its motion. Fig. 80, representing the glacier of the Aar, shows how, when two glaciers unite, separate lines of moraine also come together and float, as it were, down the middle of the common glacier.*

FIG. 81



The quantity of stony material, and the enormous size of the masses of rock transported by glaciers can hardly be appreciated from any description.

QUESTION.—What is said of the amount of detritus transported by glaciers?

* Concerning the pole attached to a rock, seen in the engraving, Fig. 80, Agassiz, in his "Etudes sur les Glaciers" (from which the illustration is taken), relates the following incident: A certain explorer fastened the pole to a large mass of rock on the surface of a glacier, high up toward its source, and carefully recorded the fact in a published account of his investigations. Some ten years after, another explorer searched for the pole and block, and found that it had traveled, in the interval, some eight or ten miles toward the termination of the glacier. The same figure also shows how tabular masses of rock, by protecting the ice beneath them from the melting action of the sun, are gradually lifted, by the waste of the exposed surface upon a pedestal or stem of ice, and at the same time are moving with the general mass toward a lower level.

Sometimes the ice is almost concealed by the accumulated piles of stone that cover it. Prof. Forbes relates that he saw, in one of the valleys of Switzerland, a rock brought down by a glacier, the dimensions of which were nearly a hundred feet in length and from forty to fifty in height.

The rocks upon and against which the glaciers have pressed are found, wherever exposed to view, to be smoothed and scratched (striated, as it is termed), and occasionally marked with deep grooves and furrows. These effects are mainly due to the friction of sand and angular fragments of rock embedded in the ice, and driven forward, under enormous pressure, by the motion of the glacier. The grooves and striæ thus produced are parallel to each other, and also correspond in direction with the movements of the glacier; but as the motion of the glacier changes, new sets of scratches will be produced, which sometimes cross those previously made, at a high angle.

Fig. 81, which is an actual sketch, drawn by Prof. Forbes, represents granite blocks jammed in between the ice of a glacier and the rock, in the process of grinding down and grooving the retaining wall.

FIG. 82.

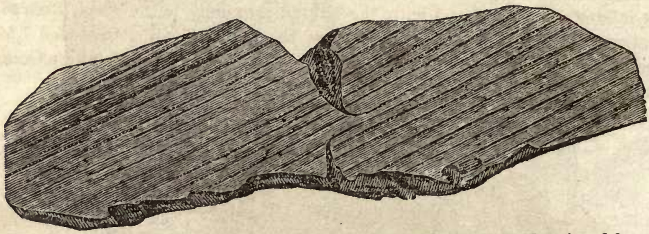


Fig. 82 represents a specimen of a rock thus smoothed and striated by an Alpine glacier.

143. **Icebergs.**—In the Polar regions, glaciers descend to the sea-coast, and even advance into the sea, so that their extremities often become separated from the main mass, and float away as icebergs.

Let *a*, *b*, *c*, *d* and *e* (Fig. 83) represent a section of a coast, along a ravine or hollow, in which a glacier, *f*, *g*, *c*, finds its way outward to the sea, *s*; the mass of ice at its extremity being lighter than water, has a tendency to float, and the movement of the waves and tides assisting, large fragments (*m*) readily become detached from the glacier and are floated off by currents.

Icebergs thus formed vary from a few yards to miles in circumference, and often rise from 200 to 300, or even 500 feet, above the surface of the ocean. But as ice floats with eight-ninths of its bulk below the surface, the greater

QUESTIONS.—What is the mechanical action of glaciers? What is said of the formation of icebergs?

portion of an iceberg must always be concealed from observation; and a height of 200 to 300 feet above the surface of the ocean would necessarily imply a vertical depth of from 2,000 to 3,000 feet below it.

FIG. 83.

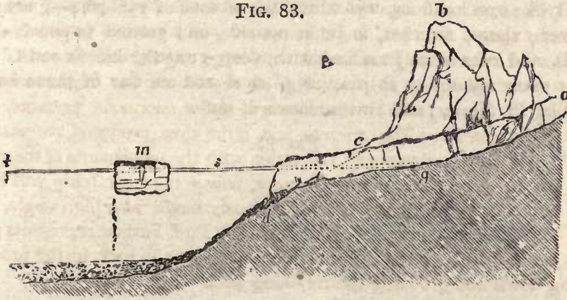


Fig. 84 represents an iceberg seen by Capt. Parry, the size of which may be inferred by comparison with the ship in proximity to it. Capt. Ross saw icebergs aground in Baffin's Bay, where the depth of water exceeded 1,500 feet. One seen by the French Exploring Expedition, in the Southern Ocean, in 1840, was thirteen miles long, with vertical walls 10C feet high.

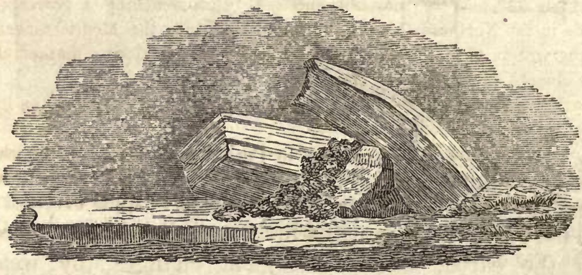
FIG. 84.

Icebergs very frequently carry great quantities of rock and earth from the lands where the bergs were formed as portions of glaciers, to new localities in warmer latitudes.

QUESTIONS.—What is said of the size of icebergs? What proportion of an iceberg floating is exposed to view? Do icebergs act as carriers of rock material?

Captain Scoresby conjectures that a group seen by him in the Northern Ocean were loaded with from 50,000 to 100,000 tons of loose materials. Dr. Kane also describes the ice-belt which lines the shores of Smith's Strait, Baffin's Bay (and which, in summer, becomes detached and floats off), as covered, in some localities, "with millions of tons of rubbish;—greenstones, limestones, slates, rounded, angular, massive, and ground to powder." He also observed rafts of ice thus loaded with large angular blocks and bowlders floating many miles out at sea. Fig. 85 represents one of these ice-rafts, figured by Dr. Kane, loaded with masses of slate.

FIG. 85.



Icebergs from Baffin's Bay frequently float, before melting, as far south as 40° north lat. (or about the latitude of New York City); in one instance, an iceberg, with bowlders upon it, was seen on the Atlantic, in lat. 36° N. (or nearly as far south as Cape Hatteras).

Whenever icebergs dissolve it is evident that their freight of earth and rock will fall to the bottom of the sea; and in this manner submarine mountains, plains, and valleys may become strewed over with gravel, sand, mud, and fragments of rock, transported from very distant localities, and of a nature dissimilar from all in the vicinity.

Icebergs are often stranded, even in comparatively deep water. When this happens, the disturbances occasioned on the sea-bottom, by the rubbing or thumping of such bodies, weighing perchance millions, or hundreds of millions of tons, and impelled by powerful currents, must obviously be very great. We may conceive that the power thus exerted would be amply sufficient to furrow and pulverize rocks, excavate valleys, and perhaps even crush and disrupt submarine hills and ridges.

From the above facts, it seems probable that if the bed of the ocean, in both the northern and southern hemispheres, between the fortieth and sixtieth degrees of latitude, could be exposed to view, its rock-surface would be everywhere smoothed and striated by the ice-bergs which have dragged over it,

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QUESTIONS.—What are some examples? To what distances do icebergs thus loaded float? What takes place when they dissolve? What effects may icebergs produce upon the sea-bottom? What would probably be the condition of the beds of the northern and southern oceans, if exposed to view?

and also strewed with sand, gravel, and bowlders, drifted from the Arctic and Antarctic regions.

Icebergs may also exercise an influence upon climate. Those which drift from Baffin's Bay along our own coast, sensibly cool the waters of the Gulf Stream for forty to fifty miles around, and the temperature of the air on approaching them has been known to fall 17° to 18° F. When driven, as they sometimes are, in large numbers into Hudson's Bay, they produce intense cold, and modify the seasons over the northern portion of the American continent. In the southern hemisphere, icebergs drift much nearer the equator than in the northern, and are occasionally seen off the Cape of Good Hope, in latitude 36°. Were they not checked before reaching a corresponding latitude in the Northern Ocean they might float into the Mediterranean, and chill the waters of that sea to such an extent as to produce a marked change in the climate of the adjacent countries.

Apart from the interest which pertains to glaciers and icebergs, as important causes of change in the condition of the earth's surface, the study of their phenomena has furnished a key to the solution of some of the most interesting and important problems in geology, and for this reason (as will be shown hereafter) they merit especial attention from the student.

144. **Springs.**—Springs, which are discharges of water from the earth, effect geological changes, by wearing and transporting, or dissolving and re-depositing mineral matter.

The mineral substances most abundantly precipitated from water, viz., travertin, tufas, stalactite, stalagmite, silicious sinter, and bog-iron ore, have been already noticed. (See §§ 63, 64, 67, 71.)

Origin of Springs.—The water of springs and wells is derived from rain.

This, falling upon the surface of the earth, sinks downward through the loose and porous soil or rock, until it reaches a bed of clay or rock impermeable to water. Here, it either accumulates and saturates the soil, or else running along the surface of the impervious stratum, it bursts out at some point where such impervious bed

FIG. 86.

or stratum comes to the surface in consequence of a valley or depression. In such a case, the flow of water constitutes a spring. Thus, suppose *a* (Fig. 86) to be a hill of sand or gravel, resting upon a stratum of clay, *b*; then

QUESTIONS.—Do icebergs exercise any influence upon climate? Show this by illustrative facts? How do springs effect geological changes? What mineral substances are most abundantly deposited by springs? What is the source of the water of springs and wells?

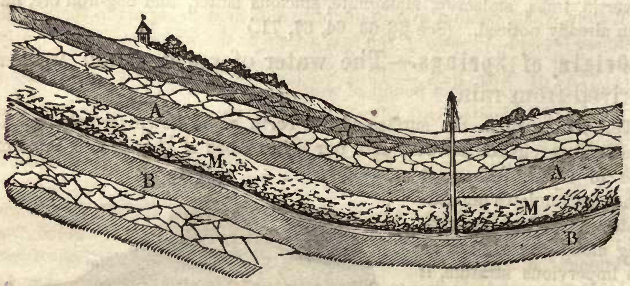
the water, percolating through the upper permeable bed, would finally reach the impervious stratum and run along its surface until it found an outlet at *c*, the foot of the hill, where a spring would be formed.

If there are no irregularities in the surface of the impervious strata so situated as to allow a spring to burst forth, the water, soaking downward, will not drain off, but will accumulate, and rise among the particles of soil, as it would among shot or bullets in a water-tight vessel. If a hole or pit be dug into such earth, reaching below the level of the water accumulated in it, it will soon be filled up with water to this level, and will constitute a well. The reason why some wells are deeper than others, is, that the distance of the impervious stratum below the surface is different in different localities.

145. **Artesian Wells.**—In many localities, if the strata be penetrated to a considerable depth by boring, a supply of water will sometimes rise with great force to the surface, and continue to flow uninterruptedly. Such excavations are termed "Artesian Wells," from the province of Artois, in France, where this plan for obtaining water is believed to have originated.

The theory of the rise of water in artesian wells will be readily understood from the following diagram, Fig. 87. Suppose *M M*, a stratum of sand or some other material pervious to water, to be inclosed between other strata,

FIG. 87.



A and *B*, which are impervious; and that all the strata are at the same time so inclined as to form a sort of basin. Then, the water which falls upon the uncovered margin or outcrop of the porous strata *M* will be absorbed and sink to the lower portion of the basin, where it will be prevented from arising to the surface by the impervious stratum above it, and from sinking

QUESTIONS.—Illustrate the formation of springs and wells. What are artesian wells? Explain their theory.

lower, by the equally impervious strata below it. It will, therefore, accumulate, as in a reservoir. If now we bore down through the upper stratum, until we reach the stratum containing the water, the water will rise in the excavation to a certain height, proportional to the height or level of the water accumulated in the reservoir *M*, from which it flows.

The great depths to which artesian wells have been sunk have already been noticed. (See §§ 8 and 111.)

The water supply afforded by some of them is also very great. One at Grenelle, near Paris, 1800 feet deep, is capable of supplying water at the rate of 600,000 gallons per day; and the district of country over which this water was precipitated as rain, judging from the curvature of the strata through which the excavation was made, is estimated to be 200 miles or more distant from the point where the water issues. An artesian well, at Louisville, Ky., excavated in 1859, discharges 333,000 gallons every twenty-four hours—the water rising (in pipes), by its own pressure, 170 feet above the surface.

146. **Mineral Springs.**—Spring-water, although it may be perfectly transparent, always contains more or less of mineral matter dissolved in it. The nature of the substances will of course vary with the character of the soil through which the water percolates. The most usual impurities are carbonate of lime, common salt, sulphate of lime (gypsum), sulphate and carbonate of magnesia, and compounds of iron.

When the waters of springs retain in solution so large a proportion of mineral or gaseous matter as to give them a decided taste, they are termed *mineral waters*, and are usually reputed to have some medicinal quality, varying with the nature of the substance in solution.

Waters which contain iron in quantity sufficient to impart to them an inky taste are termed *chalybeate;* the iron exists in the water most frequently in the state of carbonate dissolved in carbonic acid, and rarely in a proportion exceeding one grain in a pound of water.

Waters impregnated with sulphuretted hydrogen gas are termed *sulphurous* or *sulphuretted;* they may be readily recognized by their nauseous taste and odor. Remarkable springs of this character exist at Sharon, New York, and also in Virginia.

In some springs carbonic acid is very abundant, and imparts to the water an effervescent, sparkling character, like that noticed in the "Seltzer" and "Saratoga" waters.

Light carburetted hydrogen (illuminating gas) is also evolved from springs, in some instances. At Kenawha, in Virginia, it rises in immense quantities, in connection with salt water, from artesian wells, and being conducted by an arrangement of pipes under the salt-boilers, furnishes sufficient heat by its combustion to evaporate the brine. A similar natural supply of this gas,

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QUESTIONS.—To what depths have artesian wells been excavated? What is said of the supply of water afforded by them? What is said of the purity of spring waters? When are springs termed mineral? What are chalybeate springs? What are sulphuretted? What is said of the presence of gas in some springs?

in the town of Fredonia, in New York, has for many years past been extensively applied for illuminating purposes.

147. **Saline Springs.**—Springs, whose waters contain a large proportion of earthy or alkaline salts, are called *saline*, although this term is generally used to designate particular springs containing common salt.

These last, considered in an economical point of view, are the most important of all mineral springs. They occur in all parts of the world, and their waters are extensively evaporated for the purpose of obtaining salt.

In the United States, salt springs of value occur in New York, Virginia, Ohio, Pennsylvania, Illinois, Michigan, Missouri, Arkansas, the Territory of Utah, and in Canada. The amount of salt contained in these waters varies from ten to thirty-five per cent. In many localities where salt springs occur, great additional supplies of brine have been obtained by boring; and in Virginia and Ohio excavations have been made for this purpose to the depth of 1,000 to 1,200 feet.

The quantity of salt manufactured from the waters of salt springs in the United States, in 1856, was about 12,000,000 bushels. Of this quantity the salt springs of Onondaga County, N. Y., furnished about 6,000,000 bushels; those of Virginia, 3,800,000; of Ohio, 1,500,000; of Illinois, 50,000; of Michigan, 10,000; of Pennsylvania, 900,000. The waters of the Onondaga salt springs contain about one-seventh part of their weight of dry salt; and the supply of water is not less than 2,000,000 gallons per day for six months in the year.*

The amount of salt contained in sea-water is about twenty-seven per cent.; which amounts to nearly four ounces per gallon, or a bushel in from 300 to 350 gallons. At Nantucket, where salt is made from sea-water by solar evaporation, 350 gallons of water are required to yield a bushel; while at Onondaga forty-one to forty-five gallons suffice.

Numerous lakes of salt water are found scattered over the territory of the United States, between the Mississippi and the Pacific. Of these the most famous and extensive is the Great Salt Lake of Utah, whose waters contain 22,000 grains of salt to the gallon, or nearly one-third of their whole weight.

148. **Origin of Salt Springs, Lakes, etc.**—Salt springs undoubtedly originate from the percolation of water

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QUESTIONS.—What are saline springs? What mineral springs are the most important? Where do salt springs occur in the United States? What amount of salt is manufactured from them? What proportion of salt is contained in sea-water? What is said of the existence of salt lakes? What is the probable origin of salt springs?

*** The amount of salt yearly consumed in the United States (for various uses) is estimated at sixty pounds for each inhabitant, or a total of 25,000,000 of bushels. Of this quantity nearly one-half is imported from foreign countries.**

through subterranean beds of rock-salt, or through strata containing a large proportion of salt.

It is an error, however, to attribute the saltness of the sea to the presence of vast beds of mineral salt at its bottom; for the sea undoubtedly owes all its salts to washings from the land. The streams that have flowed into it for ages have been constantly bringing soluble mineral matters from the land, and as pure water alone evaporates from the surface of the ocean, the quantity of such matter has been continually accumulating, until the whole ocean has acquired its present briny and bitter condition. The evidence on this point is conclusive; and the saline condition of sea-water is but an exaggeration of that of all ordinary lakes, rivers, and springs. These all contain more or less of the mineral constituents of sea-water, but as their waters are continually changing and flowing into the sea, the salts in them do not accumulate.

Again, every lake into which rivers flow, and from which there is no outlet except by evaporation, is a salt lake; and it is extremely curious to observe that this condition disappears when an artificial outlet is provided. Examples of such lakes are the Dead Sea, the Caspian, the Sea of Aral, and the Great Salt Lake of Utah, the saltness of all of which greatly exceeds that of the ocean.

149. **Streams and Rivers**, as agents for producing geological changes, act chiefly in a mechanical way, and their influence depends partly on the nature of the rocks over which they run, the rapidity of their flow, and the volume of water.

If the rocks over which they pass are of a soft and friable material they soon cut out channels and transport the abraded material in the state of mud, sand, and gravel, to the lower level of some lake, or to the bed of the ocean. It may be generally observed that a river will have its rapids at the localities where the hardest strata or rock-material occur; as these resist the wearing action of the water for a longer period than the other portions of the river-bottom. Thus, the first waterfalls of the Rappahannock, James, Neuse, and other rivers of Virginia and North Carolina, indicate where a ridge of granitic rocks comes up to the surface.

150. The eroding, as well as the transporting power of streams and rivers, is greatly aided by the rapidity of their currents.

Questions.—To what is the saltness of the sea probably due? Under what circumstances will a lake become salt? How do streams and rivers produce geological changes? At what point in the course of a river will rapids occur? What effect has the velocity of a river on its eroding power?

Thus, it has been calculated, for example, that the velocity of three inches per second will tear up fine clay; that six inches will lift fine sand; eight inches, sand as coarse as linseed; and twelve inches, fine gravel; while it requires a velocity of twenty-four inches per second to roll along rounded pebbles an inch in diameter, and thirty-six inches per second to sweep angular stones of the size of a hen's egg. The following statement of a law, determined by Mr. W. Hopkins of England, also illustrates how rapidly the size of water-borne fragments increases in proportion to the velocity of the moving water:

The power of water to move bodies that are in it increases as the sixth power of the velocity of the current.

Thus, if we *double* the velocity of a current, its motive power is increased *sixty-four times;* if its velocity be multiplied by three, its motive power will be increased 729 times; if by four, 2,048 times; and so on. In estimating the mechanical force of water it is also necessary to bear in mind that all rocks and stones lose fully one-third of their weight when suspended in water; and this consideration will enable us to understand more readily how, in great storms, rocks weighing tons are sometimes carried to a considerable distance by the action of waves or torrents.

The eroding power of rivers is also greatly assisted by the materials mechanically suspended in, or forced onward, by the water—every particle of sand, every pebble or rock, rasping and grinding still deeper and deeper the channels down which they are borne. As familiar illustrations of this action we may instance the vertical holes drilled in rocks by means of pebbles so situated that a rotary action is given them, each in one place, by water in motion. These, which are commonly termed "pot-holes," may be found in most situations where a stream of water falls upon a rock bottom. A pebble gets so established in an eddy, that it remains there, and by constant friction works a vertical hole downward, sometimes to the depth of several feet. In some instances, where the bed of the stream has been lowered by erosive action, sections of these cavities are shown, as in Fig. 88.

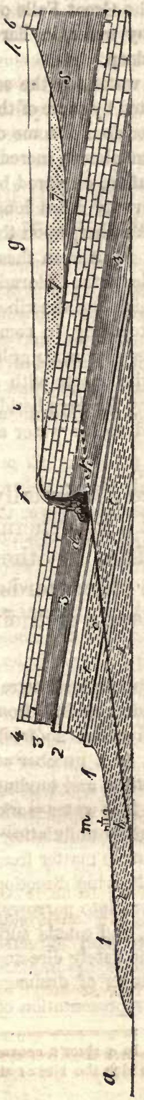
Fig. 88.

151. Valleys excavated from strata, by the action of running water, are termed *valleys of erosion* (*erosus*, gnawed away).

Of these, some very remarkable examples exist in our own country. A few may be cited in the way of illustration.

QUESTIONS.—Illustrate this. How does the power of water to move bodies increase? What circumstances assist the mechanical action of water? What is the origin of the so-called "pot-holes?" What are valleys of erosion?

FIG. 89.



The Falls of Niagara are 150 feet in height, and the average amount of water passing over each minute is estimated at 670,000 tons. This water, by its abrading power, has undoubtedly excavated for itself the gorge or channel—seven miles long, 200 feet deep, and 1,200 to 2,000 feet wide—which now intervenes between the Falls and Lake Ontario. The minimum time required to wear through this space has been estimated, by Sir Charles Lyell, at 35,000 years. At present the Falls are supposed to recede at an average rate of about one foot per annum.

An examination of the rocks over which the Niagara River flows, from Lake Erie to Lake Ontario, enables us to understand the present operations of the Falls, and also to estimate their future action. The nature and position of these rocks are clearly shown on the sides of the ravine excavated by the Falls, and also in the ideal section given in Fig. 89, in which *f* represents the Falls; *l*, *g*, *h*, the level of Lake Erie; *b*, *c*, *d*, *f*, the course of the Niagara River; *a*, Lake Ontario; and *m*, the city of Lewiston. The strata through which the Falls have cut their way consist of limestones, 4 (Niagara limestone); soft shales, 3 (Niagara shales); and sandstones, 2 (Medina sandstone); all of which are inclined, or dip to the south, as shown in the section. This inclination of the strata favors, at present, the recession of the Falls, inasmuch as the uppermost rock, over which the water is precipitated, is a hard limestone, ninety feet thick, while the lower rock, supporting the limestone and forming the base of the cliff, is a soft and friable shale. This last being easily worn away by the action of the water and by frost, leaves the superincumbent limestone unsupported, and large masses of it occasionally fall by their own weight. The well-known "Table Rock" is a portion of the upper limestone, which has assumed a tabular appearance by the removal of the shales beneath it.

An examination of the section will also show that if the Falls continue to recede, the inclination of the rocks will soon carry the shales (3) so far below the bed of the Niagara River that they will cease to be acted upon. When this happens, the hard limestone now at the top of the Falls will also constitute their base, and the excavating process will be essentially retarded.

Upon the Genesee River, N. Y., the water has excavated for itself a channel, in solid rock, which in some places ex-

QUESTIONS.—What is said of the erosive action of water exhibited at the Falls of Niagara? What are other illustrations?

ceeds 300 feet in depth. At Trenton Falls, N. Y., limestone rocks may be seen cut through to the depth of 100 to 200 feet; and at the Great Falls of the Potomac, near Washington, a gorge has been worn, by water, in hard mica schist, four miles long and from sixty to seventy feet deep.

But the most striking examples of the erosive power of water are the so-called cañons—(pronounced *kan-yan*)—or deep gulfs excavated by some of the rivers of the southwestern portion of our country. The dimensions of some of these valleys of erosion, as given by recent explorers, seem almost incredible, and certainly have no parallel elsewhere. Thus, a cañon, explored by Capt. Marcy, U.S.A., upon the Red River of Texas, is seventy miles long, with precipitous banks of rock from 500 to 800 in height. Another, upon the Canadian River, is fifty miles in length and 250 feet deep. But even these seem insignificant when compared with the excavation made by the Colorado River and its tributaries in the table-lands of California, which are described in the report of the Expedition of Lieut. Ives (1858), as exceeding, in some instances, a mile in depth. The streams flowing through these immense gulfs are generally inaccessible from above, and the traveler who meets with a cañon in crossing the plains is sometimes obliged to journey for days beside it before finding an opportunity to cross or even to descend to the water at its bottom.

152. Although rivers with rapid currents are continually modifying or deepening their channels, yet the general form and direction of river-courses are determined by other causes than the agency of the river itself. In other words, "rivers are not the producers, in the first instance, of their own valleys."

This proposition will be more readily understood by the following illustration, given by Mr. Jukes: "If we watch," says he, "the tide receding from a flat, muddy coast, we should see that the mud-flat, even where no fresh water drains over it from the land, is frequently traversed by a number of little branching systems of channels, opening one into the other, and tending to a general embouchure on the margin of the mud-flat, at low water-mark. The surface of the mud is not a geometrical plane, but slightly undulating; and the sea, as it recedes, carries off some of the looser surface matter from some parts, thus making additional hollows, and forming and giving direction to currents which acquire more and more force, and are drawn into narrower limits as the water falls. Deeper channels are thus eroded, and canals supplied for the drainage of the whole surface, which is immediately directed into them. First two, and then more of these little systems of drainage unite, until at dead low water we often have the minature representation of

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QUESTIONS.—Describe the "cañons" of the southwestern States. Is a river's course and form determined by its own action? Illustrate the manner in which the river systems of continents have originated.

the river system of a great continent (wanting of course the mountain chains), produced before our eyes in the course of a single tide, in the very manner and by the very agents by which all river systems on all islands and continents have been produced. The difference between them is this only, that our islands and continents are now above the sea, not in consequence of the gradual fall of the water, but in consequence of the gradual and irregular rise of the land. The forces of elevation and depression have acted not once only but many times; and accordingly the whole surface of the land has been, not once only, but often, subjected to the grooving tools and gouges, the planes and chisels, so to speak, of the upper surface of the sea; the hollows and excavations thus caused not having been obliterated, but generally deepened and intensified on each occasion."

153. If a person will have the curiosity to lift a gallon of water from almost any river during its muddy and turbid condition, consequent upon floods, and allow it to settle, he will be astonished at the amount of sediment or solid matter that falls to the bottom. Now, let him multiply this gallon by the number of gallons daily carried down by the river, and this day by years and centuries, and he will arrive at some faint idea of the quantity of matter worn from the land by rivers and deposited upon the bed of the ocean.

Some of the results of observations on the action of particular rivers are as follows: The total mineral matter carried by the Ganges into the sea is estimated at upward of six thousand millions cubic feet per annum. To transport this quantity, says Mr. Lyell, would require a fleet of 2,000 ships, each of 1,400 tons, to start every day throughout the year. The same matter would also cover a square space eighteen miles on the side, every year, with mud a foot deep, or would raise a surface equal to one half the area of all the New England States one foot in the space of 144 years.

The Yellow River (Hoang Ho), in China, carries down into the Yellow Sea 48,000,000 of cubic feet of earth *daily;* so that, assuming the Yellow Sea to be 120 feet deep, an English square mile might be converted into dry land every seventy days.

The quantity of solid matter annually brought down by the Mississippi, and discharged into the Gulf of Mexico, has been estimated to exceed three thousand million cubic feet; and that transported to the sea by even so small a river as the Merrimac, in Massachusetts, at 840,000 tons.

154. **Deltas.**—When the matter thus carried down by rivers is deposited at their mouths, a triangular area of land is added to the previously existing shore—the base of the triangle extending toward the open water and the apex being up the stream. Such formations, from their

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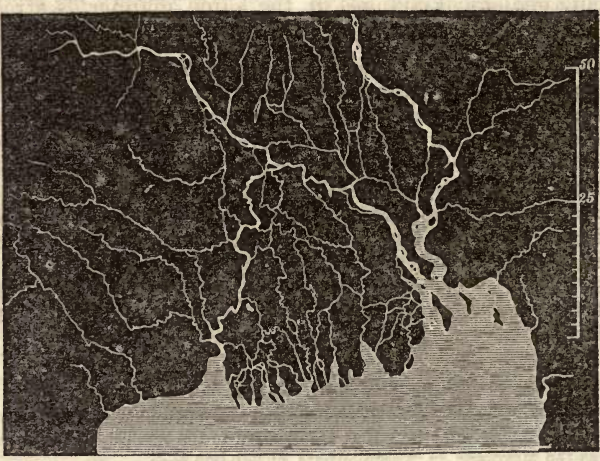
QUESTIONS.—What is said of the amount of sediment conveyed by rivers to the ocean? What is the estimated amount of sediment brought down by some of the rivers of Asia? What by the Mississippi? What are deltas?

resemblance to the fourth letter of the Greek alphabet (Δ), are termed *deltas*, and they generally divide the main stream into several branches.

The delta of the Mississippi includes a large part of Lower Louisiana, and comprises an area of over 13,000 square miles. The mean depth of the deposit of sediment, constituting this delta, is estimated at not less than 500 feet, and the formation, at the present time, advances steadily out into the Gulf of Mexico at the rate of about one mile in a century, or fifty feet per annum. The delta formed by the Ganges is of still larger dimensions. It commences 220 miles from the sea, and has a base of 200 miles, through which extent of made land the river discharges itself by eight principal channels, and an almost infinite number of smaller ones. Fig. 90. represents the delta of the Ganges, with its numerous channels.

FIG. 90.



The gain of land at the mouth of the River Po, in Italy, has been so great that the town of Adria, which was a seaport in the time of Augustus, and gave its name to the adjacent gulf (Adriatic), is now upward of twenty miles inland.

Where, however, the mouth of the river is subjected to strong tides, or is swept by powerful oceanic currents, the detritus brought down does not form a delta but is carried off directly into the sea, as in the case of the Amazon, the La Plata, St. Lawrence, and most of the rivers of Europe.

QUESTIONS.—What is said of the delta of the Mississippi? What of the Ganges? Do deltas form at the mouths of all rivers?

155. From the evidence thus presented respecting the amount of mineral matter carried by rivers into the sea, it is altogether probable that accumulations are now forming on the bed of the ocean on as large a scale as at any former period. The sedimentary matter thus deposited, moreover, will take the form of strata, as the amount of sediment swept into the ocean from the land is not constant, and is derived, at different times, in larger proportion from some districts than from others. Such formation would include also the remains of man and his productions, and of land and marine animals and vegetables; so that if the bed of any ocean, as that of the Atlantic along the coast of the United States, should ever be elevated and converted into dry land, the future geologists, by exploring its succession of strata and studying the fossils contained in them, would be able to form a very correct opinion as to the conditions of life and climate that prevailed in the vicinity at the time the deposits in question originated.

156. **Waves, Tides, and Oceanic Currents** act in producing geological changes in the same manner as streams and rivers. They all waste and wear away the sea-coast in exposed districts, and deposit the abraded material, in the form of mud, sand, gravel, etc., in other localities.

FIG. 91.

The abrading power, which waves are capable of exerting upon any particular coast, varies, of course, with their own magnitude, as well as with the nature and position of the rocks exposed to their action. Mr. Stevenson, the celebrated English engineer, proved, by experiment, some years since, that the force exerted by the waves of the German ocean during a storm, in favorable situations, was about one and a half tons per square foot, and by the waves of the Atlantic three tons.

QUESTIONS.—Are accumulations probably now forming in the ocean of great extent? In what manner do waves, tides, and currents produce geological changes? How does the action of waves on coasts vary? What is the estimated power of ocean waves in a storm?

A coast-line, consisting of soft clays and sands, will suffer more waste than one composed of sandstones and shales, and these, again, will yield more readily than cliffs of basalt and granite. Further, strata that dip seaward, and present, breakwater like, their natural slopes to the action of the waves, as in Fig. 91, will suffer less than those whose outcropping ridges are presented to the storm, as in Fig. 92.

FIG. 92.

It occasionally happens (as in the case represented in Fig. 92) that the waste produced at first by the action of the waves accumulates at the base of a cliff, and forms a natural rampart preventing further destruction. It is this condition that is frequently imitated by engineers when they desire to prevent further encroachments of the sea on an exposed coast.

157. Striking examples of the erosive action of the ocean upon the land might be cited almost without number. Thus, the English Channel is supposed to have been excavated by the ocean, inasmuch as the geological features of the coasts of England and France clearly indicate that they were formerly united. During the thirteenth century, a strait, half as wide as the English Channel, was formed in less than 100 years, separating Friesland from the north of Holland; and islands in the German Ocean, and towns and villages upon the coast of England, have also been entirely swept away by the sea within the historic period.

In the United States, the bold, rocky coasts of New England in particular, exhibit abundant evidence of the abrading power of the ocean. In many localities the rocks are scooped and hollowed into the most irregular shapes; and fragments, which once constituted part of the mainland, may be observed standing detached at some considerable distance from the shore. (See Fig. 93.) Boston Harbor has evidently been formed in great part by the wasting agency of the ocean; and many of the islands in it, which were once parts of the continent, have only been preserved from destruction, during the last few years, by artificial embankments. At Cape May, on the north side of Delaware Bay, the sea has encroached upon the land at the rate of about nine feet in a year; and at Sullivan's Island, in Charleston (S. C.) harbor, it has advanced a quarter of a mile in three years. Great accumulation of pebbles are common along many coasts, and seem to remain stationary, since there

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QUESTIONS.—What are some examples of the erosive action of the waves in Europe? What are examples upon our own coasts?

are always piles of pebbles to be found in the same places; but if these are watched, the accumulations will be found to consist of different pebbles from day to day, each pebble being in turn washed from its place, which is occupied by another like it.

158. The action of tides and oceanic currents is chiefly manifested in their power of transporting and assorting the debris borne into the ocean by rivers, or produced by the erosion of waves, or arising from the growth and decay of marine animals and plants. The action of the tide, especially, is that of constant deposition, and is, in a measure, antagonistic to the action of waves and storms.

FIG. 93.

The changes produced upon our own coast by the tides are not only geologically interesting, but of the utmost importance to the trade and navigation of the country. At Sandy Hook, New York harbor, for example, where there is now dry land, there were, in 1836, forty feet of water. In 1767, there was an open ship-channel from Barnstable Bay, Mass., to the ocean; but the deposits of the tides have closed up the opening and converted it into a part of Cape Cod. A considerable number of harbors and inlets, on our coast, particularly along Martha's Vineyard and Long Island, have been gradually closed by tidal action and converted into ponds, and in the course of a few years the salt water in them gradually gives place to fresh water. In some cases the bottom of these ponds is deeper than the bottom of the adjoining ocean.*

QUESTIONS.—What is said of the action of tides and currents? Is the influence of the tides the same as that of waves? What are some examples of tidal action on our own coast?

* This fact is one of interest, since it is found that the inhabited parts of sandy deserts, such as the oases of the Desert of Sahara, present similar depressions, the bottom of the valley being, in some instances, below the level of the sea. During the changes in the

Captain Davis, U.S.N., as the result of his investigations, thinks it probable that a great part of Long Island has been formed of materials accumulated by the action of the tides.

159. Marine currents may be regarded as great oceanic rivers. Their transporting power is, however, greater than that of terrestrial rivers, since the specific gravity, or sustaining power of sea-water is greater than that of fresh water. They also possess an advantage over rivers, in transporting small, light particles of matter, by reason of their greater depth. Thus, it has been found, by experiment, that ordinary river sediment, mechanically suspended in water, settles at the rate of about one foot per hour. A current, therefore, 500 feet deep, and moving at the rate of three miles per hour, would carry its sediment 1,500 miles before depositing it. Hence, great deposits of mud may be in the course of formation at the bottom of the open sea, even when the surface water is perfectly clear.

Currents in the ocean are of two kinds, *drift* and *stream* currents. The former result mainly from the action of winds and tides, and are of no great length or velocity. The latter are of great length, depth, and velocity, and are caused by the tendency of water, displaced in the ocean by excessive evaporation in the tropics, by the rotation of the earth, and by other causes, to maintain an equilibrium.

The number of these great ocean rivers is very large. One of the most powerful and extensive is the so-called "Gulf Stream," which, commencing in the Gulf of Mexico, flows in a northeasterly direction along the whole coast of the United States, expanding in volume and diminishing in rapidity. On striking the Banks of Newfoundland, it sets to the east, and extends to the coasts of Europe and Africa. Its length, from Florida to the Azores, is 3,500 miles, which is traversed in seventy-eight days, at an average rate of thirty-eight miles per day. The amount of water conveyed in it is more than 3,000 times the amount discharged by the Mississippi River—many times greater than all the fresh water in the rivers of the globe. In a part of its course, near the Florida Gulf, its velocity is that of a torrent—five miles per hour. Mr. Lyell thinks it not improbable that some of the sediment brought down by the Mississippi may be conveyed by the Gulf Stream as far as the Banks of Newfoundland, before it is deposited.

Another similar great current exists in the Pacific, and less extensive

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QUESTIONS.—How may marine currents be regarded? What is said of their transporting power? What two kinds of currents exist in the ocean? How do "drift" currents originate? How do "stream" currents? What is one of the most remarkable ocean currents? Describe the course, length, and velocity of the Gulf Stream. How far is the Gulf Stream supposed to convey sediment?

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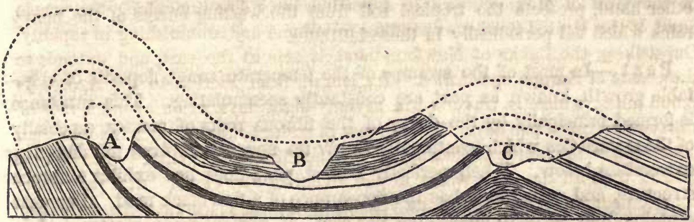
formation of these ponds they become the home, in succession, of salt water animals, brackish water animals, and fresh water animals, thus affording a beautiful demonstration of the geological formation of basins, such as those of London and Paris, in which the remains of successive races of animals are found in a fossil state.—*Capt. Davis.—Smithsonian Publications.*

ones in all the great divisions of the different oceans. All these must, in some places, be wearing down the bed of the ocean, producing indentations and irregularities in its coast lines, and accumulating in other localities an immense amount of detrital matter for the formation of new strata.

160. **Ancient Erosive Action of the Ocean.**—"As actual sea-cliffs are proofs of the erosive action of the sea now in operation, so, in almost all cases, inland cliffs, crags, scars, and precipices, as well as valleys, ravines, gorges, and mountain passes, are proofs of the former erosive action of the sea, in times when the land stood at a lower level in respect to it; and the dimensions of the gaps and portions removed, combined with the strength and durability of the materials, give us a measure of the power of the eroding forces, and the time during which they were in action." Another wonderful example of this agency is to be found in the immense accumulations of water-worn materials, *i. e.*, gravel, sand, and clay, which cover great areas of the surface of the earth to a depth, in some places, of hundreds of feet. No one who thinks for a moment over a rounded pebble can doubt that it was once a part of a continuous rock, and that it has assumed its present state through mechanical action; and the same conclusion is also applicable to every particle of sand and clay. Of the conditions of time and power requisite for the production of such effects, the mind can form but a faint conception.

FIG. 94.



In some districts of country, however, the position of strata furnishes us with very reliable data for estimating the amount of rock which has at a former period been utterly destroyed and swept away by the erosive action of water. Thus, in cases like that shown in Fig. 94, no one can doubt that the valley at *B* was once filled with rock, since the position of the strata on both sides indicate that they were once continuous, as they still are below the bed of valley. In other cases, as at *A* and *C*, the inclination of the strata shows not only that a valley has been excavated, but that an entire mountain, which formerly existed, has been swept off.

Measurements of this kind have enabled Professor Hitchcock to prove, that in some parts of the Valley of the Connecticut, nearly 10,000 feet in vertical

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QUESTIONS.—What is said of the ancient erosive action of the ocean? What inference may we draw from accumulations of sand and gravel? Show how we can, in certain cases, approximately estimate the amount of erosion by water.

thickness of rock has been removed; or, in other words, that the country in some localities was once nearly two miles higher than it is at present.

161. "In considering the destructive action of water, however, we must never forget that by destruction we do not mean *annihilation* but only *re-arrangement*. Rock-forming land, that is, rock above the level of the sea, is destroyed, but its materials are carried off and deposited, either in similar or different combinations, to form rock below the level of the sea."

SECTION III.

ORGANIC AGENCIES.

162. The organic agencies tending to produce geological changes are those depending on animal and vegetable growth.

163. **Vegetable Action.**—The growth and decay of vegetables are yearly adding to the soil, and at the same time they protect the surface from the wasting action of rain, frost, and the like. One of the great aids to rapid disintegration in Arctic countries, and in high mountain districts, is the absence of a superficial covering of vegetation—a covering which, on the other hand, protects the tropical soil from the wasting effects of the heavy rains which fall periodically in these latitudes.

Peat.—In most of the swamps of the temperate zones deposits of vegetable growth, known as *peat*, are constantly accumulating. This substance is formed principally by the decay of the fibrous roots of mosses, especially of those varieties which continually throw up new shoots from the decaying extremities below. When perfectly formed, peat does not exhibit a fibrous structure, and, when wet, has the appearance of a fine black mud. Dry peat contains from sixty to ninety-five per cent. of carbonaceous matter, and in this condition constitutes a valuable fuel. Deposits of peat are, in some instances, from thirty to forty feet in thickness, and may extend over considerable areas of the earth's surface. A peat "moss," or bog, on the River Shannon, in Ireland, covers an area of 150 square miles. In tropical countries peat is rarely formed, on account of the too rapid decomposition of the vegetable matter.

Great accumulations of vegetable matter also result from the waste and decay of forests, jungles, and cypress swamps, and from vegetable drift of rivers. On a branch of the Mississippi—the Atchafalaya—in Louisiana, the quantity of drift and *water-logged* timber that accumulated in thirty-five

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QUESTIONS.—What fact must be taken into consideration in estimating the destructive action of water? What are the organic agencies tending to produce geological changes? What is said of vegetable action? What is peat? What is said of the location and extent of peat-bogs? What of vegetable drift of rivers?

years was sufficient to form a raft ten miles long, 220 yards wide, and eight feet deep. The whole rose and fell with the water, and yet became covered with growing vegetation, and of course with soil. This raft went on increasing until about 1835, when some of the trees upon it had grown to the height of sixty feet. Steps were then taken, by the State of Louisiana, to clear it away and open navigation, which was effected, with great labor and expense, in the space of four years. Similar rafts are now in existence upon the Red, the Washita, and other rivers flowing into the Gulf of Mexico.

The prodigious quantity of wood drifted down by the Mississippi and other large rivers, which pass through heavily timbered regions, is a subject of great geological interest, since it illustrates the manner in which an abundance of vegetable matter becomes, in the ordinary course of nature, imbedded in sub-aqueous deposits. Thus, a part of this wood is carried into the main ocean, and conveyed by currents to remote latitudes. Some of the timber, for example, that comes down the Mississippi, is believed to be transported by the Gulf Stream as far as the shores of Greenland or Norway. The greater portion, however, collects in eddies or on bars along the shores, and after a time becomes saturated with water and sinks to the bottom. The deposit thus formed becomes covered with mud, and this in turn is overlaid with other layers of drift wood and sediment; and thus, in the course of time, successive strata of nearly pure vegetable matter and earthy sediment are accumulated.

It is found, in excavating at New Orleans, that the soil (which is a part of the delta of the Mississippi), to a depth considerably below the level of the sea, contains innumerable trunks of trees, layer above layer; some prostrate, as if drifted, others remaining still erect, and with their roots spreading on all sides, as if in their natural position.

Coal, as will be hereafter shown, is but a mass of mineralized vegetation, and under favorable conditions all the various vegetable accumulations above described would constitute similar mineralized deposits.

Action of Animals.—The mode in which animals tend to affect the crust of the earth is chiefly by adding their waste secretions or coverings. It is true that the bones and other remains of the larger animals are often buried in the mud of lakes and rivers, there, in time, to form solid petrifactions, and leave records of the past life of the globe; but such an effect is trifling compared with the accumulations of shells, infusorial remains, and the productions of coral animals. Many mollusks, as oysters, clams, and muscles, live in beds of considerable thickness, and if buried in sediment on the bottom of the ocean, will, in time, form layers of shelly limestone, like those occurring among the strata formed in past ages of the world. On many coasts we also find thick accumulations of drifted shells; and the marl, or whitish

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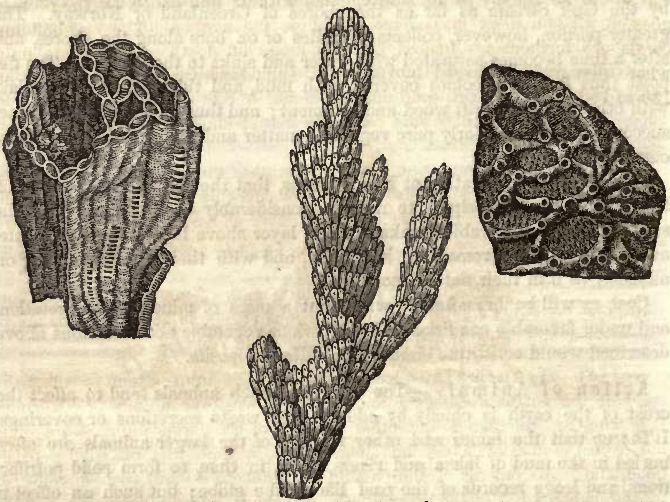
Questions.—What are remarkable illustrations of river drift? Illustrate the manner in which vegetable matter may become imbedded in strata? How do animals affect the crust of the earth? Illustrate this? What organic agent is most influential in producing geological changes?

mud, which constitutes the bottom of many fresh-water lakes, is often almost wholly composed of fresh-water shells and the remains of infusoria.

164. **Corals.**—But the most important and wonderful exhibition of *organic* agency in modifying the crust of the earth is found in the operations of the coral polyps.

Endowed with the power of secreting lime from the waters of the ocean, these minute animals construct banks or reefs of coral rock around every island and shore of the tropical oceans, where conditions of depth and current are favorable to their development. Many of these reefs, in the Pacific and Indian Oceans, extend for hundreds of miles, and are of great breadth and thickness. Thus, on the northeast coast of Australia, a coral reef exists, which is more than 1,000 miles in length, from ten to ninety in breadth, and

Fig. 95.



in some places rises, at its seaward edge, from depths of at least 1,800 feet. This reef is parallel with the shore, but at a considerable distance from it, *i. e.*, from twenty to sixty miles. Another reef, along the island of New Caledonia, is 400 miles long; and many others in the Pacific have a nearly equal extension. In fact, "the absolute area of sea-bottom, in this ocean, thus occupied at intervals by the work of the coral animals, is so enormous, that it would be difficult to parallel it by reference to any existing mountain district."

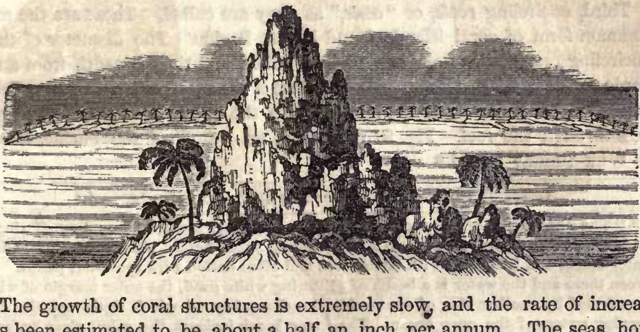
Questions.—What is the nature of the action of the coral animals? What is said of the extent of their operations?

"The animals which produce coral are very simple, and resemble plants, both in their figures and colors. Indeed, they were formerly described as marine plants. They vary in size from a minute fraction of an inch to several inches in diameter; and live either solitary or associated in immense numbers. From their resemblance to plants, the coral animals, as a class, are often called 'zoophytes.'

"The coral secreted by the polyps is not a collection of cells in which the animals may conceal themselves, but an internal skeleton; nor do they exhibit any industry or instinct in forming it, but it results from vital processes in their system, which they no more control than do the more highly organized animals the formation of their bones. Every part of live coral also is wholly enveloped by the texture of the polyps which produced it." Figs. 95, 106, and 147, represents some of the varieties of coral.

The coral polyps increase mainly by buds, which shoot out from their sides in a manner similar to the buds of plants. On coral formations these buds spread out so thickly as to stop the life within; and hence, as the process goes on, all is a dead mass except just at the surface. The reef-building corals are furthermore limited in their range of depth, and operate only where perpetually covered by the tides and downward to the extent of 120 to 180 feet.

FIG. 96.



The growth of coral structures is extremely slow, and the rate of increase has been estimated to be about a half an inch per annum. The seas, however, in which corals occur, abound also with shells and other marine animals, which by their remains contribute greatly to augment the mass of the coral formation.

Three classes of coral reefs are recognized: First, "fringing reefs," or belts of coral attached to the coasts of islands or continents;

Second, "barrier reefs," which form rising walls at some distance from the land, and between which and the land a broad, safe channel frequently exists.

QUESTIONS.—What is said of the structure of the coral animals? What relation does the coral rock sustain to the organism that produces it? Do the coral animals work in all depths of water? How fast does coral increase? How many classes of coral reefs are recognized? What are fringing reefs? What are barrier reefs?

Such reefs are, in some instances, ninety miles in diameter. On the ocean side they terminate abruptly in deep water, but within, the slope is gradual. Fig. 96 represents a barrier reef encircling the island of Bolabola, in the Pacific; it will be observed to be entirely separated from the island and covered with trees;

FIG. 97.

Third, encircling reefs, or "*atols*," as they are called. These are the most common form of coral islands found in the Pacific. The diameter of these encircling reefs varies from one to forty miles, and their breadth from a few yards to more than a mile. They inclose a space of quiet waters, called a *lagoon*, which generally communicates with the ocean by one or more openings through the reef. Fig. 97 represents an "atol" of the Pacific, known as Whit-Sunday Island.*

QUESTION.—What are the characteristics of the circular reefs?

* "The appearance of these coral islands is extremely picturesque. A small ring of land, of circular or oval shape, and a few hundred yards across, rises barely above high water-mark, and is fringed with mangroves and often dotted with cocoa-nut palms. Between these and the water is a beach of glittering white sand, the outer margin of which is encircled by another ring of snow-white breakers, beyond which again are the dark heaving waters of the open ocean. The inner beach incloses the calm, clear water of the lagoon, resting, for the most part, on white sand, and showing the most vivid green color when the sun is shining."

"The ocean," says Mr. Darwin, "throwing its breakers on the outer shore, appears an invincible enemy, yet we see it resisted, and even conquered, by means which at first seem weak and inefficient. No periods of repose are granted, and the heavy swell caused by the steady action of the trade wind never ceases. The breakers exceed in violence those of our temperate regions; and it is impossible to behold them without feeling a conviction that rocks of granite or quartz would ultimately be demolished by such irresistible forces. Yet these low coral islands stand and are victorious, for here another power, antagonistic to the former, takes part in the contest. The organic forces separate the atoms of carbonate of lime, one by one, from the foaming breakers, and unite them into a symmetrical structure; myriads of architects are at work day and night, month after month, and we see their soft and gelatinous bodies, through the agency of the vital laws, conquering the great mechanical power of the waves of the ocean, which neither the art of man nor the mechanical works of nature could successfully resist."

Coral reefs, as has been stated, consist of living corals only at their upper and outer surface; all the interior is composed of dead corals and shells, either whole or in fragments, and the calcareous portions of other marine animals. The interstices of the mass are filled up and compacted together by calcareous sand and mud, derived from the waste and debris, the wear and tear of the corals and shells, and by countless myriads of minute organisms, mostly calcareous also. The surface of a reef, where exposed at low water, is composed of a solid-looking stone, which is often capable of being split up and lifted in slabs, bearing no small resemblance to some of our oldest limestones. These slabs and blocks, when broken open, are frequently found to have a semi-crystalline structure internally, by which the forms and the organic structure of the corals and shells are more or less disguised or obliterated.

When a growing reef has reached the level of low water, the growth of coral ceases, and loose materials begin to accumulate upon its summit. Large blocks of coral are thrown up by the waves and gradually ground into calcareous sand and gravel; sea-weeds and wood are washed up, and upon the soil thus formed vegetation commences, and the reef finally becomes a habitable island. This action, on our own coast, is strikingly illustrated in Florida, the southern portion of which State, according to Professor Agassiz, "is only a vast coral bank composed of a series of reefs, which have successively grown up from the bottom of the sea to the surface, and have been added to the main-land by the gradual filling up of the intervals which separate them, with deposits of coralline sand and debris, brought thither by the action of tides and currents. On *the solid reefs*, the action of the waves accumulates mud and sand to a height of twelve feet above the sea-level; and this soil becomes rapidly fixed, by the growth of mangrove trees and other plants. The intervals being lower, form large fresh-water swamps, filled with many kinds of aquatic plants, through which the Indian can only penetrate with a boat. The higher and drier reefs are the so-called 'Hummocks,' which rise like islands from the deep green swamps that bear the name of 'Everglades.' This formation is still in progress, and the so-called 'Keys' which border the Florida coast, are only a new line of hummocks, which will eventually be added to the mainland by everglades formed by the deposits of the sea."

The peculiar form of the coral islands and reefs of the Pacific, and the great depths from which they rise, has been the subject of much speculation among geologists, since, as has been already stated, the coral animal does not live in very deep water. The explanation of these phenomena most generally accepted, is, that the coral is reared upon a foundation which has gradually subsided, and as the depression has gone on slowly, the coral has continued

Questions.—Describe the structure of a coral reef. When a growing reef has reached the surface of the water, what takes place? What striking illustration of the action of the coral animals as found in our own coast? Describe the formation of the Florida everglades? To what is the peculiar form of the coral islands and reefs of the Pacific attributed? Illustrate how the circular coral islands are supposed to be formed.

to grow to a corresponding extent upward. On such a supposition, the circular coral islands (as represented in Fig. 97) would indicate the position of a former mountain, around which the coral has formed a fringe or reef. As the mountain continued to sink, the reef would draw inward around the summit, and finally, as the summit went under, the reef would still remain a ring, with a lake or lagoon in the center—for the polyps could not work in the middle till the whole was submerged, and even then, these animals prefer the open sea. The depth of water in the immediate proximity of such islands, is, as might have been expected, almost unfathomable. Thus, in one instance, noticed by Mr. Dana, in the geology of the U. S. Exploring Expedition, the sounding line, within three quarters of a mile of the shore, ran out, first 2,000 feet; then at a short distance further off, 3,000 feet; and at seven miles from the shore, no bottom was found at 6,800 feet. At Keeling Island, another coral island of the Pacific, no bottom was found with a line 7,200 feet, at a distance of only 2,200 yards from the shore.

The study of the action of the coral animals in existing oceans prepares the mind of the geologist for the investigation of operations of a similar character, which have taken place in the seas of former periods of the earth's history. Many of the limestone rocks, which now form portions of the dry land, are undoubtedly ancient coral reefs, which appear to have been formed under conditions analogous to those which now prevail in the waters of the Pacific.

SECTION IV.

CHEMICAL AGENCIES.

The changes in the structure of the earth's crust, resulting from chemical agencies, are numerous and complicated.

They have, however, been noticed, for the most part, in previous sections. Thus, the formation and deposition of travertine and calcareous tufa, stalactite, and stalagmite, silicious sinter, bog-iron ore, hydrate of manganese, gypsum, rock-salt, and the cementation of various sands into compact rocks, are all the result of chemical action. Many of the phenomena connected with volcanoes and earthquakes may also be referred to a similar origin.

In addition to these results, which especially appear at the earth's surface, chemical forces, called into activity by the agency of heat, water, electric and magnetic currents, are continually operating in the interior of the earth's crust to produce changes or metamorphism in the structure of existing rocks,

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QUESTIONS.—What facts tend to confirm this theory? Why is the study of coral growth of peculiar interest to geologists? What is said of the changes in the earth's crust effected through chemical agencies? What are some illustrations of this action on the earth's surface?

viz., hardening and consolidating some strata, softening and dissolving away others, filling fissures with metallic ores, and elaborating new compounds by the union of different substances.

M. Bischoff, a German chemist, who has made chemical geology "a special study, asserts that *all* rocks, through the action of chemical forces, are continually subject to alteration, and that their sound appearance is no indication that alteration has not taken place in them." A detailed discussion of these subjects, however, presupposes a somewhat extensive acquaintance with the facts of terrestrial chemistry, and would be foreign to the plan of the present work.

CHAPTER IX.

CLASSIFICATION OF THE MATERIALS COMPOSING THE EARTH'S CRUST INTO PERIODS, SYSTEMS, AND GROUPS.

165. To a mere casual observer, the different mineral or earthy materials constituting the crust of the globe must appear to be thrown together confusedly and without order. Such, however, is not the case; but all the various rock-formations have been found capable of arrangement into divisions or classes, which occupy definite positions in the earth's crust, and have undoubtedly been formed at different epochs of the earth's history.

The fundamental idea involved in every system of classification of rocks, is that of *relative age.*

This, in the case of the stratified rocks, may be determined: *first,* by the relative position of strata; *second,* by differences in mineral composition; and, *third,* by differences observed in the nature of the imbedded fossils, if any such are present.

166. It is evident, in the first instance, that the various layers, beds, or strata constituting the crust of the earth, are the result of a succession of operations, all requiring time; and that in every case, except where beds have been inverted by violence, the lowest in position of a series of strata must be the oldest, while the other superimposed layers must have been subsequently formed, in the order of their upward succession.

QUESTIONS.—Do changes through chemical action take place in the interior of the earth? Do the earthy materials composing the crust of our globe occur confusedly and without order? What is the fundamental idea involved in every system of classification of rocks? How may the relative age of the stratified rocks be determined? How does the position of strata indicate their age?

If the various layers of stratified rocks extended uniformly over the whole globe, and had never been disturbed or broken, they would inclose one another, and envelop the earth in a manner similar to the concentric coats of an onion; and the determination of the relative age of all the strata could be accurately ascertained by simply determining their relative position. There is, however, no place on the globe where any such uniformity prevails, or where, if a section was made sufficiently deep into the earth, all the various rocks would be found superimposed in order upon each other.

The reason of this is not difficult to comprehend, since, as changes in the distribution of land and water are known to have occurred at every epoch of the earth's history, particular portions of its surface must have been successively dry land and sea-bottom;* and as the stratified rocks have been formed by the deposition of sediment in water, it is obvious that those portions of the globe, which constituted dry land during the formation of a deposit in a surrounding ocean, could have received no portion of such deposit, and therefore we find, as might naturally be expected, that certain varieties of rocks are restricted to particular localities.

167. Differences in mineral composition may also aid in determining the relative age of rocks, inasmuch as some mineral substances have been deposited more abundantly at certain periods than at others. Thus, the occurrence of extensive beds of chalk characterizes and gives name to a system of rocks, known as the "cretaceous" or "chalk" formation; while beds of rock-salt and of coal are usually found associated with other rocks of a distinctive and peculiar character. If rocks, moreover, belonging to one formation are found to contain imbedded fragments of another formation, the evidence is conclusive that the rocks to which the fragments belonged were formed, consolidated and broken up, before the others were deposited.

168. The evidence, however, upon which geologists mainly rely for determining the relative age of rocks, is the character of the organic remains, or fossils imbedded in them. An examination and comparison of these have

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Questions.—Do the various layers of stratified rocks extend uniformly over the whole globe? If such were the case, how could we determine the relative age of rocks? What is the reason that all the stratified rocks are not everywhere found imposed in order upon each other? How do differences in mineral composition aid in determining the relative age of rocks? Illustrate this proposition. Upon what evidence do geologists mainly rely for determining the relative age of rocks?

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* "The mere place and outline of the dry land has frequently changed. Most of our present dry lands have been deep-sea, and then dry land, and then deep-sea again, several times; and the same thing has probably happened to those parts of the earth's surface that are now covered by water. The solid crust of the earth seems to have been always subject to a gentle fluctuating movement of elevation and depression, affecting first one area and then another, while large parts remain stationary for long periods, until they, in their turn, are moved, and the others left to rest. We may look upon the dry land of any period, therefore, as merely so much of the solid surface of the earth as happens to be taking its turn to stand above the level of the sea."—*London Quarterly Review, July*, 1859.

established the important fact, that different races of animals and plants lived, flourished, and became extinct at different epochs of the earth's history, and have left their forms impressed or imbedded in the rocks deposited contemporaneously with the period of their existence. The fossils, therefore, peculiar to each geological formation, or group of rocks, have distinct and recognizable characters; and a geologist who has once rendered himself familiar with these characters is enabled to readily determine, from the presence of certain forms, whether strata, geographically remote, as in America and Europe, were deposited at the same, or at different epochs.

Furthermore, the organic remains found in any series of strata have a distinct relation to the circumstances under which the materials composing such strata were accumulated. Thus, it is clear that the layers of mud, sand, clay, and gravel, depositing at the present day in tropical seas and lakes, will contain more or less of the remains of animals and plants peculiar to the tropics; and deposits forming in temperate regions will contain in like manner the remains of animals and plants peculiar to temperate climates; and should a time arrive, when these layers are converted into solid strata, the fossilized plants and animals contained in them will become a certain index to the conditions of the region at the time of their entombment. And as with deposits now in progress, so with strata constituting the solid crust of the globe. Strata abounding in shells, corals, and other marine remains, must have been deposited from the sea; while those containing fresh water plants and animals, mingled with the remains of land animals and vegetables, give unmistakable evidence of having originated in lakes of fresh water or at the mouths of rivers.

These and similar propositions are so apparent, that the student can have little difficulty in comprehending the principles upon which geologists have proceeded in classifying the different rock-formations of the globe.

169. As the unstratified or igneous rocks occur in no regular order of succession, and are not characterized by the presence of fossils, their relative age can only be inferred from an examination of the stratified rocks with which they are associated. (See Fig. 112.)

Thus, if igneous rocks are found displacing and breaking through any set of strata, they must be more recent than the strata disrupted; and if another set of strata overlie these igneous rocks, then the latter must have been deposited from water at a period subsequent to the igneous eruptions.

170. **Progress of Geological Classification.**—A brief review of the history of the progress of geological classification is almost indispens-

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QUESTIONS.—Illustrate this proposition. What relation have the organic remains, or fossils found in strata, to the circumstances under which the strata were formed? Show how this is. How may the relative age of the igneous rocks be inferred? Illustrate this by example.

able to enable the learner to understand how geologists have been led, step by step, to their present conclusions, and in what manner various technical terms have originated and been introduced into geological nomenclature.

Most of the hypotheses put forth by the earlier philosophers respecting the geological structure of the globe were more curious than instructive; and it is only within the last half century that any very correct notions upon the subject have been arrived at.

In modern times, geological facts first began to excite attention in Italy, in the early part of the sixteenth century. The strata of the Italian mountains are singularly rich in fossil shells; and when these remarkable objects arrested the attention of thoughtful men, controversies arose, whether they were really the remains of living creatures or the productions of some mysterious power by which the forms of such creatures were mimicked; and again, if the shells were really the spoils of the sea, whether they had been carried to the hills by the deluge, of which the Scripture speaks, or whether they indicated revulsions of the earth of a different kind. These questions occupied the learned world for nearly three centuries.

One of the first persons who applied a sound and vigorous intellect to these subjects was the celebrated painter, Leonardo da Vinci, and a philosopher by the name of Frascatora, whose attention was engaged by the multitude of curious petrifactions which were brought to light, in 1517, in the mountains of Verona, in quarrying materials for repairing the city. They exposed the absurdity of the theories which referred these petrifactions to a certain plastic force in nature that could fashion stones into organic forms, and maintained that all fossil shells once belonged to living animals, and that the deluge of Noah was too transient an event to explain the phenomena.*

171. The truth, however, made but slow progress in the face of the established prejudices of the times; and as late as 1617 we find distinguished Professors of Anatomy, and learned men, in Italy, Switzerland, and England, maintaining that the fossil ivory tusks of elephants were mere earthy concretions, or that the bones of elephants, mastodons, and huge marine animals, found imbedded in the earth, were those of giants, or even of the fallen angels.

172. In 1680, the celebrated German mathematician, Leibnitz, first proposed the theory, that the earth was originally in a state of igneous fusion, and that its solid crust was the result of a gradual cooling. He also instituted a division of rocks into stratified and unstratified—the former term

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QUESTIONS.—What is said of the earlier geological hypotheses? Where and when, in modern times, did geological facts first attract attention? What questions arose among learned men respecting fossil shells? Who were especially advocates of the reality of their former existence?

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* "You tell me," says Leonardo da Vinci, in one of his statements, "that nature and the influence of the stars have formed these shelly forms in the mountains; then show me a place in the mountains where the stars at the present day make shells of different ages and of different species in the same place. And how will you explain the gravel which is hardened into rocks at different heights in the mountains?"

embracing rocks deposited from water, and the latter those which had consolidated from a melted state.

173. In 1756, Lehmann, a German miner, proposed to divide rocks into three classes; the first and oldest to be called *primitive* (comprising the igneous and metamorphic rocks); the second to be termed *secondary* (comprehending the aqueous or fossiliferous strata); while the remainder, or third class, called *local*, included the supposed effects of local floods, and the deluge of Noah, and corresponded to what, in modern classifications, are known as alluvium and drift. In the primitive class (such as granite and gneiss), he said, there are no organic remains, nor any signs of materials derived from the ruins of preëxisting rocks. Their origin, therefore, may have been purely chemical, antecedent to the creation of human beings, and probably coeval with the birth of the world itself. The secondary formations, on the contrary, which often contain sand, pebbles, and organic remains, must have been mechanical deposits, produced after the planet had become the habitation of animals and plants. This bold generalization formed at the time an important step in the progress of geology, and sketched out correctly some of the leading divisions into which rocks may be separated.—LYELL.

174. The next important advance was made by Werner, an eminent German mineralogist, Professor in a mining school at Freyburg, in Saxony. He asserted the existence of four rock formations, which originally extended over the whole globe, and followed each other in an invariable order. The first and lowest of these, termed "*primary*" or "*primitive*," included granite —the basis; then mica-slate and clay-slate—rocks of a crystalline character and wholly devoid of organic remains. Resting upon these, Werner taught the existence of a series of strata, intermediate in character between the older and the newer formations, having to some extent a crystalline texture, but yet exhibiting occasionally signs of a mechanical origin and also a few organic remains. For this group, which apparently formed a connection betweed Lehmann's primitive and secondary rocks, he proposed the name of "*transition*." The rocks belonging to it consisted principally of slates and schists, an argillaceous sandstone, called "graywacke," and some limestones. Succeeding the transition were regular fossiliferous strata—sandstones, limestones, coal, gypsum, etc.—which he termed "*secondary*;" and to every deposit more modern than the secondary he gave the name "*alluvial*."

These divisions were extensively adopted by geologists, and have continued to influence, more or less, the systems of classification down to the present day. Tabulated, they appear as follows:

1. ALLUVIAL—*Sand, gravel, clay, etc.*
2. SECONDARY—*Fossiliferous rocks, with a mechanical structure.*
3. TRANSITION—*Partially crystalline, partially mechanical, and sometimes fossiliferous.*
4. PRIMARY OR PRIMITIVE—*Crystalline, and wholly wanting in fossils.*

QUESTIONS.—Did correct geological opinions soon receive the support of scientific men? What theory was proposed by Leibnitz? What divisions of rocks were proposed by Lehmann? Who next was instrumental in advancing the science of geology? What were the views of Werner?

Werner supposed that all rocks, the stratified as well as the unstratified, were deposited from water; and that veins were filled by matter introduced from above in aqueous solution. On account of this reference of all geological deposits to water, his theory was called "Neptunian."*

175. Nearly at the same time, a Scotch geologist, by the name of Hutton, published a "Theory of the Earth," opposed in most respects to the doctrines of Werner. He taught, that the rocks which form our present continents were derived from the ruins of former continents, which were abraded and carried into the sea by the agency of running water; just as the same agency is now spreading over the bottom of the ocean deposits of mud, sand, and gravel. Granite and trap rocks, he asserted, were of igneous origin, and have been intruded in a melted state into fissures in the earth's crust. The crystalline stratified rocks, included in the classes "primary" and "transition," of Werner, he regarded as merely sedimentary strata, altered by heat —a supposition which accords very well with the views at present entertained respecting the origin of the metamorphic rocks.

These rival theories excited a controversy among the scientific men of Europe, which for years was carried on with a bitterness and animosity almost unprecedented in the history of such disputes; and all geologists allied themselves to various schools or sects, under the name of "*Wernerians*" or "*Neptunists*;" "*Huttonians*" or "*Plutonists*;" "*Cosmogonists*," "*Diluvialists*," "*Fossilists*," etc., etc. The final result was, that the views of Werner were almost universally abandoned, and those of Hutton, in their essential features, adopted.†

QUESTIONS.—To what cause did Werner refer the production of rocks? By what name was his theory designated? Who especially opposed Werner? What were the views advanced by Hutton? What was the result of the promulgation of these different geological views?

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* "The theory of Werner assumed that the globe had been first invested by an universal chaotic ocean, holding the materials of all rocks in solution. From the waters of this ocean, granite, gneiss, and other crystalline formations were first precipitated; and afterward, when the waters were purged of these ingredients, and more nearly resembled those of our actual seas, the transition strata were deposited. These were of a mixed character, not purely chemical, because waves and currents had already begun to wear down solid land, and to give rise to pebbles, sand, and mud; nor entirely without fossils, because a few of the first marine animals had begun to exist. After this period the secondary formations were accumulated in waters resembling those of the present ocean, except at intervals, when, from causes wholly unexplained, a partial recurrence of the "chaotic fluid" took place, during which, various trap-rocks, some highly crystalline, were formed. This arbitrary hypothesis rejected all intervention of igneous agency —volcanoes being regarded as partial and superfluous accidents, of trifling account among the great causes which have modified the external structure of the globe."—*Lyell's Elements of Geology.*

† At the present day, the tendency among geologists is to the belief that the crystalline and compact condition of many rocks, which has been heretofore attributed to the action of dry heat, should be rather referred to the agency of heated water, or possibly of steam under great pressure. Thus, glass, which is a silicate, allied in composition to many of the hardest rocks, can be entirely dissolved by the action of water, heated under pressure;

176. About the beginning of the present century, William Smith a humble engineer in England, Saussure and Cuvier of France, and others, began to investigate the structure of the earth's crust in a more philosophic manner. Group after group of strata were examined, and their relative position and fossil contents determined and compared; and it was then shown, for the first time, that strata, very remote from one another geographically, could be identified as of the same age and position, by means of the fossils contained in them.

177. As a result of these investigations, the following modifications of Werner's classification were adopted, and continued for many years to give direction and consistency to the researches of modern geologists:—

FORMATIONS.

- RECENT.—*All superficial accumulations, such as sand, gravel, marl, clays, peat, coral-reefs, etc.; which contain the remains of existing animals and plants.*
- TERTIARY.—*Local and limited deposits of stratified rocks, clays, and marls, lying below the recent and above the secondary, and containing the remains of animals and plants not differing widely in character from those now existing.*
- SECONDARY.—*Strata of fossiliferous rocks, containing the remains of animals and plants, of species entirely different from those now existing. This formation embraced all the strata known as chalk, oolite, lias, coal-measures, and old red-sandstone.*
- TRANSITION.—*Strata of slaty rocks, argillaceous sandstones known as "graywacke," limestones, etc.; containing few or no fossil plants, and only the remains of low orders of marine animals, shells, crustacea, corals, etc.*
- PRIMARY.—*All hard, compact, crystalline rocks, entirely destitute of all traces of organic remains. In this class were included the clay-slates, gneiss, mica, talcose, and hornblende schists, and the various quartz rocks.*
- IGNEOUS.—*Succeeding the primary rocks, and constituting the basis upon which all the other formations rest, was granite, and other rocks of like character, of assumed igneous origin.*

178. **Classifications of Modern Geologists.**—As the result of a more extensive examination of the stratified rocks of different countries, and especially from the study and comparison of their fossils, the above noticed divisions of the earlier geologists have been for the most part abandoned, and more minute and exact classifications instituted.

The classification accepted at present by most geologists, divides the stratified or aqueous rocks of the earth's crust into ten separate systems or formations, each one of which

QUESTIONS.—What was the condition of the science of geology at the commencement of the present century? What classification of rocks was recognized by the earlier investigators of this century? How has a more extensive examination of the strata of different countries affected classification?

and in some experiments of this nature, made by Daubrée, the silica of the glass was found to have crystallized in the form of quartz. Now, it is not improbable that we may have had all the forces of pressure, heat, and the dissolving power of water combined, in the interior of the earth.

includes a great assemblage of strata which have been formed during the epoch of the system, and have certain fossil and mineral characters in common.

The strata included in each system are, in turn, divided into groups, each of which is characterized by some minor mineral or fossil peculiarities; and each group into separate beds or series of strata, all of which may have distinctive names expressive of some marked feature.

179. If for the sake of illustration we compare the different geological systems to separate books (not all, however, of the same size or thickness), containing a record of the earth's past history, then the groups into which each system is divided will correspond to the separate parts of a book, the beds or series to the chapters, the separate strata to the leaves, and the laminæ composing the strata to the lines of the leaves. The comparison, moreover, will seem still more apt, if we bear in mind that each geological system indicates an entirely new era in the history of the earth, and each of the subordinate groups and series some partial revolution or change in the previously established order. (See Frontispeice).

Proceeding from the surface of the earth downward, or from the most recent system to the most ancient, the modern classification of the stratified rocks may be stated as follows:

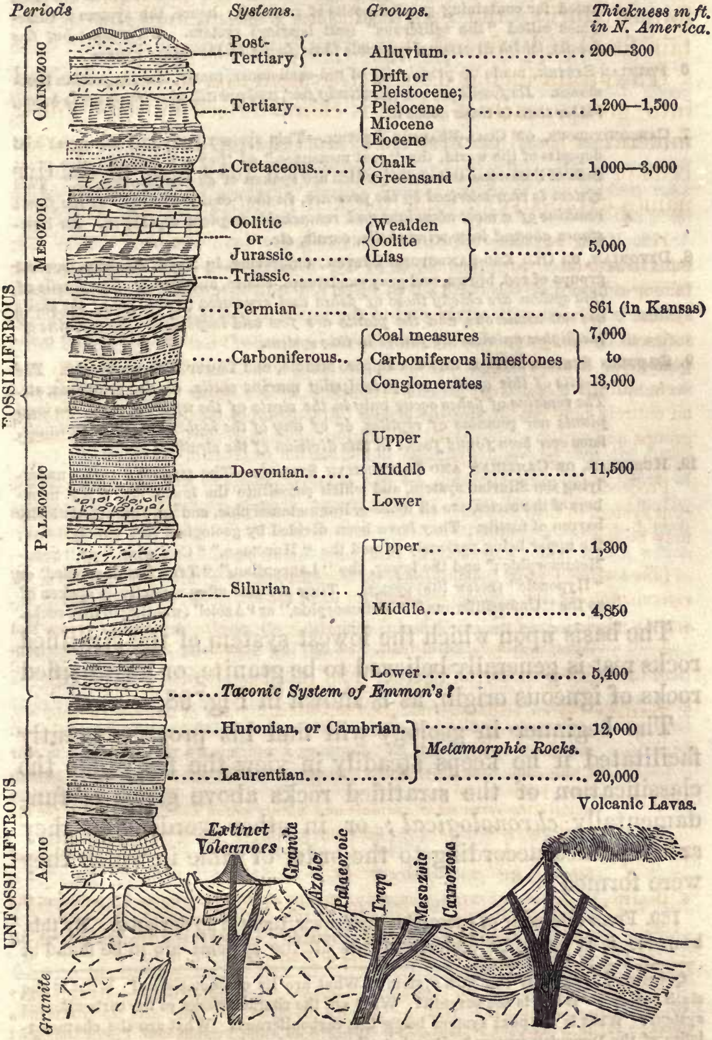
(*The learner will be assisted in comprehending the classification here given by referring to Fig.* 98, *which represents an ideal section of the earth's crust.*)

1. **Post-Tertiary, or Recent System, comprising all modern deposits of rivers and lakes, peat-beds, coral-reefs, and all the formations that have been produced during the human or historic period. *The strata of this system contain the remains of animals and plants belonging to species now existing.***
2. **Tertiary System, embracing the great superficial deposits of water-worn materials, and bowlders, known as the "drift;" and a succession of regularly stratified clays, sands, marls, and limestones, which have been arranged in four groups, and named as follows (commencing with the most recent): pleistocene, pliocene, miocene, and eocene. *These groups of the tertiary system contain the remains of animals and plants which belong to species for the most part extinct, but not differing widely from existing species.***
3. **Chalk, or Cretaceous System. *The fossils of this system are chiefly marine, and belong to species which are extinct.***
4. **Oolitic, or Jurassic System, comprising groups of strata known as the wealden, the oolite, and the lias. *The strata of this system abound in the remains of plants and animals (the most remarkable being those of huge reptiles), all of which belong to extinct species or genera.****

Questions.—Into how many systems do modern geologists divide the stratified rocks? What constitutes a system? How are systems divided? To what may these divisions of the stratified rocks be compared? What does each system and group indicate? Which is the first system? What are its characteristics? Name the second and its characteristics? What is the third system? What is said of the oolitic system?

*** For definition of species and genera consult § 209.**

FIG. 98.



Ideal Section of the Earth's Crust, showing the arrangement of the Stratified Rocks into Periods, Systems, and Groups; and also (at the base) the position and relation of the Igneous Rocks to the Great Divisions of the Stratified Rocks.—(See also Frontispeice).

5. TRIASSIC, OR NEW RED-SANDSTONE SYSTEM.—This system is made up principally of strata of red or variegated sandstones and marls, the latter of which are often noted for containing great deposits of rock-salt; hence, the system is sometimes called "the saliferous" (salt bearing) system. *It contains but few fossils, which in general resemble those found in the oolitic system*

6. PERMIAN SYSTEM, made up principally of red-sandstones, marls, and magnesian limestones. *Its fossils are comparatively few, and are allied to the systems below, rather than to those above it.*

7. CARBONIFEROUS, OR COAL-BEARING SYSTEM.—This system embraces the great coal deposits of the world, the "coal measures," as they are termed; also great beds of limestone and slates, which are spoken of as "carboniferous." *This system is characterized by the presence, in the "coal measures," of the fossil remains of a most abundant and remarkable tropical vegetation. Its limestones abound in marine shells, corals, etc.*

8. DEVONIAN, OR OLD RED-SANDSTONE SYSTEM, embracing, in North America, several groups of red, brown, and gray sandstones, shales, and slates. *The fossils of this system are chiefly those of fishes and crustacea (crabs, etc.); the shells are not numerous, and the plants are few and imperfect. No remains of the higher animals are found in this system.*

9. SILURIAN SYSTEM, divided into the Upper, Middle, and Lower Silurian groups. *The fossils of this system are principally marine shells, corals, crustacea, etc. The remains of fishes occur only in the strata of the upper group. No land plants nor remains of reptiles, or of any of the higher orders of animals, have ever been found fossil in this division of the stratified rocks.*

10. HURONIAN, OR CAMBRIAN AND LAURENTIAN SYSTEMS.—The stratified rocks underlying the Silurian system, and which constitute the lowest and oldest members of the series, are all more or less metamorphic, and are characteristically barren of fossils. They have been divided by geologists into two systems; the upper being variously named the "Huronian," "Cambrian," or "Semi-Metamorphic;" and the lower, the "Laurentian," "True Metamorphic," or "Hypozoic" (below life) system. They are also often collectively spoken of as the "Unfossiliferous," "Metamorphic," or "Azoic" (wanting in life) rocks.

The basis upon which the lowest system of the stratified rocks rest is generally believed to be granite, or unstratified rocks of igneous origin, as is shown in Fig. 98.

The beginner in geology will find his progress greatly facilitated if he keeps steadily in view the fact, that the classification of the stratified rocks above given is fundamentally *chronological;* or, in other words, that they are classified according to the order of time in which they were formed.

180. From this order of succession, moreover, there is no deviation. By this, however, it is not to be understood that all the systems are to be found at

QUESTIONS.—What is the fifth system? What are its characteristics? What is the sixth system? What is the seventh? What are the characteristics of the carboniferous system? What is the next system below this carboniferous? What are the characteristics of the Devonian system? By what other name is this system sometimes called? What are the characteristics of the Silurian system? What is the lowest system? What is known about it? Upon what basis is the lowest system supposed to rest? What is the principle upon which the classification of the stratified rocks is established?

any part of the crust of the earth lying one above the other like the coats of an onion (and as is the case in the ideal section represented in Fig. 98); but that, wherever the rocks of two or more systems come together, they are never found out of place; that is, the rocks of the Carboniferous system are never found beneath those of the Silurian; or those of the Oolite beneath the Carboniferous; or, in short, any rocks of a higher system beneath those of a lower.

Furthermore, as any particular area of the earth may have been an area of destruction (erosion and degradation) during one period, and an area of production, or even of neutrality during another, strata of one system may rest directly upon those belonging to a much older system, without the presence of the naturally intervening series. Thus, for example, the rocks of the Devonian system and those of the Silurian might, in some districts, be wholly wanting; and in this case the strata of the Carboniferous system would rest directly upon those of the Huronian; or the Oolite, Triassic, and Permian rocks being absent, the Cretaceous would rest directly upon the Carboniferous. In every such case, the principle that the higher system invariably overlies the lower, would be maintained; while a reversal of the order of succession, from the nature of the case, would be impossible.

181. The learner must here be cautioned against supposing that the rocks which make up the different systems are so different from each other in appearance as to admit of easy recognition by mere inspection. On the contrary, the varieties of stratified rocks are comparatively few, and each system contains limestones, sandstones, and argillaceous (clay) rocks, which do not differ materially in appearance or composition from similar rocks in other systems.

This circumstance, however, occasions but little embarrassment to the geologist, for the reason that the fossils found in each of the different systems of rocks are peculiar and different from those of any other system; so that, although sandstones from the Oolite may exactly resemble sandstones from the Carboniferous system, or limestones from the Devonian system those from the Silurian, yet an experienced geologist, by the difference of their contained fossils, is at once enabled to designate their true character and the relative age of their formation.

182. **Division of Geological Time into Periods or Ages.**—Each system of stratified rocks, as has been before stated, contains fossils peculiar to itself, and these do not ever recur in strata belonging to contiguous systems either above or below it in the order of succession. At the same

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QUESTIONS.—What is understood by the invariable order of succession of the different systems? Explain how it happens that some systems of rocks are wanting in certain localities? Are the rocks belonging to each system peculiar in their appearance? If, then, they are alike, how can a geologist refer them to different systems?

time, there is a connection between the different systems more strong in proportion to their proximity to each other. The fossils of the Cretaceous system, while they differ from those of all other systems, are nevertheless much more nearly related to those of the Oolite system, which immediately precedes, than to those of the Carboniferous system, which is much more ancient; and in the same manner the fossils of the Carboniferous approach more nearly those of the Silurian system than those of the Tertiary.

These relations have suggested to geologists and naturalists a classification of the different systems of rocks according to the general type or character of the living beings which predominated during certain periods or ages of the earth's history; just as in the history of man several grand periods or ages have been established, which are marked by peculiarities in his social and intellectual condition, and are illustrated by contemporaneous monuments.

The names applied to these several periods are derived from the Greek, and, commencing with the most recent, are as follows:

1. Cainozoic (καινος, recent, and ζώη, life), or period of recent life. *This period includes the Post-Tertiary, or recent system of rocks, and the Tertiary system.*

2. Mesozoic (μεσος, middle), or the period of middle life. *This period includes the Cretaceous, Oolitic, and Triassic systems.*

3. Paleozoic (παλαιος, ancient), or period of ancient life. *This period includes the Permian, Carboniferous, Devonian, and Silurian systems.*

4. Azoic (α, privative, and ζωη, life), or the period deficient in the evidences of life. *This period includes the Laurentian rocks, or all the unfossiliferous and metamorphic rocks which lie below the base of rocks included in the Paleozoic period, and which have thus far yielded little or no evidence of the existence of life at the time of their deposition.**

QUESTIONS.—What differences and points of resemblance exist between different systems? What classification of the geological systems has been established? What analogy exists between the periods or ages in geology and the periods instituted in the history of man? What is the first or most recent period? What systems does it include? What is the second period? What systems does it include? What is the third period? What systems are included in it? What is the fourth period? What are the systems included in it?

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* The relation of the geological periods to the several systems is clearly shown in Fig. 98, in the pependicular section, on the left. Their relation to each other, and to the igneous or unstratified rocks is also shown at the base of the same figure.

183. By this arrangement we understand, therefore, that during certain epochs there was a certain typical or general resemblance among the beings then populating the globe; that down to the Cretaceous system (*i. e.*, the recent period) the fossil species closely resemble those now existing; from the Cretaceous to the Permian (*i. e.*, the middle period) the departure from recent forms was greater; from the Permian to the Silurian (*i. e.*, the ancient life period) the species were altogether distinct from the recent, and different, in a majority of instances, from those of the middle period; and that from the Silurian downward (*i. e.*, the period deficient in life) traces of organic life are very obscure, or altogether wanting.

184. In recognizing these classifications "the student should remember—and he can not be too early cautioned to bear ever in mind—that throughout the whole of creation there is only ONE SYSTEM, and that, in time past as in time present, every aspect of nature gives evidence of only ONE all-pervading, all-directing MIND. The matter of the universe may undergo change of place, appearance, and arrangement; still it is the same matter, and is subject to the same laws that have operated through all time. The plants and animals may assume different specific aspects at different epochs and under different conditions, still they are constructed on the same plan and principle, and the laws which influence their being now, are identical with those which have governed life since the dawn of creation. Without this uniformity of law the study of nature would be impossible. There is only ONE GREAT SYSTEM in creation, and the periods and systems of the geologist must be regarded as mere provisional expedients toward the elucidation and comprehension of that system."

185. **Geological Nomenclature.**—To beginners, the nomenclature employed by geologists is often exceedingly difficult to understand, and seems to render the whole subject needlessly obscure. The reason of this is undoubtedly due in part to the double signification of many of the terms used by geologists to designate stratified rock-groups, or systems. The original name given by the early observers to a system or group of strata, was often descriptive of the kind of stone of which it was principally composed, or the most important mineral substance it contained. Thus, the Cretaceous system was so named, because in the district in which it was first studied a large part of it consisted of chalk (Lat., *creta*); the Oolitic system, in like manner, contained, in the typical district, many beds of oolitic limestone (see § 15); and the Carboniferous, many beds of coal. Other names had a geographical signification, such as Devonian—the formations to be seen in Devonshire, England; Silurian—those in the district of Wales, the ancient Siluria. As soon, however, as extended observation showed that all the aqueous rocks occurred in a certain order, and formed a series or succession

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QUESTIONS.—What is to be understood by this arrangement of geological time into four periods? Is there in any of these classifications any evidence of a diversity of plan on the part of the Creator? Explain how it is that many geological terms have acquired a double signification.

of beds regularly and invariably superimposed upon each other, these terms lost their original import and acquired a purely chronological meaning. Thus, for example, when we trace the Devonian or Silurian rocks beyond the borders of the district where they were first observed, it is clear that the strictly geographic term becomes no longer applicable. It is, moreover, somewhat of a contradiction to speak of Silurian or Devonian rocks as existing in the State of New York, or in India. But what is meant is, that the Silurian or Devonian rocks of America or Asia are a continuation of those of Wales or Devonshire; or, in other words, that they were deposited together with them, *at the same epoch*, in similar seas, and contain similar fossils.

In like manner, when we come to trace the Cretaceous, Oolite, or Carboniferous systems from one area to another, it often happens that the nature of the rock gradually changes. Each system consists of a vast number of separate beds of rock, every one of which varies almost indefinitely in extent. The beds of coal, which gave their name to the Carboniferous rocks, because of their economical importance, are very few compared with the whole bulk of the rocks in the Carboniferous system, and sometimes get thinner and fewer till they disappear altogether; while the other portion goes on and spreads, perhaps over large areas, in which we may have the apparent contradiction of Carboniferous rocks almost or entirely destitute of any carbonaceous matter. In like manner, the Oolitic system in many parts of the world contains no oolites, and the Cretaceous system no chalk. In South America the Cretaceous system consists of clay-slates, not differing in any essential character as a kind of rock from the slates found in the Silurian system; but the contained fossils are similar to those of the chalk formations of Europe. Therefore, in speaking of Cretaceous rocks, we mean merely rocks that were consolidated at an epoch which was especially characterized by the formation of the chalk of Europe, and so of other similar terms.

CHAPTER X.

PALÆONTOLOGY.—GENERAL CHARACTERISTICS OF FOSSILS.

186. **Palæontology.**—That department of geological science which treats of the forms and conditions of life which prevailed during the former epochs of the earth's history, is termed *Palæontology*.

QUESTIONS.—What do we mean when we say that Devonian or Silurian rocks occur in America or Asia? Do the Cretaceous or Carboniferous rocks necessarily abound in chalk or coal? What is that department of geology which treats of the former life of the globe termed? What is the derivation of the term? (See § 1.)

The only data which can afford us evidence on this subject are the fossils found in the rocks of the various geological periods or systems. (See § 22.)

187. Fossils, whether vegetable or animal, are *generally* converted into the same substance as the rock in which they are imbedded; that is, if occurring in limestone, they will be more or less calcareous; if in coal, carbonaceous; and if in sandstone, more or less arenaceous (sandy). Sometimes, however, the fossils are converted into mineral matter, altogether different from the containing rock.

In numerous instances the form and bulk of the organism is entire and perfect, and may even retain something of the color which it had when alive.

Thus, the shells found in some of the tertiary rocks of the southern States exhibit tints and markings of color almost as bright as those of the shells now living on the adjoining Atlantic coast. Insects occur, perfectly preserved, sealed up in amber—a fossil resin; and in Siberia, the entire carcass of a fossil rhinoceros, with the skin and flesh preserved, has been taken from a stratum of frozen sand.

In other instances, the substance of the animal or plant has been altogether removed, so that merely an *impression* of its external surface, or a *mold* of its form, is left in the rock that inclosed it.

After this mold has been formed, it may become so filled with mineral matter, infiltrated through the pores of the rock, as to present a perfect *cast* or model of the fossil that was originally imbedded.

In other instances, the fossil consists of merely the impression of a part of the body of an animal, as a foot-print, for example.*

Different forms of fossils are common in every group or system of the fossiliferous rocks, and by a little practice the eye of the student will readily

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QUESTIONS.—Where do we find evidence on this subject? What are fossils? (See § 22.) In what state are the remains of animals and plants generally preserved as fossils? To what extent are plants and animals sometimes preserved as fossils? When is a mold or *cast* of the organism only preserved?

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* The teacher (or the student for himself) will derive great advantage by procuring, and subjecting to examination, specimens of fossils—plants and animals—in their various conditions of preservation. Such specimens can readily be obtained with little trouble, or may be purchased at a slight expense. (See Appendix.)

detect the slightest trace of organized structure in any mass of mineral matter; and where the naked eye may fail, a common pocket magnifier will often enable an observer to detect the presence of an organism.

188. **Petrifaction**, generally speaking, consists in the infiltration of stony matter into the pores of vegetable or animal substances.

"In some specimens the organic body has entirely disappeared, and the stony matter has been so gradually substituted, particle for particle, that the petrifaction presents a perfect resemblance in its minutest parts to the original structure. It is as if a house were gradually rebuilt, brick by brick or stone by stone—a brick or a stone of a different kind having been substituted for each of the former ones, without either the shape or size of the house, or the form or arrangement of one of its rooms, passages, or closets, or even the number and shape of the bricks and stones, having been altered. All the hollow spaces are, however, generally filled up either by the earthy matters in which the fossil is inclosed, or by mineral substances which have percolated through their walls."

Lime (in the form of a carbonate) and silica, held in solution in water, are the most abundant petrifying substances.

The same result is also sometimes produced through the agency of metallic salts contained in water, especially by the sulphuret and oxyd of iron; and we find, not unfrequently imbedded in strata, bones, shells, and fishes, which have been almost entirely converted into iron-pyrites (crystals of sulphuret of iron), with a nearly perfect retention of form.

In other instances, the organism is converted into coal or bitumen. Hugh Miller, in describing the fossil fishes found in the Old Red-sandstone (Devonian), says, that their muscles, blood, etc., have been converted into a kind of pitch or bitumen, which in some places pervades the rock to such an extent as to cause it to be mistaken for coal; and this animal pitch, by its antiseptic properties, has preserved, in all their elasticity, the bones, fins, and scales enveloped in it, better than the oils and gums applied by the old Egyptians to their mummies.

Incrustations not Petrifactions.—Organic substances, *i. e.*, moss, twigs, leaves, etc., which have been exposed to the action of mineral waters, and have thereby become incrusted with calcareous or silicious matter (see § 64) are very often erroneously termed petrifactions; since in such cases the object is merely coated with the stony matter, and not fully permeated by it.

Questions.—What is petrifaction? To what extent is petrifaction sometimes carried? What may the process be compared to? What are the most abundant petrifying substances? What substances occasionally act as petrifiers? What are illustrations of this? What is the difference between incrustations and petrifactions?

Theory of Petrifaction.—Petrifaction is, undoubtedly, a chemical process, but the exact manner in which it takes place has never been satisfactorily explained, neither has it been successfully imitated.* Some authorities have supposed that petrifaction is effected suddenly by the combination of gaseous fluids with the constituent principles of the organic structure. In some instances it would appear certain, that the conversion of the animal or vegetable substance into silica or lime must have been almost instantaneous, for the most delicate parts—those which would undergo decomposition with the greatest rapidity—are often preserved; such, for example, as the capsule of the eye, the membranes of the stomach, the soft bodies of shell-fish, and, in plants, the most delicate tissues. In specimens of petrified wood, it may be often observed that the petrifaction did not commence until the wood had begun to decay, since the decayed part, and even the mould upon it, are preserved as perfectly as the solid wood. The apparently delicate vegetable fibres, sometimes seen in polished sections of agate or chalcedony, especially in the so-called "moss agates," are generally produced by oxyd of iron or manganese; but in some instances they have been proved to be really the remains of marine plants, which have become involved in the silica when it was in a fluid state.

M. Gœppert, a German geologist, placed leaves of fern in clay, dried them in the shade, and exposing the clay to a red-heat, obtained, in this way, striking resemblances to fossil plants. According to the degree of heat, the plant was found to be either brown, shining black, or entirely lost—the impression only remaining; but in the latter case the surrounding clay was stained black by the diffusion of the particles of carbon derived from the leaves, and resembled the shales and slates that are associated with coal.

189. Classification of the Animal and Vegetable Kingdom.—In order to rightly understand the facts which the study of fossils have brought to light concerning the past history of the earth, it is necessary to have some knowledge of existing animals and plants.

Vegetable life subsists upon inorganic food—matters that may be found in the earth, the water, or the air, independently of animal life; while animal life subsists entirely upon organic food, either of vegetable or animal

QUESTIONS.—Is it known how petrifaction is occasioned? What have been some of the suppositions on the subject? In what manner has the production of fossil plants been imitated? In order to fully understand the facts of palæontology, what is necessary?

* Some years since a Florentine physician claimed to have discovered a method of artificially petrifying animal substances, and at the same time perfectly preserving their color and internal structure. The specimens exhibited by him appeared to confirm his assertions, and there is now in one of the Italian museums a table, in which different portions of the human body, petrified, cut, and polished, are inserted as Mosaics. The secret, however, was never revealed by the discoverer, and died with him.

origin. It would, therefore, follow, that no plant-eating animal could continue to live unless vegetable life already existed in sufficient abundance to serve as its food; and no flesh-eating animal could exist until there was an abundance of plant-eating animals. The order of existence, therefore, of organic beings may be assumed to be—1st, *plants;* 2d, *plant-eating animals;* 3d, *animal-eating animals.*

THE VEGETABLE KINGDOM.

190. Vegetables have been arranged in two grand divisions:

1st, PHANEROGAMIA, OR FLOWERING PLANTS.
2d, CRYPTOGAMIA, OR FLOWERLESS PLANTS.

191. **Phanerogamia.**—The first division (Phanerogamia) embraces all the higher forms of vegetation; and all the plants included in it bear true flowers and produce seeds. It naturally subdivides into two classes—EXOGENS (*outside growers*), and ENDOGENS (*inside growers*).

192. The Exogens comprise all those plants which increase by additions of woody-fiber to the outside—a new layer being added each year just beneath the bark, to the previous growth. Hence, the age of an exogenous plant is indicated by the number of concentric rings exhibited by a cross section of its stem or trunk. The leaves of exogenous plants have also net-like veins. All our forest trees and shrubs belong to this class. A slice across an exogenous stem shows a separate cellular part, as bark, on the circumference; then a ring of wood; and in the center a pith, as is seen in Fig. 99, which represents a piece of flax stem magnified; and also in Fig. 100, which is a stem of maple of a year old, cut crosswise and lengthwise.

FIG. 99.

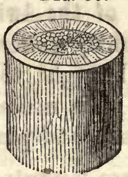
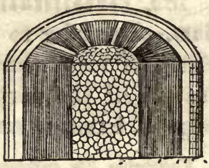


FIG. 100.



193. The Endogens embrace all flowering plants, whose stems are not composed of concentric layers, but whose woody substance is mixed with pith and distributed throughout every part of the stem in the form of threads or bundles. They have almost always parallel-veined leaves, which sheath

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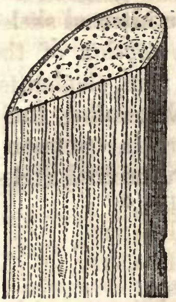
QUESTIONS.—What may be supposed to be the order of existence of organic beings? How have plants been classified? What are embraced in the first great division? What are the characteristics of the exogenous plants? What plants belong to the class Endogens?

the stem, and decay without falling off. Their bark also can never be peeled off clean from the wood. This class of plants comprises the lilies, palms, canes (sugar, and Indian corn), rushes, and grasses. Fig. 101 shows an endogenous stem of a corn stalk, cut both crosswise and lengthwise.

FIG. 101.



194. **The Cryptogamia**, or flowerless plants, produce no real flowers, and no true seeds; but only something of a simpler sort, answering to flowers, and giving rise to minute and very simple bodies, which serve the purpose of seeds, and are called *spores*. This division comprises all the lowest forms of vegetation, and is subdivided into three classes, ACROGENS, ANOPHYTES and THALLOPHYTES.

195. The Acrogens comprise those plants whose growth is wholly or mainly at the summit.

This class includes the *Fern* family (the brakes); the *Equicetaceæ*, or horse-tail and cat-tail family; and the *Club-mosses*.*

The Anophytes comprise the true mosses.

The Thallophytes comprise the *algæ*, or sea-weeds; the *Lichens* (which incrust stones and decaying trees); the *Confervæ* (green scum, like aquatic growths); and the *Fungi* (mushrooms, puff-balls, toads-tools, etc.).

Such are the fundamental groupings of existing plants, and so constant are the characters which distinguish these great natural groups, that an experienced botanist or palæontologist by inspecting simply the fragments of a leaf, or a portion of the structure of a stem, can at once decide on the nature of the plant to which it belonged.

THE ANIMAL KINGDOM.

196. Animals, according to Cuvier, may be arranged in four great divisions or sub-kingdoms—VERTEBRATA, MOLLUSCA, ARTICULATA, and RADIATA.

QUESTIONS.—What are some of the plants of this class? What plants are embraced in the second great division? Into what three classes are the Cryptogamia divided? What are the Acrogens? What the Anophytes? What the Thallophytes? Are the characters which mark the great divisions of plants constant? How is the animal kingdom divided?

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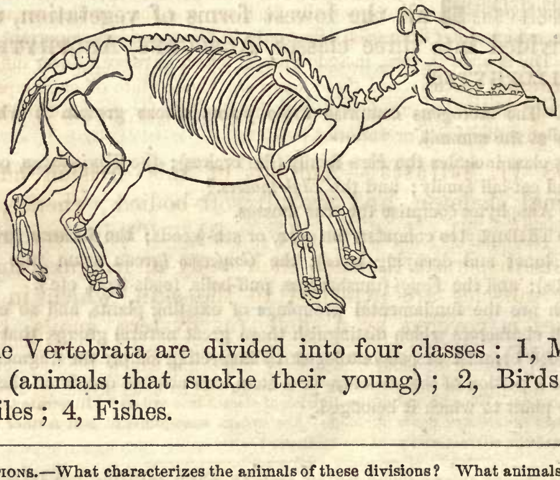
* The trailing evergreens, used for Christmas decorations, are familiar examples of the club-mosses.

All the animals in any one of these divisions are built upon the same plan, or, in other words, after the same type.

197. I. **Vertebrata.**—All the animals belonging to this division have a back-bone (vertebræ), and an internal skeleton. (See Fig. 102, which represents a section of the body and skeleton of a quadruped.) Thus, men, elephants, whales, birds, reptiles, and fishes, notwithstanding their manifold differences, have these characters in common; they are all back-boned; they all have an internal skeleton; they are all formed upon the same plan.*

FIG. 102.



The Vertebrata are divided into four classes: 1, Mammals (animals that suckle their young); 2, Birds; 3, Reptiles; 4, Fishes.

QUESTIONS.—What characterizes the animals of these divisions? What animals belong to the class vertebrata? Why are the vertebrata so called? Into what classes are the vertebrata divided?

* The fact that all the animals included in this division or sub-kingdom (Vertebrata) are formed upon one plan, will be made more clear if we institute a comparison between the skeletons of different vertebrate animals. "Thus, every bone in the body of a lizard has a corresponding bone in the body of a man, or of a mouse; and every bone preserves the same connection with other bones, no matter how unlike may be the various limbs in which we detect its presence. Thus, widely as the arm of a man differs from the fin of a whale, or the wing of a bird, or the wing of a bat, or the leg of a horse, the same number of bones and the same connections of the bones are found in each. A fin is one modified form of a typical limb; an arm is another; a wing another. That which is true of the limbs is also true of all the organs; and it is on this ground that we speak of the vertebrate type. From fish to man, one common plan of structure prevails."

All mammals resemble each other more than they resemble birds; all reptiles resemble each other more than they resemble fishes (notwithstanding a superficial resemblance between serpents and eels).

Each class is susceptible of still more minute division into orders. Thus, of the mammalia, those which live upon flesh are grouped in one order, *carnivora;* those which live upon plants constitute the order *herbivora;* and those which resemble whales, the order *cetacea.* In like manner, birds are *grallatores* (waders); *natatores* (swimmers), etc.; and reptiles are *batrachian* (frog-like); *saurian* (lizard-like); *ophidian* (serpent-like), etc.

Fishes are divided, as they exist in the present creation, into two orders—"*osseous*" and "*cartilaginous*"—according as they are furnished with a skeleton of bone, or of cartilage (gristle).*

In each order there are generally families; and the families separate into genera, which differ from each other only in fewer and less important characters. The genera, in turn, include groups, which have still fewer differences, and are called species; and these again are divided into other groups, which have only minute and unimportant differences of color, size, and the like, and are called sub-species or varieties.†

198. II. **Mollusca.**—Animals of this division have no internal skeleton, and are all soft-bodied; (hence, their name from the Latin *mollis*, soft). Their nervous system is dispersed through their body in irregular masses; their muscles are attached to the skin, which in many species is covered by a shell (as oysters, snails, cuttle-fish, etc.). This division embraces three classes.

QUESTIONS.—What is said of the division of classes into orders? Illustrate this. Into what two orders are fishes divided? Are orders susceptible of still farther division? What are the characteristics of the mollusca?

---

* The osseous order includes "fishes proper," whose skeletons, like those of mammalia, birds, and reptiles, are composed chiefly of calcareous earth pervading an organic base. The remains of such fishes are, therefore, extremely durable. In the cartilaginous order (sturgeons, sharks, etc.), on the contrary, the skeleton contains scarcely any mineral matter, but is a frame-work of indurated animal matter, elastic, semi-transparent, yielding easily to the knife, and, like all mere animal substances, inevitably subject to decay. The huge cartilaginous skeleton of a shark will be lost in a mass of putrefaction in a few weeks; while the bones of a minute osseous fish may remain entire for a great length of time.—*Hugh Miller.*

† "Thus, suppose a dwarf terrier dog is presented to us, with a request that we should indicate its various titles in the scheme of classification; we begin by calling it a vertebrate; we proceed to assign its class as the mammalian; as it feeds upon flesh, its order is obviously that of the carnivora; its family is that of the wolf, jackal, fox, etc., named Canidæ; its genus is, of course, that of Canis (dog); its species, terrier; its variety dwarf terrier."—*Lewes.*

1. **Acephala** (headless), or those which have *no* distinct heads, and are inclosed in bivalve shells, as the oyster and clam.

2. **Gasteropoda** (belly-footed), or those which creep upon a flat disc or foot, as the snails.

3. **Cephalopoda** (head-footed), or those which have arms or tentacles arranged about their mouth, as the cuttle-fish, the nautilus, etc.

As the different classes of mollusca lived in situations favorable to the preservation of their shells, we find great numbers of them fossil, and they are more frequently used to determine the identity or relations of strata than any other variety of fossils.

FIG. 103.

FIG. 104.

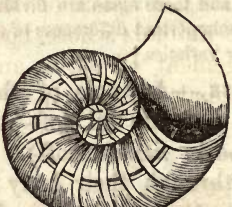
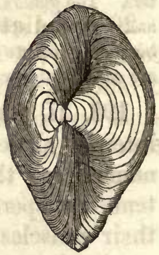


FIG. 105.



Shells are either *univalve* (Figs. 103 and 104); *bivalve* (Fig. 105), or *multivalve*, according to the number of pieces which make up the shell. Some univalve shells are divided by partitions into numerous chambers, which are connected by a tube called a siphuncle (see Fig. 104), and are hence termed chambered shells.

That branch of science which classifies and describes shells is called *conchology.*

199. **Articulata.**—Animals of this sub-kingdom have, as the name implies, bodies which are composed of segments *articulated* or *jointed* together, as lobsters, crabs, insects, worms, etc.

QUESTIONS.—Into how many classes are they divided? Enumerate them. What is said of the abundance of fossil mollusca? How are shells of mollusca designated? What are chambered shells? What is that branch of science which treats of shells called? What are the characteristics of the articulata?

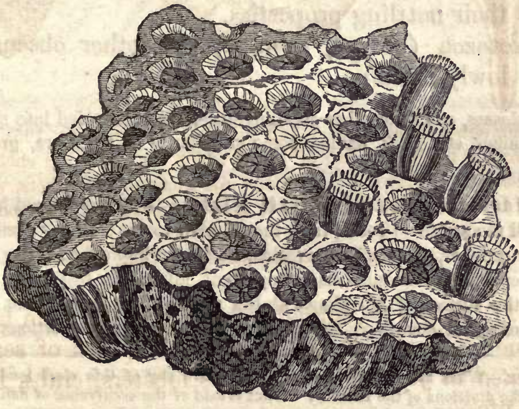
The limbs of articulata are also *jointed*, and they have mostly a hard covering, which forms a sort of external skeleton. Sometimes the segments of their body are numerous, as in the centiped, lobster, etc.; sometimes several segments are fused together, as in the crab; and sometimes, as in worms, they are indicated by slight markings, or depressions of the skin, which give the appearance of little rings; and hence the worms have been named *annelida* or *annulata*. In these last-named cases, the segmental nature of the type is detected in the fact that the worms grow segment by segment; and also in the fact that in most of them each segment has its own nerves, heart, and stomach.

The articulata have been divided (Agassiz) into three classes:

1. Insects, including spiders.
2. Worms.
3. Crustacea—lobsters, crabs, and other similar animals.

200. **Radiata.**—This division of the animal kingdom comprises all those animals whose bodies have a radiated or star-like arrangement of parts, and whose organs of sense and motion are also circularly disposed around a center or axis.

FIG. 106.



Many of the radiata are fixed as the coral polyp (see Fig. 106, which represents a species of coral, termed, from its star-like figure, *astræa*); while

QUESTIONS.—What is said of the construction of the varieties of this division? How many classes are comprised in this sub-kingdom? Enumerate them. What are radiata?

others move and float about, as the star-fishes (see Fig. 107, which represents a fossil species), and the sea-urchins.

"All the animals of this division are aquatic, and not a single terrestrial representative has as yet been discovered. Only one species, moreover, is found in fresh-water."

FIG. 107.

The radiata are arranged in three classes:

1. Echinoderms (sea-urchins, star-fish, etc.).
2. Acalephs (jelly-fish, medusæ, etc.), so called from their nettling properties.
3. Protozoa (polyps, sponges, and other obscure and lowly forms).

These classes, as in the other sub-kingdoms, are subdivided into numerous orders, families, etc., each having some peculiarity of structure, growth, or habit.*

201. **Classification of Fossil Fishes.**—Fish are found in a fossil state in all the stratified rocks, from the Silurian to the Tertiary system; and from their number, state of preservation, and remarkable forms, the geologist has been enabled to deduce many important inferences respecting the condition of the surface of our planet at the period of their existence. As the scales or external coverings are often the best preserved portions of fossil

QUESTIONS.—What are examples of radiata? Are any of this class land animals? What are the divisions of the radiata? What is said of the occurrence of fish in a fossil state?

* There is considerable diversity of opinion among naturalists in regard to the classification of animals; the divisions recognized by some authorities being much more minute than those adopted by others. The system of classification above given is substantially that instituted by Agassiz.

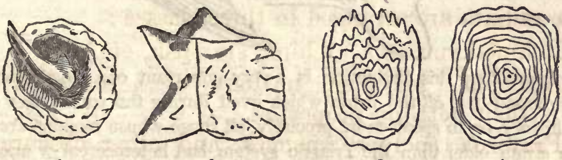
fishes, it occurred to Prof. Agassiz to arrange them into orders according to the structure of these parts; and, on an examination of the subject, he discovered, that there is always a relation between the form of the scales of fishes and their organization; and that this relation, moreover, is so intimate and constant, that if different species of fish, having similar scales, be compared, they will be found to correspond very closely in their nature and structure.*

As the result of these investigations, the class of fossil fishes has been divided, by Agassiz, into four great orders, according to the structure of their scales, viz.: 1. Placoids; 2. Ganoids; 3. Ctenoids; 4. Cycloids.†

The characteristics of these orders are as follows:

1. Placoids (Gr., πλαξ—a plate) are so called because they have their skin irregularly covered with plates of enamel, furnished with spines, like the shagreen on the skin of a shark. Fig. 108, No. 1, represents a scale from a shark, highly magnified. This order comprises all the cartilaginous fishes, with the exception of the sturgeon.

FIG. 108.



1 2 3 4

2. Ganoids (Gr., γανος—splendor) are so called from the shining or enamelled surface of their scales. These scales are generally angular (see Fig. 108, No. 2), and are composed of bony or horny matter, coated externally with bright enamel. Nearly all the species referable to this order are extinct; the sturgeon, and the gar-pike of the American lakes, are living examples.

QUESTIONS.—What curious discovery has been made by Agassiz in relation to the scales of fishes? How have fossil fishes been classified by Agassiz? What are the characteristics of the Placoids? Of the Ganoids?

* As illustrative of intimate relation between the scales of fishes and their general organization, it is related of Agassiz, that on one occasion, at a meeting of geologists, he restored the form of a then unknown fossil fish, from the mere inspection of a few isolated scales found imbedded in rock; and when, after the lapse of a considerable period, a complete specimen of the fish in question was discovered, the predicated description was found to be correct in almost every particular.

† This classification has, until quite recently, been made to embrace all existing as well as all fossil forms of fishes; but within a very recent period a more minute classification has been proposed by Prof. Agassiz; for an explanation of which, the student is referred to his "Essay on Classification," page 187 (1857).

3. The Ctenoids (Gr., κτεις—a comb) have horny scales, without enamel, and serrated on the posterior edge, like the teeth of a comb. (See Fig. 108, No. 3.) The perch may be taken as a living example of this order.

4. The Cyloids (Gr., κυκλος—a circle) have smooth scales, also without enamel, which are entire or rounded at their margins. (See Fig. 108, No. 4.) The herring, trout, and salmon are living examples of this order, which embraces the majority of existing species.

202. Fish have also two distinctive forms of tail; and may be arranged in two classes, *heterocercals* and *homocercals*, according as their tails are equally, or unequally lobed.

Thus, in *heterocercal* species, the tail is chiefly on one side, like that of the shark and sturgeon (Fig. 109), the backbone being prolonged into the upper lobe; in *homocercal* species, the lobes of the tail are equal and similar, as in the trout, perch, etc. (See Fig. 110.)

FIG. 109.

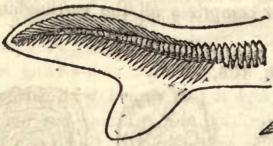
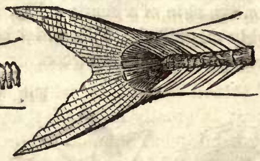


FIG. 110.



In palæontology this distinction is a very important one; inasmuch as it has been found that *all* the fishes which lived during the earlier ages of the earth's history, or, to speak more precisely, all those whose remains are found fossil in strata older than the Triassic system had heterocercal or unequally lobed tails; while the great majority of those found fossil in more recent strata, and existing at the present day, have symmetrical or homocercal tails.

203. Besides those distinctions which depend on the structure and form of animals and plants, there are others of importance constantly recognized by the geologist and naturalist, which depend on climate, habitat, and mode of life.

Adaptation of Organization to Condition.—Each race of plants and animals is perfectly adapted by the Creator for the functions it has to perform in the economy of nature; and is furnished with peculiar organs, according to the kind of food upon which it lives and the habits it displays.

QUESTION.—What are the characteristics of the Ctenoids? Of the Cycloids? What is said of the forms of tails of fishes? When are fishes said to have hetrocercal tails? When homocercal? Besides form and structure, what other distinctions between animals and plants are recognized? What is said of the adaptation of animals and plants to their condition?

Thus, one set of organs indicates swiftness; another strength; a third, prehensile or seizing powers; a fourth, climbing, leaping, or swimming powers; and, a fifth, that the animal lives on roots, on herbage, or on the flesh of others.

Furthermore, all the parts of animals or plants sustain a definite relation to each other. This law was first stated by the great naturalist, Cuvier, in the following terms: "*Every organized being forms a whole—a complete system—all the parts of which mutually correspond. None of these parts can change without the others also changing; and, consequently, each taken separately, indicates and gives all the others.*"

For example, the sharp-pointed tooth of a lion requires a strong jaw; a skull fitted for the attachment of powerful muscles, both for moving the jaw and raising the head; a broad, well-developed shoulder-blade; an arrangement of the bones of the fore-leg which admits of the leg, with the paw, being rotated, and turned upward, by which its application as a seizing and tearing instrument is greatly increased; and a paw armed with strong claws. On the other hand, teeth adapted for bruising and grinding, but not for tearing food (as the teeth of the ox, and like animals which feed upon herbage), are connected with a peculiarly shaped skull, blade-bone, fore-leg, and hoofed foot. So that, if we possess but a single tooth, or any other characteristic part of an animal, it is quite possible to pronounce with certainty upon the general form and habits of the animal to which it belonged.

204. **Distribution of Plants and Animals.**—The distribution of animals and plants is twofold—vertical and lateral.

205. Both on land and in water, animals and plants vary as we depart upward or downward from the level of the sea.

We are all familiar with this variation on the land—every one being aware that vegetation undergoes a greater change in ascending vertically upward from the level of the sea, up the sides of a lofty mountain to the regions of perpetual snow, than it does in traveling laterally toward the pole till we reach the point where perpetual snow comes down to the sea-level; and with

Questions.—Do all the parts of an animal structure sustain a relation to each other? What law was expressed by Cuvier? Show by examples how all the parts of an animal are related. What is said of the distribution of plants and animals? How do plants and animals vary as we depart from the level of the sea?

a change in vegetable life, an equal change in animal life is a necessary consequent effect in all regions of the globe.

The climates of the sea vary more rapidly in depth than those of the land do in height; since the light and heat of the sun—the great vivifying principles of nature—lose all influence at the depth of a very few hundred feet into the ocean, even under the tropics, where, in the air, life ranges through a vertical zone of 16,000 feet. The level of the sea, and a few feet above and below it, is the populous film of the earth; departing from that film in either direction, living beings rapidly become less numerous, and shortly disappear.

206. With the lateral distribution of terrestrial life, all persons are more or less familiar. We know, for instance, that plants, such as the vine, the apple, the banana, the cocoa-nut, rice, wheat, oranges, etc., do not grow indiscriminately wherever they may be planted; they are confined to certain portions of the globe, where the climate is suitable for them. We know, also, that the polar-bear and the lion, the reindeer and the camel, the musk ox and the giraffe, could not exchange habitats, and could not, in a wild state, inhabit the same countries.

The inhabitants of the ocean are, in like manner, similarly confined within certain definite boundaries. Each coast and sea has animals which are peculiar to it. Of the 200 species of molluscs living on the coast of New England, fifty are never found north of Cape Cod, and over eighty are never found south of the Cape.

207. From these natural provinces, or districts, animals and plants, with few exceptions, never wander; and when forced to remove, do not long endure the differences of climate, food, and other changes to which they are subjected.*

QUESTIONS.—What are illustrations of this fact? What is said of the climate of the ocean? What zone of the earth is most densely populated? What is said of the lateral distribution of terrestrial life? What of marine life? What are some examples of the geographical limitation of species? Do animals and plants naturally wander from their peculiar province?

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* The information which has been collected upon this subject is exceedingly curious and interesting. Thus, the mammals found upon the great island continent of Australia are all "*pouched*" animals, like the opossum, kangaroo, etc., known as an order by the name of Marsupials. It is also stated, that with a single exception, there is no species of mammal found in Eastern Australia that lives in the western portion of this great island. Even with regard to birds, creatures whose powers of easy and rapid locomotion seem to place the whole world at their disposal, we find the same restriction in their geographical boundaries, which they rarely or never overstep. The "lammergeyer" (a species of vulture) is found only amid the Alps; and the condor dwells only amid the Andes of South America. "We might sail round the world in the latitude of the Cape of Good Hope, or thereabouts, ever surrounded by flights of albatrosses and cape-pigeons, which seem sometimes to people the air; but if the navigator turns his vessel toward the north he soon reaches a latitude where all these creatures disappear. This takes place not gradually, but at once. The ship may be surrounded by the usual flocks at night, and the next morning not one of them will be seen, or ever after, till the navigator returns to the line where they left, and then he finds fresh flocks, as if awaiting his arrival."

A few species of animals and plants, however, seem capable of adapting themselves to all climates, and range over the whole earth. Among animals, this is especially true of man, and the dog.

208. From these statements, the student will readily understand how the geologist is able, by comparison and analogy, to decide as to the character of the fossil animals and plants which he discovers; and how he can tell, with precision, whether they lived in the waters or on dry land; in fresh or salt water; in a cold or hot climate; whether the animals fed upon plants or lived upon other animals; whether they are furnished with organs indicating an amphibious existence; and, in general, he can determine their nature and modes of existence. Moreover, as certain classes of plants and animals indicate certain conditions of the earth's surface, the geologist is enabled, by the study of their remains, to decipher the past history of our globe, and so arrive at results which, at first thought, seem hopelessly beyond the grasp of the human intellect.

209. **Number of Species in the Animal and Vegetable Kingdom.**—The number of species of animals now living upon the surface of the earth, is estimated at about 250,000.

What is a Species?—A species may be defined to be a kind of animal or plant, so distinct from all others that the continuation of the "kind," or species, is possible *only* between a pair belonging to that species. In other words, the individuals of a species may be regarded as the descendants of a single pair.*

210. The number of species of vertebrate animals is estimated at about 20,000, divided as follows: 1,500 to 2,000 species of mammalia; 5,000 to 6,000 species of birds; 1,500 to 2,000 of reptiles; and from 8,000 to 10,000 of fish.

211. The number of species of molluscs already in collections (museums) probably exceeds 20,000; there are collections of *marine* shells, bivalve and univalve, which have over 19,000 species; and collections of land and fresh-water shells, which count as many as 2,000.

QUESTIONS.—What use are all these facts in natural history to the geologist? What is the estimated number of species of animals and plants now living? What is a species? What is said of the number of living vertebrate animals? Of molluscs?

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* Offspring cannot be produced by a pair of individuals of different species, except when those individuals are very nearly allied to each other, and even then the progeny (termed a hybrid), it is said, can never be perpetuated; thus clearly showing "that nature repudiates such amalgamations, and keeps her species jealously distinct and invariable." For example: the horse and the ass belong to the same genus, and although allied to each other in many respects, yet belong to different species. The progeny of the two species is a mule—a hybrid—partaking of the qualities of both the horse and the ass. But mules do not propagate their kind.

212. The number of species of articulata (worms, insects, crustacea, etc.) has been estimated at 200,000. There are collections of coleopterous (beetles) insects alone which number 25,000 species.

213. The number of species included in the division of radiata (the star-fishes, medusæ, polypi, etc.) has been estimated as at least 10,000.

The number of species of plants now living upon the earth has been supposed to be 150,000.

214. **Number of Fossil Species of Animals and Plants.**—No reliable estimate can be made of the number of species of animals and plants existing in a fossil state; but it is safe to say, that the sum total exceeds many times the number of all the species now living.

Thus, a deposit of limestone in the neighborhood of Paris, France, which is merely one division of one of the four groups of strata included in the tertiary system, contains not less than 1,200 species of fossil shells; whereas the species *now living* in the Mediterranean Sea do not amount to half that number.

Similar relations may be also pointed out in America;—

Thus, there have been described from the so-called "Trenton limestone" of New York (one of the stratified deposits that belong to the Silurian system of that State), 170 species of fossil shells—a number almost equal to that of all the species now found living on the coast of Massachusetts.*

215. The number of individuals included in the several fossil species, moreover, was not less than is comprised by existing species.

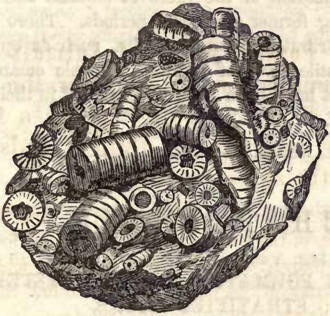
In thousands of localities in the State of New York, and throughout the Valley of the Mississippi, the great bulk of the rocks may be seen to be almost entirely formed of animal remains, particularly corals and shells. Fig. 111 represents a limestone found near Lockport, N. Y., which is almost wholly composed of the remains of radiated animals, known as *crinoids* or

QUESTIONS.—What is said of articulata? Of radiata? What is said of the number of fossil species of animals and plants? What facts prove the great abundance of extinct fossil species? What is said of the number of individuals included in the fossil species?

* The stratified rocks of Great Britain have probably been studied more minutely than those of any other equal area of the earth's surface, and as the result of these investigations it has been found—that the number of species of extinct mammalia, contained in the fossiliferous rocks of the British islands, is more numerous by one half than all the species now existing there; of molluscs, the fossil species are nine times as numerous as the living species; the fossil fish five times; the reptiles ten times; and the radiata at least fourteen times. In instituting such a comparison, moreover, it should be remembered that while the existing population is almost entirely known from recent elaborate researches, we are as yet only imperfectly acquainted with the extinct fossil races.

stone-lilies;—Fig. 29 exhibits the structure of the animal entire. Now, if we consider the slowness with which corals and shells are formed, it will give us some idea of the vast series of ages that must have elapsed in order to allow of the formation of these rocks, and their regular deposition under water, to so great a thickness.

FIG. 111.



Fossils occur abundantly, not only in rocks at great depths below the present surface of the earth, but also in the rocks that constitute the highest mountains of the globe. In Switzerland, a large part of some of the mountains of the Jura is composed of fossil corals. In the Alps and Pyrenees, the rocks, to a height of 6,000 to 8,000 feet above the level of the sea, abound in marine fossils—shells, corals, etc.; and in the Andes and Himalayas, they are found at a height of from 16,000 to 20,000 feet.

216. Furthermore, of the hundreds and thousands of species of animals and plants found fossil in the stratified rocks which were formed before the epoch of the Tertiary system, not one has ever been proved to be identical with any animal or plant now living.

"The dust we tread upon was once alive,"

is thus proved, by the researches of the geologist, to be no poetical exaggeration.

217. **Causes of the Extinction of Species.**—Every extensive area of the earth's surface that has yet been examined bears unmistakable evidence of having been subjected to successive great geological changes:

QUESTIONS.—Illustrate this. What is said of the distribution of fossils? What facts illustrate this? Are the species found fossil the same as those now living? What fact is true of every area of the earth's surface thus far examined geologically?

i. e., of having been alternately sea-bottom and dry land. With each of these changes, it is obvious that all existing forms of life comprised within the area affected, must have perished; leaving their various remains imbedded in stratified deposits, to testify of their existence.

In such alternations of the earth's surface, and in the changes of climate that must necessarily have accompanied them, the geologist finds sufficient explanation of the extinction of the races of animals and plants that inhabited our earth during former geological periods. There may have been other causes which contributed to such results, such as epidemic diseases, the introduction of hostile races of animals, volcanic emanations, and the like; but these last must have been more or less local in their influence.*

CHAPTER XI.

HISTORY OF THE FORMATION OF THE SYSTEMS OF THE STRATIFIED ROCKS.

218. A CAREFUL consideration of the statements presented in the preceding chapters will have prepared the student now to commence intelligently the study of the history of the formation of the several great systems of stratified rocks; or, in other words, *the history of our earth and of the life upon its surface during the successive epochs of time when the several great divisions of the stratified rocks were in the process of formation.*

This history may be presented in two ways; namely, by investigating, or *tracing* it backwards, from the present to the past; or by *narrating* it as nearly as possible in the order in which it occurred. The latter method is preferred as the most intelligible, and as being also in conformity with the manner in which history in general is studied.

"As, however, to present this history in full, even so far as already known, would require a library rather than a book, what will be here given must be taken as a mere abstract—a chronological table—rather than a history, by means of which the student will be able to refer to its proper place every detailed account (which he may either read or observe for himself) of its different portions."

219. **What are the Oldest Rocks?**—Regarding the formation of the rocks which compose the crust of the earth

QUESTIONS.—What causes are assigned by geologists for the extinction of species? What subject in order comes next under consideration? In what order may the history of the stratified rocks be presented? What question of interest presents itself in this connection?

* In 1842, a large proportion of the molluscs on the shores of Northern Australia were suddenly exterminated by some apparently rapidly contagious disease.

as the result of successive processes, the question naturally suggests itself: What were the first formed rocks? or, What are the oldest rocks of which we possess any positive information?

If we accept the supposition that the entire mass of our earth was at one period of its history in a molten fluid condition (see § 133), then the first formed rocks were the product of the cooling and consolidation of the planet's exterior.

Concerning the nature of this primeval crust, we have probably no positive information. The general opinion of geologists at the present day is, that no part of it is now in existence, and that none of the rocks now open to observation can date back their formation to this pre-historic or pre-geologic epoch of the earth's duration.

"Whatever may have been the nature of this primeval crust of the globe," says Prof. Ramsay, "it must have been more or less completely destroyed and remodeled by the erosive action of water, and the remelting action of heat, long before the commencement of even the earliest of our geological periods."

The variety or type of rock open to our observation, generally believed to be the oldest, is granite.

The principal evidence, which induces this belief, is derived from the fact, that in all parts of the globe, wherever the base of the aqueous or stratified rocks has been upheaved to the surface and thus exposed to view, *that base has been found to rest upon granite.** "And we have every reason, moreover, to believe," says Mr. Jukes, "that if we could penetrate the crust of the earth, at any part of its surface, vertically, to a sufficient depth, we should in all cases, eventually encounter granite, and find it to be the final, underlying material."† The structure of granite, and its occurrence as an eruptive rock—*i. e.*, in veins, dikes, etc.—is also evidence that it has been formed entirely or in part through the agency of heat.

QUESTIONS.—According to the theory of the former molten fluidity of the earth, what were the first formed rocks? What information have we concerning the primæval crust of the earth? Is any part of it probably in existence? What type or variety of rocks is generally believed to be the oldest? What facts lead to this inference?

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* By the "base of the aqueous rocks" is meant the lowest aqueous or sedimentary rocks known in the particular locality, whatever may be their age, and not necessarily the absolutely oldest aqueous rocks.

† By some geologists the universality of this proposition has been questioned. (See paper on "The Theory of the Transformation of the Sedimentary Deposits into Crystalline Rocks," by T. S. Hunt. Jour. Geological Society, London. 1859. pp. 488–496; also Annual Scientific Discovery, 1860. pp. 304–311.) The affirmative is, however, maintained by Mr. Jukes, at present one of the directors of the Geological Survey of Great Britain, and by other leading authorities.

These facts, therefore, led geologists at one time almost universally to suppose that granite, *wherever* found at the surface of the earth, was *always* the oldest of the rocks, and in reality represented a part of the original primeval crust of the globe. But these views are at present, however, wholly abandoned, since it is now known *that intrusive masses of granite penetrate and overlie rocks which have been formed during almost every period of the earth's history.*

FIG. 112.

When granite also forms, as it frequently does, the nucleus or axis of mountain masses, the stratified rocks which rest upon the flanks of the mountain dip from the granite in every direction, as is represented in Fig. 112; thus conclusively proving, that the period of the elevation of the granite, and the formation of the mountain, was subsequent to the deposition of the most recent of the strata that have been disrupted by it.*

While granite, therefore, is undoubtedly, in many cases, the oldest and lowest in position of all known rocks, it is not invariably so; and its relative age in all cases can only be inferred from the age of the stratified rocks with which it is associated.

Furthermore, if we adopt the generally received hypothesis, that all the materials of the earth, at a certain depth in its interior, are in a state of fusion, it is probable that granite is even now in the process of formation, wherever molten mineral matter of the proper chemical composition is consolidating under the requisite physical conditions.

220. If we are inclined to speculate on the character of the material which would result from the cooling of the crust of a molten globe, we may reason-

QUESTIONS.—To what conclusions were the earlier geologists led respecting granite? Is granite always the oldest rock? What facts prove that it is not? What is said concerning its relative age?

* In Fig. 112, G represents a mass of granite forming the axis of a range, and 1, 2, 3, stratified rocks, dipping from it in each direction, the eldest or lowest, No. 1, being next to the granite, and highest, or newest, No. 3, the farthest from it. Now, as the strata 1, 2, 3 must have been deposited in a nearly horizontal position, it is clear that the granite' G, was not intruded until after the deposition of N. 3 on the top of No. 1 and 2.

ably doubt the possibility of the formation of so dense a rock as granite on a surface where the expansive power of heat must have acted with the greatest intensity. (See § 45.) Mr. T. S. Hunt, of the Canadian Geological Survey, inclines to the opinion that the primitive rock must have rather resembled a variety of trap (dolerite); while other geologists have supposed that it had the character of porous trachyte, pumice, or obsidian (volcanic glass). (See § 30.)*

But however this may be, the granitic rocks may be assumed to constitute the basis upon which the stratified rocks rest. We know, also, that the agencies which produced granite in the first instance continued to operate during the formation of all the systems of the stratified rocks as high up in the series as (and including) the Tertiary system.

221. **Relation of the Unstratified or Igneous Rocks to the Different Systems of Stratified Rocks.**—The general relation and position, which the three classes of igneous rocks (granitic, trappean, and volcanic) sustain to the different systems of the stratified rocks, may be briefly indicated, as follows:

Intrusive masses of granite are found most abundantly associated with the stratified rocks of the Azoic period, and with the older systems and groups of the Palæozoic period. The great epoch of the eruptive intensity of granite would seem to have terminated with the deposition of the rocks of the Silurian and Devonian systems, and its occurrence in the succeeding systems must be considered as exceptional. In Great Britain granite veins are found traversing rocks of the Carboniferous and Triassic systems; and in the Alps and in Southern Italy granitic outbursts and upheavals are associated with strata of the Cretaceous and Tertiary systems. No eruption of granite is believed to have taken place within the Recent or Historic period.

Eruptions of trappean rocks took place most abundantly in the Mesozoic period, especially in the Triassic and Oolitic systems; and also in the Tertiary system of the Cainozoic period; while to all igneous rocks which have erupted during the recent or present epoch we apply the name Volcanic. It is, however, almost impossible, as has been before remarked, to recognize any very clear distinction between some volcanic lavas and certain of the more ancient traps. (See § 38.)

QUESTIONS.—What was probably the nature of the first formed rocks? What may we assume as the bases of the stratified rocks? With which of the systems of stratified rocks is granite found most abundantly associated? How high up in the series does it occur? In what sysems do the trap rocks occur most abundantly? In what the volcanic?

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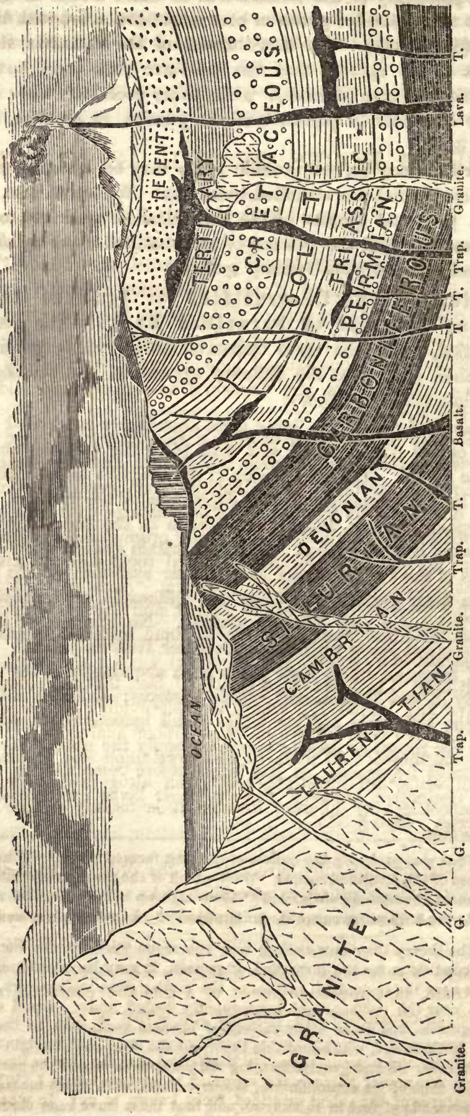
* If we accept the theory that slow cooling and enormous pressure are the necessary and concomitant conditions for the formation of granite, it may be questioned if it was ever formed at or near the immediate surface of the earth; since molten rock, that once reached or came near the surface, and consequently cooled under normal conditions, would not form granite, but some other variety of igneous rock, such as trap or lava. Some geologists, furthermore, who adopt this theory of the deep-seated origin of granite, maintain, that wherever we find granite forming the present surface of the earth we may be sure, that at the time of its consolidation, it was covered with great masses of other rocks (possibly thousands of feet in thickness), and that these have been since swept off and removed by the action of water.

FIG. AA.



IDEAL SECTION OF THE EARTH'S CRUST; ILLUSTRATING THE MANNER IN WHICH THE DIFFERENT VARIETIES OF IGNEOUS ROCKS, ERUPTED FROM BELOW, PENETRATE AND DISTRIBUTE THEMSELVES THROUGH THE VARIOUS SYSTEMS OF THE STRATIFIED ROCKS.

Fig. AA, which represents an ideal section of the earth's crust, illustrates the manner in which the three classes of igneous rocks, erupted from below, penetrate and distribute themselves throughout the various systems of the stratified rocks.

STRATIFIED ROCKS OF THE AZOIC PERIOD.

222. **The First Formed Stratified Rocks.**—The adoption of the theory, that our earth was once in a state of entire molten fluidity, involves the existence of a subsequent period, when its primeval crust had sufficiently cooled down to allow of the condensation of watery vapor and of the existence of a sea upon its surface. Whenever this happened, the eroding and destructive action of water must have immediately manifested itself, while the particles of the consolidated igneous crust, worn off by the action of waves, tides, and currents, and deposited as sediments, would naturally produce stratified formations.

The internal heat of the earth at that period, however, must have continued to act with great intensity near the surface, and the strata first deposited, consequently, were, in all probability, soon greatly metamorphosed, *i. e.*, remelted down to form igneous rocks, or converted into hard, crystalline, semi-igneous rocks, that retained, in part, their original lines of stratification.

Whether any of these first formed stratified rocks are in existence, and open to our inspection, it is impossible to affirm. Some geologists incline to the opinion that they were entirely re-melted, and are now represented by the older or fundamental granites, which, in some instances, appear to have an obscurely stratified structure.

Be this as it may, it is, however, a matter of fact, that the oldest rocks of which we have any knowledge, which exhibit evidence of a sedimentary origin, appear to have been formed under conditions analogous to those above supposed. Thus, they are all more or less crystalline and indurated; their lines of stratification are indistinct, and often altogether obliterated; and their whole aspect is very different from what is usually ascribed to rocks deposited in water.

223. Geologists are not fully agreed as to the order of succession of the several varieties of these primitive stratified rocks, or as to the manner in which they may be best arranged, or divided into groups or systems—the whole formation being of immense thickness, and imperfectly explored. As regards the order of succession of rock varieties, it may, however, be received as a general truth, that gneiss, or rocks of a gneissic character, occupy the lowest position, or constitute the base of the series of stratified rocks. In

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Questions.—Under what circumstances is it inferred that the first sedimentary rocks were deposited? Are any of these rocks supposed to be in existence? What are their characteristic features of the oldest stratified rocks known to us? In what manner do the varieties of these older rocks succeed each other?

many instances, this gneiss can hardly be distinguished from granite, and sometimes undoubtedly passes into it.

Succeeding the gneiss, and resting upon it, we have groups, or deposits, of schistose rocks—*i. e.*, *hornblende-schist*, *talcose-schist*, *mica-schist* or *slate*—occurring in about the order named; with formations of crystalline or metamorphic limestones, serpentine, and steatite; while above them, we find quartz rocks and argillaceous or clay-slates.*

Of this series, the gneiss at the bottom, the mica-schists occupying an intermediate position, and the clay-slates at or near the top, are the rocks which appear to be the most extensively developed.

224. The period of time represented by the formation of these most ancient sedimentary rocks, and by the unstratified or igneous rocks below them, is generally termed the Azoic (wanting in vestiges of animated nature), inasmuch as we have little or no evidence that any form of animal or vegetable life existed at that epoch upon the surface of the earth—all the rocks above described being characteristically barren of fossils.†

225. **Scenery of the Azoic Period.**—A picture of the scenery of this period of the earth's history has thus been imagined by Hugh Miller. During the earlier part of the Azoic period, "we may imagine," he says, "a dark atmosphere of steam and vapor, which for age after age, conceals the face of the sun, and through which the light of moon or stars never penetrates; oceans of thermal water, heated in a thousand centers to the boiling point; low, half-molten islands, dim through the fog, and scarce more fixed than the waves themselves that heave and tremble under the impulsions of the igneous agencies; roaring geysers, that ever and anon throw up their intermittent jets of boiling fluid, vapor, and thick steam, from these tremulous lands; and in the dim outskirts of the scene, the red gleam of fire shot forth from yawning cracks and deep chasms. Such would be the probable state of things among the times of the earlier gneiss and mica-schist deposits—times

QUESTIONS.—What rocks of these series are most extensively developed? What name is given to the period represented by the formation of the oldest rocks?

* The physical characters and mineral composition of these rocks has been particularly described in Chapter VI., entitled "Varieties and Lithological Characters of the Metamorphic Rocks."

† The student should here be cautioned against receiving the impression that gneiss, mica-schist, talcose-schist, hornblende-schist, quartz rock, clay-slate, etc., wherever found, belong exclusively and invariably to the Azoic period. On the contrary, rocks possessing the same characters are *occasionally* found interstratified with fossiliferous rocks of other and much more recent geological periods. All the rocks above enumerated are supposed to be sedimentary rocks, changed and altered; and although they are the especially characteristic rocks of the Azoic period, yet similar formations have been produced wherever metamorphic influences have operated under similar circumstances.

buried deep in that chaotic night which must have continued to exist for, mayhap, many ages after that beginning of things in which God created the heavens and the earth."

"At length, however, as the earth's surface gradually cooled down, and the enveloping waters sunk to a lower temperature—let us suppose, during the latter times of the mica-schist and the earlier times of the clay-slate—the steam atmosphere would become less dense and thick, and finally the rays of the sun would struggle through it, at first doubtfully and diffused, forming a faint twilight, but gradually strengthening as the latter ages of the slate formation passed away, until, at the close of the great primary period, day and night—the one still dim and gray, the other wrapped in a pall of thickest darkness—would succeed each other as now, as the earth revolved on its axis."

226. Fanciful and imaginative as this picture of Hugh Miller undoubtedly is, it must nevertheless be confessed that the structure of the rocks of the Azoic period does not militate against its correctness. Thus, no one of the rocks to which a sedimentary origin is ascribed, exhibits more remarkable examples of flexures and contortions than the older or fundamental gneiss; and the most unskilled observer, on inspecting them, is irresistibly led to the conclusion that the layers of the rock were once in a semi-fluid state, and in that condition were subjected to great disturbance. (See § 80, also Figs. 23, 25, and 27.) "In the overlying layers of mica, talcose, and hornblende-schists, there is also much contortion and disturbance; whereas the clay-slate, which lies at the top of the series, gives evidence, in its mere mechanical texture and the regularity of its strata, that a gradual refrigeration had been taking place, and that the close of the Azoic period was comparatively cool and quiet."—MILLER.

227. **Classification of the Rocks of the Azoic Period.**—We have already said that geologists are not fully agreed as to the manner, in which the stratified rocks of the Azoic period—the gneissic rocks, the schists, clay-slates, etc.—should be arranged into systems or groups. The nomenclature also used to designate them by different authorities is not uniform.

By many geologists, especially by those of Great Britain, the stratified rocks *here* referred to the Azoic period have been divided into two groups or systems;—the upper, termed the "*Cambrian*," from Cambria, an ancient name of North Wales, where the system is extensively developed; while the lower and older rocks, from their changed and altered appearance, have been known as, or called the "*Metamorphic System*."

In North America, the stratified rocks of the Azoic period have also been divided, by the geologists engaged in conducting the survey of Canada, into two groups or systems—the lower system being designated as the "*Laurentian*," and the upper as the "*Huronian*"—names derived from localities

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QUESTION.—In what manner have the rocks of the Azoic period been classified by different geologists?

where the rocks in question have been especially studied; namely, the Laurentine mountains of Canada, and a district in the vicinity of Lake Huron.

The eminent American geologists, Profs. W. B. and H. D. Rogers, who have conducted the geological surveys of Virginia and Pennsylvania, also divide the stratified rocks, formed prior to the Palæozoic period (*i. e.*, in the Azoic period), into two groups, but designate the upper group as the *Azoic*, or Semi-metamorphic; and the lower, the *Hypozoic*, Gneissic, or True Metamorphic. The term Hypozoic (*ύπο, under;* and *ζωη, life*) thus used, implies that this particular class of rocks is not only barren of fossils, but that it lies below all the formations that can be considered as fossiliferous.

Taconic System.—Another distinguished American geologist (Prof. E. Emmons, of New York) considers that a portion of the older sedimentary rocks of America exhibit such marked and agreeing characteristics as to warrant their arrangement into a distinct and independent system, called the *Taconic;* but this opinion has not, however, been generally accepted.

The enumeration of these divisions of the rocks of the Azoic period may possibly seem to the student as needlessly minute; but as they are constantly referred to in modern geological treatises and discussions, some acquaintance with them is certainly desirable. At the same time, the classifications of the English and Canadian geologists, as well as those instituted by the Messrs. Rogers, may be considered as in general equivalent, and corresponding to one another. With these explanations, and adopting the nomenclature of the Canadian geologists, a description of the several systems will now be given in order.

LAURENTIAN SYSTEM.

SYNONYMS.—*Metamorphic System—True Metamorphic—Gneissic—Hypozoic.*

228. The Laurentian mountains, from whence this system derives its name, traverse Canada, north of the St. Lawrence, throughout its entire length, running parallel with the river, and at some points in close proximity to it. The rocks composing this system—principally gneissic rocks, crystalline schists, and crystalline limestones—are the most ancient sedimentary rocks known upon the continent of America; and are supposed to correspond in age with similar ancient rocks found in Finland, Scandinavia, and the north of Scotland.

QUESTIONS.—What relation exists between its differently designated divisions? From whence does the Laurentian system derive its name? What is said of the age of the Laurentian rocks?

Distribution.—In North America the Laurentian system extends throughout Canada—including the Laurentian mountains—and through a portion of the Hudson's Bay Territory, as far north as the Arctic Ocean. It also occupies the eastern shores of the continent, north of the Gulf of St. Lawrence. In New York, the rocks which compose the Adirondac Mountains are believed to belong to this system; as do also the rocks which constitute the Ozark Mountains of Missouri, the Washita Hills, south of the Arkansas, and the Whitchita Mountains of Texas. Another area of these rocks occurs in northern Michigan.

The rocks of the Laurentian system are unfossiliferous, or azoic; and, in fact, are generally regarded as having been deposited prior to the introduction of life upon the surface of our planet. They are everywhere traversed by veins, or immense intrusive masses of granite, syenite, porphyry, or other eruptive rocks—a circumstance which, of itself, would indicate a most disturbed condition of the crust of the earth during the period of their formation.

229. **Economic Minerals of the Laurentian System.**—The rocks of the Laurentian system afford many valuable minerals. Of these the most important are ores of iron, which occur for the most part associated with hard, crystalline limestones. In Missouri, the deposits of iron ore, which exist in these rocks, are among the largest on the globe, and include the celebrated Iron Mountain, which is 300 feet high, two miles in circumference, and entirely composed of magnetic oxyd of iron. Immense deposits of iron ore also occur in Laurentian rocks in the Adirondac district of New York, and at various localities in Canada. Ores of lead, copper, and baryta, graphite (black-lead), large plates of mica, and many valuable gems, are also afforded by the rocks of this system in Canada and the United States.

The aggregate thickness of the rocks of the Laurentian system in North America has been estimated at 20,000 feet.*

QUESTIONS.—What of their distribution? Do they afford any traces of fossils? What important minerals are found in this system? What is the estimated thickness of the Laurentian rocks of North America?

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* Notwithstanding what has been already said on this subject, (see §§ 89, 96), it may be a matter of wonder to the student "how strata, many of which are evidently of a superficial nature, can be collected in piles, amounting to several miles in thickness, and how such an extent of vertical accumulations can ever be known and measured. Coal beds, for example, are understood to have been deposited, each originally at the surface, yet they are repeated at intervals of variable distances apart, amid parallel layers of sandstones, shales, and limestones, any one of which may occupy from a few feet to one hundred feet or more in its recurrence. Sandstones, like those of the Connecticut River Valley, containing impressions of tracks of animals, are also found in beds of several hundred feet in thickness. Now, the only explanation for such phenomena must be, that the surface was gradually subsiding during the periods of these accumulations. The times of slow subsidence were represented by the gathering of the fine sediments, or the growth of the coal plants, and those of rapid subsidence by the in-flow of the coarse sand and pebbles which now form the beds of sandstone and conglomerates. Thus, the strata continued to be piled upon each other so long as the same system of operations lasted; and thus it was that the Laurentian rocks reached their aggregate thickness of 20,000

CAMBRIAN, OR HURONIAN SYSTEM.

230. In many localities in North America there is found, resting unconformably upon the rocks of the Laurentian system, a series of schists, slates, hard sandstones, and conglomerates (with some limestones); which, from the fact of their attaining a vertical thickness of about 12,000 feet on the north shore of Lake Huron, have been termed the "Huronian System."

The constituents of these rocks, moreover, have evidently been mainly derived from the waste of the older rocks, on the eroded surfaces of which they rest. They also exhibit less striking evidence of metamorphic action than the rocks of the Laurentian system beneath them.

In Europe, a series of rocks, supposed to correspond with the Huronian in geological age and position, is known as the Cambrian, and is very extensively developed in Great Britain, Bohemia, and Scandinavia—the beds in some localities attaining an apparent thickness of 26,000 feet. In Great Britain especially, the Cambrian system includes vast beds of clay-slate, which in Wales furnish the celebrated quarries of Welsh roofing slate.

FIG. 113.

231. Notwithstanding the great thickness of the rocks of this system, they afford scarcely any traces of the existence of life during the period of their deposition.

In America and Bohemia none whatever have been recognized; but in Great Britain, in the clay-slates, which occur high up in the system, and appear to have been deposited as fine sediments in quiet waters, a few fossils have been discovered. The principal of these are the impressions of a small, plant-like zoophyte, Fig. 113 (called *Oldhalmia*, from Prof. Oldham, its discoverer), a few fucoids (sea-weeds), and certain tracks and burrows, which are believed to have been made by marine worms.

QUESTIONS.—What rocks are super-imposed upon the Laurentian System in this country? What is said of their composition and character? What corresponding series of rocks exists in Europe? What organic remains have been afforded by this system?

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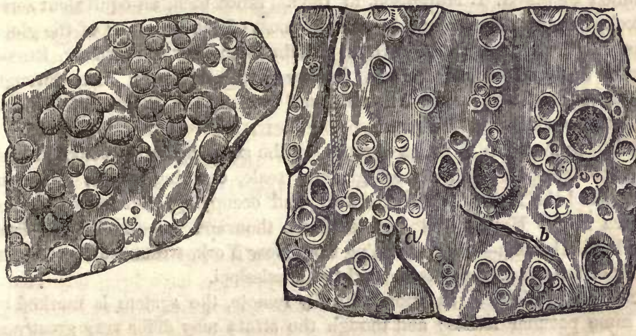
feet. When uplifted to form the hills and valleys of a continent, their horizontal arrangement is disturbed, the strata are turned upward so as to present disrupted ends and edges (see Figs. 31 and 42), and by their sloping and undulating position, each in its turn is brought to the surface, and all may be measured, some in one locality and some in another. Subsequently to this uplifting, denuding forces have been in action, removing immense portions, chiefly of the most elevated masses, and building up, in more recent seas, newer formations from the wreck of the old, in the same manner as these had been produced. Thus, after a systematic plan, and with evident provision for the future wants of man, the various useful materials of all the strata are brought within his reach."

The interest which attaches to these few fossils is very great; for as the most assiduous researches have thus far failed to detect any other traces of organization in this system, we may fairly regard these relics as the representatives of the first forms of life that appeared upon our planet. Had other animals or plants really existed during this ancient epoch, it seems probable that some indications of them would have been discovered; especially as the hardened sediments, in which the above-mentioned fossils occur, are composed of such fine particles, and are so little altered, that they have retained the most minute impressions which have been made upon their surfaces.

Thus, in some instances, where the strata appear to have constituted the shore of an ancient ocean, they are covered with distinct wave or ripple-markings; in others, "they have evidently been subjected to a drying process, so that, as happens with the bottom of a muddy pool, laid dry during a summer drought, they are cracked into irregular polygonal divisions; and as, when again submerged, a sudden deposition filled up the cracks, we can still trace the marks of desiccation as distinctly in the stone as if they had been made by the sun of a previous week."

FIG. 114.



The same surfaces are also frequently covered with small pits or impressions, which are believed to have been made by the striking of drops of rain; and these, sometimes, by their uniform obliquity of imprint, clearly register the direction in which the wind was blowing at the time of their production. Fig. 114 represents the upper and under surface of a thin layer of shale marked with rain impressions and worm-tracks.

Such impressions or markings, are not, however, confined to the rocks of the Cambrian system; but, on the contrary, they may be observed upon almost all strata, composed of finely divided particles, which have been deposited under similar circumstances.

QUESTIONS.—What peculiar interest attaches to them? What interesting markings characterize some of the rocks of this system?

PALÆOZOIC PERIOD.

232. The stratified rocks of the Palæozoic period are arranged into four systems, viz.: the Silurian, the Devonian, the Carboniferous, and the Permian.

SILURIAN SYSTEM.

233. This system of stratified rocks derives its name from the circumstance that it was first studied and investigated, by Sir R. I. Murchison, in the district of country between England and Wales, anciently inhabited by a tribe of the Britons, called "Silures."

Distribution.—The existence of this system, in Great Britain, was determined by Sir R. I. Murchison, in 1839. Since then, an equivalent series of rocks has been ascertained to exist in most of the countries of the globe. Thus, they have been found in Great Britain, Scandinavia, Germany, Russia, France, Spain, Portugal, Turkey, various parts of Eastern Asia, throughout Siberia, in South Africa, Australia, and even at the Falkland Islands, in the extreme southern hemisphere.

In North America, a series of rocks, of the same age and geological position, is developed upon a most gigantic scale, covering a vast extent of Canada and the Hudson's Bay Territory, and occupying, in detached masses, an area in the United States more than a thousand miles in length—from Canada to Alabama—and extending from New York, westward through the Valley of the Ohio, to points beyond the Mississippi.

In all these districts, so geographically remote, the system is marked by the same peculiar fossils; and though the strata may differ very greatly as regards their mineralogical composition—shales in one locality being replaced by slates in another, sandstones by quartz rocks, and soft calcareous rocks by hard limestones—yet the moment the geologist detects certain characteristic organic remains he can have no doubt as to their position in the geological series.

234. **Characteristics of the Silurian System.**—Under whatever circumstances the strata, which constitute the systems (Laurentian and Huronian) which precede the Silurian, were deposited, they exhibit, for the most part, as has been already stated, a peculiar metamorphic, or altered appearance; while the lines, which indicate the alternations of deposits of

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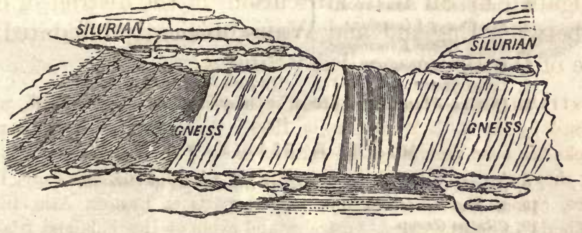
Questions.—What systems are included in the Palæozoic period? What is the derivation of the name Silurian? What is said of the distribution of the rocks of this system? Are the strata of the Silurian system all alike, mineralogically, in different parts of the world?

sedimentary matter, are indistinct, and often entirely obliterated. We can not, for example, in inspecting a formation of gneiss, mica-schist, hornblende-schist, quartz-rock, or other crystalline sedimentary deposit, say exactly what was the original condition of its constituent particles; neither can we arrive at any satisfactory conclusions as to the nature of the seas in which they were deposited.

In the Silurian system, however, the aspect of a series of strata is widely different. Every alternation of deposit is distinct and evident. Beds of shale, sandstones, pebbly conglomerates, argillaceous slates and limestones, follow one another in frequent succession, and retain their original structure so perfectly, that it is not difficult to judge of the circumstances of their formation.

FIG. 115.



The Silurian system in Europe rests upon the rocks of the Cambrian system. In this country it rests unconformably upon the Huronian rocks, in the vicinity of Lake Huron,* and elsewhere (in localities where the Huronian rocks are wanting), upon the Laurentian system.

Fig. 115 represents the manner in which the rocks of the Silurian system rest unconformably upon gneiss, at the Falls of Montmorency, Canada East.

235. **Divisions of the Silurian System.**—The rocks of the Silurian system may be divided into three great groups, viz.: the UPPER, MIDDLE, and LOWER SILU-

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QUESTIONS.—How are they recognized? As compared with the formations of the preceding systems, what are the characteristics of Silurian rocks? Upon what basis does this system rest?

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* The attention of the student is here particularly directed to the great significance of the circumstance of an unconformability (see § 94) between the stratified rocks of two systems or series. In this particular instance, it implies unmistakably that the rocks of the Huronian system were deposited, consolidated, and elevated into angular positions, before the epoch of the formation of the Silurian system commenced—a series of events which must have required a vast period of time (the Huronian system being 12,000 feet thick), as well as the action of powerful disturbing forces.

RIAN; which are distinguishable from each other by a want of conformity, or by the peculiarities of their contained fossils.

236. **Subdivisions.**—These three groups in America have been further subdivided into (at least) fourteen minor groups, or series of Strata, which have been named mainly from localities in the State of New York, where the rocks in question are typically developed. They are as follows, commencing with the lowest:

LOWER SILURIAN.

1. *Potsdam Sandstone.*
2. *Chazy Limestone.*
3. *Calciferous Sand-rock.* }
4. *Bird's-eye Limestone.* } Trenton Group.
5. *Black River Limestone.* }
6. *Trenton Limestone.* }
7. *Utica Slates* } Hudson River Group, or the
8. *Hudson River Slates.* } Blue, or Galena Limestone of the West.

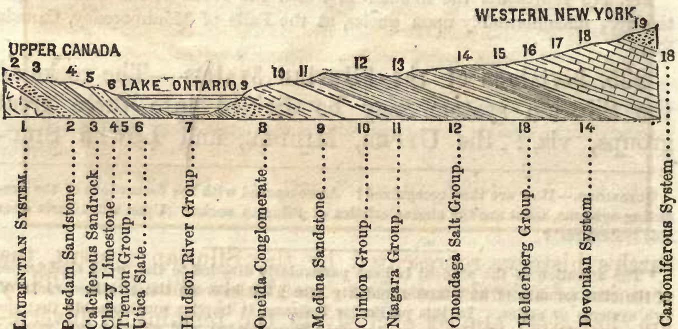
MIDDLE SILURIAN.

9. *Oneida Conglomerate, or Sillery Sandstones of Canada.*
10. *Medina Sandstone.*
10. *Clinton Group.*

UPPER SILURIAN.

11. *Niagara Shale.* } Niagara Group.
12. *Niagara Limestone.* }
13. *Onondaga Salt Group.*
14. *Lower Helderberg Group.*

FIG. 116.



QUESTIONS.—How are the rocks of the Silurian system divided? What is said of the subdivisions of the principal groups?

Fig. 116 shows the position of the rocks of the Silurian system as they occur in Upper Canada and Western New York. On the left, it will be observed that they rest upon the Laurentian system, and are succeeded upon the right by the rocks of the Devonian system. In this section the Huronian rocks are wanting, as well as are several of the other subdivisions; it being very rare to find all the divisions of a system in one locality.

In Europe, similar, or equivalent divisions of the rocks of the Silurian system, have been recognized, but the names by which they are designated are different from those adopted in America.

237. Life of the Period Represented by the Silurian System.—In the rocks deposited during the period of the

FIG. 117.

earth's history, represented by the Silurian system, the remains of animals are often exceedingly abundant. They are, however, almost exclusively the remains of inverte-

QUESTION.—Have equivalent divisions been recognized in Europe?

brate* marine animals—*i. e.*, corals, echinoderms, molluscs, annelids (worms), and crustacea—a circumstance which induces the belief that only a small portion of what is now dry land was then above the surface of the water.

Fig. 117 is a map, showing (approximately) how much of the present continent of Europe was elevated above the water during the Silurian epoch; the unshaded portions representing land.

238. **Lower Silurian.**—In the lower Silurian rocks, no trace of a fish, or of any of the higher manifestations of vertebrate existence, has ever been detected; and although we find in them delicately rippled-marked shales and sandstones, which point to the existence of quiet wave-washed shores; and pebbly conglomerates, which bespeak gravel beaches, yet not a trace of a land plant, any more than of a fish, can be discovered. "It seems to have been," says Hugh Miller, "for many ages together, a creation of molluscs, corals, and crustacea."

239. The first *positive* evidence of the existence of life in the *American* series of stratified rocks occurs in the Potsdam sandstone, which constitutes the base of the Lower Silurian group. In this formation, the greatest thickness of which is about 300 feet, a very few species of fossils have been found. Of these, the most characteristic is a small bivalve shell, called *Lingula* (see Fig. 118), which also occurs in that division of the Lower Silurian rocks of Europe which is supposed to be equivalent in age and position to the Potsdam sandstone of America.

FIG. 118.

There are also found in these oldest Silurian strata, the remains of an exceedingly curious family of Articulate (jointed) animals, which, from the circumstance that their shell or body is divided into three lobes or parts, are called *Trilobites*. (Gr., τρεις, three; and λοβος, a lobe.) See Figs. 119, 120, and 121. When first discovered, these fossils were supposed to be the remains of insects, but they are now known to belong to the class *crustacea*. The animals were of oval figure, protected by a shell which covered the anterior part of the body, while the abdomen, or posterior

QUESTIONS.—What is said of the life of the period represented by the Silurian system? What is the character of the fossils of the Lower Silurian? In what member of the Silurian system in America do we find the first traces of life? What are some of the principal fossils found in the Potsdam sandstone?

* Invertebrate—without vertebræ or a back-bone—used in contradistinction to vertebrate.

portion, had numerous segments, that folded over each other like the plates in a lobster's tail. By this arrangement they were enabled to roll themselves up into a ball, so as to present their hard plates in all directions in self-de-

FIG. 119.

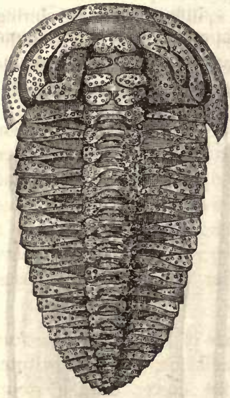
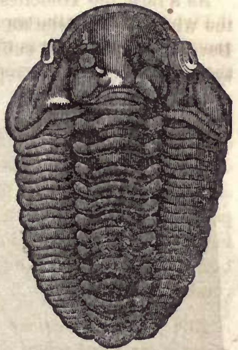


FIG. 120.

FIG. 121.



fense; as do the wood-louse and the armadillo of the present day. In this condition they are often found. Their eyes, which in many specimens are very perfectly preserved, were very curious, and consisted of a great number of angular facettes, or lenses, similar to the eye of the dragon fly (in which there are 25,000). "In order to extend the field of vision, since the eye was immovable, it was elevated above the body; while its form was that of the frustrum of a cone, incomplete on the side opposite the corresponding part of the other eye; thus enabling the animal to see in all directions horizontally." This structure of the eye indicates that the phenomena of light, and the conditions of vision, were essentially the same during the Silurian epoch as at the present time; and also, that the trilobites lived in water sufficiently transparent to transmit light. It may be also remarked, in this connection, that Hugh Miller has suggested, that the existence of a clear, transparent atmosphere was the most conspicuous feature which distinguished the scenery of the Silurian epoch from that of the close of the Azoic period.

FIG. 122.

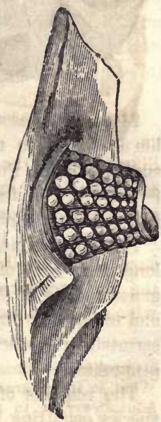


Fig. 122 represents one of the eyes of the Trilobite (magnified), as it is found fossil.

The Trilobites were among the most abundant of the early forms of life that peopled our globe—no less than 400 distinct species having been recog-

QUESTIONS.—Describe the Trilobites. What is said of their abundance?

nized in the Palæozoic systems. They varied in length from one to twenty inches; and seemed to have swarmed in the Silurian waters, just as crabs and shrimps swarm in the seas of our day—whole rocks, in some instances, being formed almost exclusively of their remains. In the Trenton limestone, at Trenton Falls, N. Y., they may be seen in the greatest profusion.

As a race, the Trilobites continued to flourish (*i. e.*, different species) during the whole of the Silurian epoch, but gradually died out in the epoch of the Devonian system, and entirely disappeared from creation in the Carboniferous system, since when, no representative of these curious animals has existed.

FIG. 123.

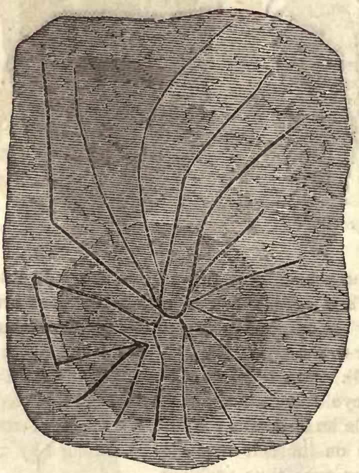


FIG. 124.

240. As we ascend in the series of the Lower Silurian rocks, the forms of life are found to multiply rapidly; and in the groups of strata immediately succeeding the Potsdam sandstone, which, as already stated, contains but a few species, the fossil remains of more than one hundred distinct species of invertebrate animals have been discovered.

Some of the most common forms in these ancient sedimentary deposits belong to a family of plant-like zoophites (radiata), known to geologists by the general name of *Graptolites*. They seem to have lived upon a muddy bottom and to have thrown out, in all directions, from a center, (see Fig. 123) small serrated or feather-like arms. Fig. 124 represents portions of the arms of graptolites.

The remains of corals are also found in the greatest abundance; more species occurring in the different divisions of the Silurian rocks in the State

QUESTIONS.—In what locality in the United States are their remains particularly noticeable? What is observed as we ascend in the series of Lower Silurian rocks? What are some of the most common forms of life in these deposits?

of New York alone, than are now living upon the coast of Florida. Fig. 95 represents various forms of Silurian corals; Fig. 125, a species (Columnaria alveolata) from the Black River limestone of N. Y.; and Fig. 126, a beautiful species of chain coral, which is peculiar to the Upper Silurian.

FIG. 125.

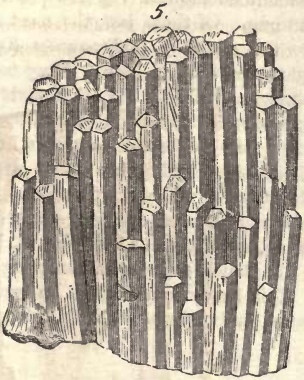
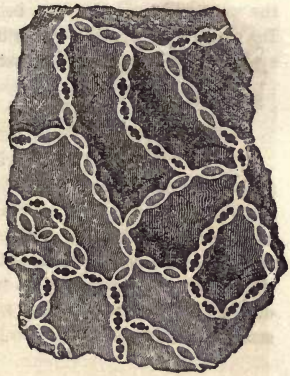


FIG. 126.



Besides graptolites and corals, the radiata are represented in both the Upper and Lower Silurian rocks by a curious and beautifully organized family of Echinoderms, which, from the resemblance of some species to a lily, have been called *Crinoids* (Gr., κρινος, lily; and ειδος, form), and also Encrinites. As these animals were developed more fully at a later geological epoch, we defer further notice of them until we come to the Carboniferous system, but for the present a good idea of their form may be obtained by examining Figs. 29 and 111.

FIG. 127.

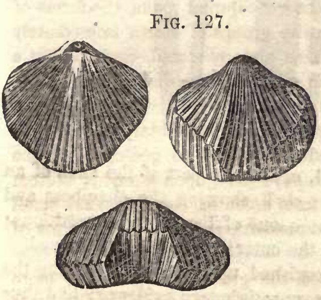
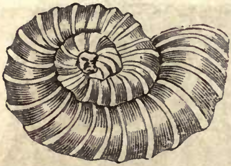


FIG. 128.

FIG. 129.

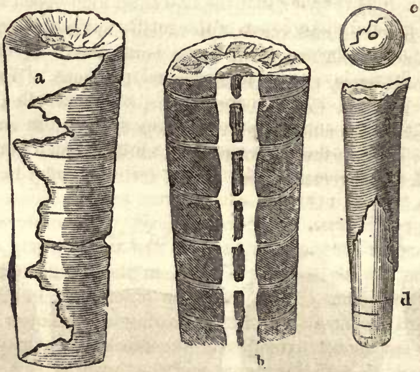
Great numbers of molluscs (shells) are also found in all the groups of the Silurian system, and comprise representatives of each of the three classes, viz.: Acephala, Gasteropoda, and Cephalopoda (see § 198); some species being closely allied to existing forms, while others have no likeness to any living animal. Figs. 127, 128, and 129 represent some of the most common of these fossils—Fig. 127 representing a bivalve shell, termed *Terebratula;* Fig. 128, a similar shell, known by the name of *Orthis;* and Fig. 129, a gasteropod, univalve shell, called *Bellerophon.*

FIG. 130.



Many of the Silurian shells are chambered (Cephalopoda); some being curved or coiled as in the species termed Lituites (Fig. 130); while others are straight. Of these last, the most interesting are the so-called *Orthoceratites* (Gr., *ορθος*, straight; and *κερας*, a horn). They consisted of a straight shell (see Fig. 131), divided into numerous chambers by septa or partitions, which, in turn, were perforated, so that a tube (siphuncle) might communicate with all of them. They are found of all sizes, from a few inches to ten feet in length, and a foot in diameter. In some specimens upward of seventy chambers have been counted. In many of the Silurian rocks (Black River Limestone, and Trenton Limestone, N. Y.) they occur so abundantly as to overlie and touch each other, rendering it difficult to procure a perfect specimen. This family continued to be represented by different species, in the Devonian, Carboniferous, and Triassic sys-

FIG. 131.



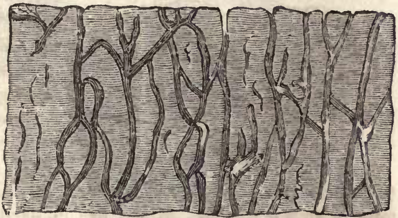
tems, when it became extinct. Fig. 131, *a*, shows a part of the shell of an *Orthoceratite;* *b*, a vertical section of the shell, showing the chambers and the central tube running through them; *c*, one of the septa or partitions; and *d*, the termination of the shell, with the outer shell partially removed.

With regard to the vegetation that flourished upon the earth during the tho Lower Silurian epoch, we have no very satisfactory evidence; and thus far, the only remains discovered, appear to have belonged to low orders of marine plants or sea-weeds. These occur, however, very abundantly in

QUESTIONS.—What was the character of the vegetation of the Lower Silurian?

some localities, and in the Lower Silurian rocks of England they even compose impure beds of anthracite coal several feet in thickness. In all cases the individual plants, apparently from the original looseness of their texture, are but indifferently preserved, so that it is difficult to trace any very close resemblance between them and the plants which darken the half-tide rocks of our coasts at the present time. Fig. 132 represents the appearance of one of the oldest of these fossil sea-weeds from the Lower Silurian of America—the *Phytopsis tubulosum* of the Bird's-eye Limestone of New York.

FIG. 132.



241. **Middle and Upper Silurian.**—The question may here naturally suggest itself to the learner; What reasons have geologists for dividing the rocks of the Silurian system into two or more groups—upper and lower—or upper, middle, and lower? and is there any evidence of such divisions really existing in nature? To this we reply, that in many localities the strata of the Upper and Middle Silurian rests unconformably upon those of the Lower Silurian; thus showing that the Lower Silurian epoch terminated with a more or less general disturbance of the earth's surface, which not only produced a break in the deposition of the series of strata, but elevated the previously formed rocks into angular, unnatural positions. We also find, that between these two epochs, the character of the life peopling the surface of the earth manifestly changed; not only many species, but even some entire genera dying out, and other new ones being introduced. Thus, according to Prof. Owen, of forty-three genera of Trilobites, found in the Lower Silurian rocks, thirteen genera, including many species, seem to have entirely perished before the Upper Silurian epoch commenced, while other species, forming new genera, appear for the first time, in the upper group, to occupy their places. In short, while the fossils found in the Middle and Upper Silurian rocks belong to the same classes, the same orders, and in many instances to the same genera of animals, as those occurring in the Lower Silurian, only a comparatively few *species* extend over the break (if we may so express it), and are common to both the upper and the lower groups. "These long-surviving species," says a recent authority, "appear to have lived in great depths of water, and to have ranged over large areas of the earth's surface," a circumstance which may account for their exemption from the destruction that involved their cotemporaries.

The species of marine animals (invertebrates) are more numerous in the rocks of the Middle and Upper Silurian groups than in those of the Lower Silurian; but some great beds of limestone, in both groups, however, can

QUESTIONS.—What reasons have induced geologists to divide the Silurian system into groups? Are the same fossils found in all the divisions of the Silurian rocks?

scarcely be regarded as deposits at all, inasmuch as every calcareous particle of which they are composed, was at one time associated with animal life, as the segments of Trilobites, the frame-work of corals, or the shells of molluscs; all of which lived and died upon the spot that the rocks now occupy.

FIG. 133.

Of the corals of the Upper Silurian, Fig. 133 represents one of the most striking species—*Cyathophyllum*—the remains of which are often mistaken for fossil horns. Fig. 134 represents a curious cup-shaped coral, the *Cyathaxonia.*

Concerning these ancient corals, a very curious fact has been noticed, which the student can verify for himself; namely, they are all stars of four rays, or of multiples of four; while the modern corals are stars of six rays, or of multiples of six. At a certain definite epoch, however (about the close of the Palæozoic period), nature, in forming this class of creatures, discarded the number four, and adopted the number six; retaining at the same time the idea of the star pattern, which characterizes equally the modern and the ancient types.—HUGH MILLER.

FIG. 134.

Figs. 135, 136, 137, and 138 represent a few of the characteristic shells of the Upper Silurian: Fig. 135, *Leptæna depressa;* Fig. 136, *Delthyris Niagarensis;* Fig. 137, *Spirifer radiatus;* and Fig. 138, a fossil shell termed *Pentamerus*, some species of which occur in such abundance that they form no inconsiderable part of the mass of some limestones belonging to the Helderberg series of the (American) Upper Silurian group—viz., the Pentamerus limestones.

New forms of crustacea make their appearance at the close of the system, some of which resembled our present lobsters in external shape, but appear to have had a length of from six to eight feet—a circumstance which strikingly illustrates a characteristic of the animals and plants of these ancient times—namely, that they united great size with such a low grade of organization, as at the present day we find to be always restricted to forms comparatively minute.

QUESTIONS.—What is said of the abundance of animal remains in the Upper Silurian rocks? What new forms of fossils occur in the uppermost rocks of the Silurian system?

FIG. 135.

FIG. 136.

FIG. 137.

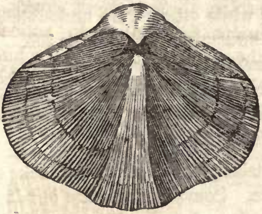
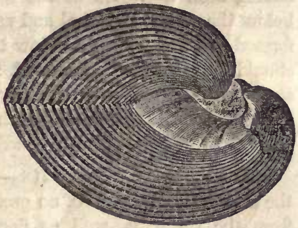


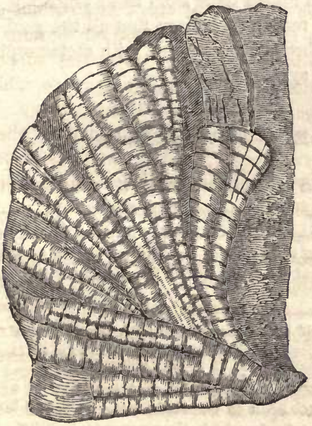
FIG. 138.



Of marine plants, or sea-weeds, ten species have been described, from the Upper Silurian rocks of America, one of the most interesting of which (*Arthrophycus Harlani*) is represented by Fig. 139.

Fig. 107 represents a fossil Silurian star-fish; and Fig. 140, certain tracks or markings found on strata of the Upper Silurian, which are supposed to have been made by marine worms (Annelids), crawling over a mud surface.

FIG. 139.



242. **Fishes.**—In the uppermost rocks of the Silurian system, immediately under the base of the next overlying system (the Devonian), the remains of the earliest known fishes occur—associated with what also appears for the first time, namely, the fragmentary remains of a terrestrial vegetation—thus indicating that the first vertebrate animals, and the first land plants, were

FIG. 140.

called into existence upon our planet at nearly the same epoch. As these remains, however, seem to be in anticipation, as it were, of a greater development of the same forms of life during the Devonian era, a description of them is deferred for the present.*

243. **The Thickness of the Silurian System.**—The estimated aggregate thickness of the stratified rocks of the Silurian system varies for different countries. In North America it has been estimated at about 11,500 feet; but in Great Britain the estimates are much greater, viz., 20,000 feet at least for the lower Silurian group, and 7,600 for the middle and upper groups; or an aggregate of nearly five miles of strata. Many of these strata must, moreover, have been of exceedingly slow deposition; some evidently having been deposited at the bottom of profound seas, far from land, and below the zones of animal and vegetable life; while others were undoubtedly formed more rapidly in shallow tropical seas, swarming with marine life. It should be also borne in mind, that, throughout all this great thickness of strata, no remains, or trace of any reptile, bird, or mammal, have ever been discovered; a circumstance which may be considered as conclusive, that there were none of these animals in existence at this epoch.

244. **Mineral Deposits.**—In an industrial point of view, the rocks of the Silurian system are of no great importance. Some marbles are obtained from the series, as well as flagging and roofing slates; also some architectural sandstones, and limestones suitable for building and mortar. The mineral deposits belonging to the Silurian system of the United States, are, however, very valuable. As examples, we may mention the deposits of lead (galena) found in the Valley of the Upper Mississippi, which are the most remarkable in the world; and occur in that division of the Silurian system known as the Hudson River group. The rock also in which much of the native copper of the Lake Superior district occurs is the Potsdam sandstone.

Most of the salt springs of the United States issue from rocks belonging to the Silurian system; and there is also reason to believe that all the gold of the eastern United States and of California is associated with metamorphic rocks of either the Silurian or Devonian systems.

DEVONIAN SYSTEM—*Old Red-Sandstone.*

245. This system, which is next in order *above* the Silurian, derives its name—"Devonian"—from Devon-

QUESTIONS.—What is said of the thickness of the rocks of the Silurian system? What of its mineral deposits? What system is next in order above the Silurian? By what names is it designated?

* The student who desires to render himself better acquainted with the fossils of the Silurian system, as developed in North America, will find detailed descriptions of them, with illustrations, in the reports of the geological surveys of the different states and of Canada, especially in the reports of the Geological Survey of New York. At the State Geological Hall, at Albany, N. Y., there is also open to inspection a complete collection of the fossils themselves, arranged in the order in which they occur in the different groups and beds of this system, and conspicuously labeled.

In inspecting this collection, the interest of the observer will be greatly enhanced if he shire, in England, where portions of it are especially developed. It is also very generally known as the "*Old Red-Sandstone,*" from the circumstance that in Great Britain and other localities the system is largely made up of a succession of sandstones and shales, which are colored red, by the presence of oxyd of iron.

246. **Distribution.**—The Devonian system, like the Silurian, is one of the great general systems of the stratified rocks, and there are few regions of the globe, it is believed, in which some one or more of its groups do not occur.

In Europe it is very extensively developed; as in Great Britain (where it has been made celebrated through the labors of Hugh Miller); in France, Spain, Belgium, and especially in Russia, where it covers at least 150,000 square miles of surface.

In this country it also occupies extensive areas, but is less geographically extended than the Silurian system. Its greatest development occurs in the States of New York and Pennsylvania; but from thence, stretching to the west and southwest, it gradually diminishes in thickness and ultimately disappears. Devonian rocks are also known to exist in New England, in Canada East, and in the more northern portions of the continent.

247. **Divisions.**—The groups and subdivisons of the rocks of the Devonian system recognized in New York are as follows, proceeding from the highest of the series downward:

Catskill Group.
Chemung Group. } Waverly Sandstone of Ohio.
Portage Group. }
Genesee Slate.
Hamilton Group.
Marcellus Shale.
Upper Helderberg Group.
Cauda Galli Grit. } Oriskany Group.
Oriskany Sandstone. }

Fig. 141 is an ideal section representing the divisions of the rocks of the Devonian system in North America.

QUESTIONS.—What is said of the distribution of the rocks of the Devonian system? What of its divisions into rocks and groups?

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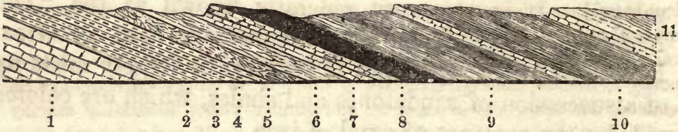
considers for a moment the great antiquity of the forms before him—an antiquity so vast, that the period representing the duration of the human race upon our planet dwindles, by comparison, into an insignificant moment.

FIG. 141.



1. Upper Silurian; 2. Oriskany Sandstone; 3. Cauda Galli Grit; 4. Upper Helderberg Group; 5. Marcellus Shale; 6. Hamilton Group; 7. Genesee Slate; 8. Portage Group; 9. Chemung Group; 10. Catskill Group; 11. Carboniferous System.

These rocks and groups of the Devonian system, although mainly named from localities in the State of New York, where they are typically developed and have been especially studied, are represented by equivalent formations in different parts of the country. Thus, the *Oriskany Group*, named from Oriskany, in New York, extends from Southern New York southwesterly to Tennessee, and westerly about 300 miles. The *Chemung* and *Portage Groups* have also an equal extension. Limestones belonging to the *Upper Helderberg Group* are widely developed throughout the Appalachian chain of mountains south of the Hudson River, and westward, both in the United States and Canada. The Catskill Group is principally developed in New York and Pennsylvania, and forms the greater portion of the Catskill mountains. Succeeding the Catskill group we find rocks belonging to the Carboniferous system.

248. **Characters.**—In New York and Pennsylvania the rocks of the Devonian system consist mainly of red, brown, and gray sandstones, shales and conglomerates, with some limestones. At the West, the equivalent rocks are for the most part limestones.

249. **Life of the Period represented by the Devonian System.**—The organic remains of this system, though often not well preserved in consequence of the arenaceous (sandy) nature of the rocks, are nevertheless of high and increasing interest, inasmuch as they furnish abundant evidence of terrestrial vegetation, as well as distinct traces of vertebrate life upon the surface of our planet.

Plants.—As already stated, the fossil plants found in the Silurian system are almost exclusively marine, and it is only in the uppermost strata—just on the borders of the Devonian system—that we detect any traces of a terrestrial vegetation. As we ascend, however, into the overlying system, the number of land plants gradually increases. At the same time, the Devonian system, as a whole, is not fertile in plant remains, and it would seem as if during the period of its deposition, the vegetation of our globe was confined to a few detached and limited areas.

QUESTIONS.—What is the character of the rocks composing this system in America? What is said of the life of the earth during the period of the Devonian system?

In speaking, moreover, of the land plants of these ancient times, the student should also understand that they were not like the land plants *commonly* met with upon the surface of the earth at the present day; but, on the contrary, judging from the remains we find, they would appear to have belonged mostly to the low class of Acrogens (§ 195); or, in other words, to have resembled our ferns, rushes, sedges, and similar plants inhabiting marshy localities. Some plants, allied to the Coniferous or Pine family, and of as high an organization, would also appear to have existed. All these remains, however, generally occur in a fragmentary and carbonized state, as if they had been drifted from a distance upon an ocean to the place where they were deposited. The marine plants of the Devonian system are similar to those found in the Silurian.*

Animals.—In the Devonian system, the same forms of animal life that especially characterize the Silurian era—namely, the corals, shells, trilobites, etc.—are continued, and in some of its groups of rocks their remains are very abundant. With few exceptions, however, the fossils of the Devonian system are of different species, and often of different genera from those of the Silurian.

But the most interesting of all the fossils of the Devonian system are the fish, which occur in some localities in such abundance that the rocks seem to form one great cemetery of their remains.

The first indications of the existence of fish are found, as has been already stated, in the uppermost rocks of the Silurian system; and these—"the first-born of their family, so far as is yet known," all belonged to the order of Placoids (See § 201)—an order of low organization and ferocious habits, and of which the dog-fish and the sharks are the best living representatives.

"Some of these old Placoid fishes," says Hugh Miller, "were furnished with strong palates, and squat, firmly-based teeth, well adapted for crushing the strong-cased zoophytes and shells of the period, fragments of which occur in their fecal remains (which have even been preserved in a fossil state); while others have teeth so sharp, thin, and deeply serrated, that every individual tooth resembles a row of poniards set up against the walls of an armory; and these last, says Agassiz, furnished with weapons so murderous, must have been the pirates of the period."

In the Devonian system, however, an entirely new order of fishes—the *Ganoids* (see § 201)—were called into existence; while the Placoids of the Silurian era continue to be represented, but only by new species, the former

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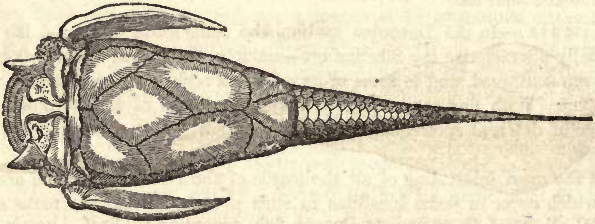
QUESTIONS.—What is known of its vegetation? What is said of the animal remains found in this system? What are its most interesting fossils? What was the character of the first created fishes? What types of fishes exist in the Devonian system?

*** "A distinguished French geologist, M. Brongniart, has shown that all existing marine plants can be classified with regard to zones of climate—some being fitted to the torrid zones, some for the temperate, and some for the frigid. And he establishes the fact that the marine plants of these early times indicate a tropical climate, although they may be found in what are now temperate regions; and he also states, that those of the higher rocks betoken, as we ascend, a gradually diminishing temperature."**

species of this order having previously become extinct. And from this epoch, says Hugh Miller, during the times of the Devonian, Carboniferous, Permian, Triassic, and Oolitic systems—"a period comprising, mayhap, millions of years"—all fishes, though apparently as numerous, individually, as they are now, belonged, so far as is yet known, exclusively to these two orders.

These Ganoid fishes of the Devonian system were characterized by some of the most remarkable and peculiar forms that have ever appeared in nature, and in some species it is at first difficult to see any resemblance whatever to a fish. Some of them seem to form, as it were, a connecting link between the Crustacea (crabs, lobsters, etc.) and the true fishes, and all of them were

FIG. 142.



covered over with hard, enamelled scales, or bony plates, and not unfrequently armed with sharp fin-spines of bone. Some seem to have been cased in a complete armature of solid bone. Hugh Miller describes one species, the *Pterichthys*, or winged-fish (Gr., πτερον, a wing; and ιχθυς, a fish), see Fig. 142, as having its head "covered with a strong helmet, perforated in front by two circular holes, through which the eyes looked out; its chest protected by a curiously constructed cuirass, formed of plates, and the

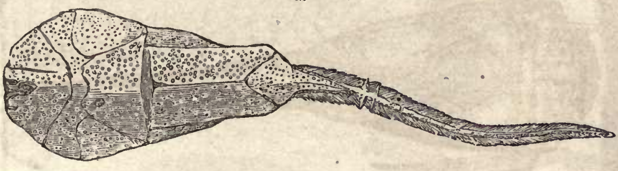
FIG. 143.

tail sheathed in a flexible mail of osseous scales. In addition, the creature had two arms or wings, that combined the broad blade of the paddle with

QUESTIONS.—What is said of range of the Placoid and Ganoid fishes? What was the character of the Ganoid fishes of the Devonian system?

the sharp point of a spear, and served both for propulsion through the water and as weapons for defense. Another characteristic fish of the Devonian system, the *Cephalaspis*, had a comparatively small elongated body, inserted within the cusp of a large crescent-shaped head, something like a saddler's cutting-knife. This curious head was, furthermore, covered on the upper side with a hood, or single large plate of bone, as with a buckler; hence the name, implying buckler-headed. Fig. 143 represents a side and under view of one species of the Cephalaspis. Similar bone-bucklers, which covered the head of another Devonian Ganoid—the *Asterolepis*—have been found, sufficiently large "to cover the front skull of an elephant, and strong enough to have resisted a musket bullet." Fig. 144 represents a curious bone-plated Devonian fish, called the *Coccosteus*.

FIG. 144.



250. Many of these ancient Ganoid fish, according to Prof. Agassiz, were invested, to some extent, with the characters of reptiles, and seem to have foreshadowed, as it were, the existence of a higher class of animals, long before they were created. Another interesting fact noticed respecting these extreme forms of Devonian fishes, is, that they were comparatively short-lived, "as if," says Hugh Miller, "some such law influenced the destiny of genera in this class of fishes, as that which we find so often exemplified in the human species—namely, that the giant, the dwarf, or deformed person, is seldom a long liver." Many of them were restricted to a single formation or group of strata—appearing for the first time in the lowest deposits, and becoming extinct with the uppermost. In many instances also, they appear to have all died at once, and died of violence.

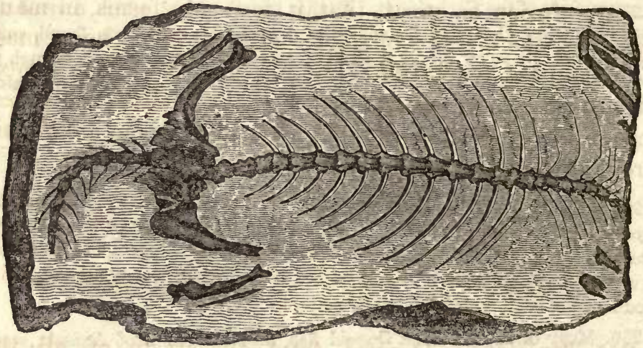
"We see them still presenting, over wide areas, the stiff curved outline—a result of the unequal contraction of the muscles—which, as in the case of recently netted herrings, indicates that dissolution had been sudden. We find, too, that their remains did not suffer from the predatory attacks of other fishes, and it would seem as if all the finny inhabitants of wide tracts of sea had been at once cast dead to the bottom, so that not an individual survived to prey upon the remains of his deceased neighbors."—MILLER. Such phenomena clearly indicate the occurrence of great convulsions of the sea-bottom during this ancient period of the earth's history.

251. **Reptiles.**—In the strata deposited just a little before the close of the Devonian system, we obtain, for the

QUESTION.—What new class of animals appears for the first time in this system?

first time, evidence of the existence of reptiles, or of *true* air-breathing animals upon the surface of our planet; just as representatives of the class of fishes appear for the first time a little before the close of the Silurian system.

FIG. 145.



The actual remains of such creatures obtained from Devonian rocks, are thus far limited, however, to a very few specimens, and appear to have been those of small terrestrial lizards, or animals of the order of Batrachians (frogs). Fig. 145 represents the best preserved specimen of a Devonian reptile yet discovered—the *Telerpeton Elginense*—a creature whose existence at this epoch indicates the presence of dry lands and swampy shores; in all likelihood the same shores and river-banks on which grew the reeds, ferns, and rush-like plants already referred to.

In addition to these actual remains, the tracks or foot-prints impressed by reptiles, as they walked over the muddy or sandy shores of the Devonian epoch, have also, in some instances been very perfectly preserved, and now exist in the consolidated rock.

252. Economically, the products of the Old Red-Sandstone, or Devonian system, are neither very numerous or of prime importance.

The aggregate thickness of the strata which compose the system in this country is about 11,700 feet. In England, the thickness of the entire system has been estimated, by Sir Roderick Murchison, at 10,000 feet; and as these 10,000 feet include (in that country) three formations so distinct in their groups of animal life that not one species of fish has been found common to both the higher and the lower, it must represent in the history of the globe an enormously protracted period of time.

QUESTION.—What is the character of the remains of these animals? What is said of the economical products of the Devonian system? What of the thickness of its strata?

CARBONIFEROUS SYSTEM.

253. This system is next, in the ascending order, above the Old Red-Sandstone, or Devonian system, and derives its name from the profusion of fossil vegetation found in it—a profusion so great, that it not only forms, in many instances, thick seams of solid coal (coal being but a mass of mineralized vegetation), but also enters to such an extent into the composition of some of the shales, sandstones, and limestones of the system, as to give them a carboniferous or coaly aspect.

254. **Distribution**.—The geographical area occupied by the Carboniferous system is very great, and there are but few regions of the globe in which some one or more of its groups of rocks do not occur. The countries in which those portions of the system are developed, which are especially productive of coal, will be hereafter noticed more particularly.

255. **Divisions**.—Derived from the waste of all the previously formed rocks—the granitic, metamorphic, Silurian, and Devonian—the strata which make up the Carboniferous system necessarily present a great variety and complexity of composition, and may be said to be composed of frequent alternations of sandstones, shales, slates, and limestones, with beds of coal and earthy ores of iron.

This assemblage of strata is generally separable into two well-marked groups or formations, which differ widely from one another as respects the nature of their contained fossils.

The lower group is especially characterized by the presence of immense beds of limestone, which abound to a most wonderful extent in marine fossils—shells, crustacea, corals, crinoids, fish, etc.—and have evidently been deposited at the bottom of a tropical ocean. These formations of limestone are collectively termed the "*Carboniferous*," or "*Mountain Limestone;*" and in some localities (as in the Western States) they constitute almost exclusively the lowest division of the rocks of the Carboniferous system, while in others, they are associated with, or (as in Pennsylvania) almost entirely replaced by conglomerates, shales, slates, and sandstones.

QUESTIONS.—What system lies next in order above the Devonian? Why is it called the Carboniferous? What is said of its distribution? What is the nature of the rocks which compose the Carboniferous system? How may they be generally divided? What are the characteristics of the lower group?

The upper group of the Carboniferous system, from the circumstance that it contains most of the beds or seams of coal existing in the crust of the earth, is termed the "*Coal Measures;*" and consists of beds of sandstones, shales, conglomerates, limestones, coal, and ores of iron, alternating irregularly.

The following section of a portion of the upper Carboniferous rocks of Ohio well illustrates the composition of the coal measures, and the manner in which beds of coal are distributed through them:

Sandstone.		
Coal,	6	feet thick.
Slaty Sandstone,	50	"
Bed of Iron Ore,	1.5	"
Sandstones,	75	"
Coal,	3	"
Dark Bituminous Shales,	4	"
Sandstones,	80	"
Iron Ore,	1	"
Sandstones,	80	"

The sandstones and limestones of the coal measures are not distinguishable from the sandstones and limestones in the lower part of the system. The iron ore occurs either in nodular masses, often formed around some organic nucleus; or as a clayey (argillaceous) carbonate of iron, having a slaty structure; in either case, however, it forms comparatively thin beds, associated with beds of shale.* The beds of coal vary in thickness from a fraction of an inch to several feet; and, in some instances, beds have been found measuring forty and even fifty feet in thickness. The average thickness of workable beds of coal is from three to six feet.

The characteristic fossils of the coal measures are the remains of terrestrial plants. Marine fossils also abound in some of the strata; but the remains of land plants so predominate, that they constitute the distinguishing features of the formation, and everywhere allow its easy recognition.

The general character of the fossils found in the coal measures would also indicate that the sediments which inclose them were not of exclusively marine

QUESTIONS.—What of the upper group? What are the coal measures? With what rocks are beds of coal usually associated? What are the characteristic fossils of the coal measures?

* This association of iron ore with coal, in the same series of rocks, is a matter of great practical importance, inasmuch as the mineral ore, and the fuel for smelting it, are thus brought in almost absolute contact with each other. The coal measures, moreover, very generally furnish the limestone (or flux) which it is necessary to mix with the iron ores in smelting to facilitate their fusion; and very often also those peculiar clays from which fire-bricks can be made for the construction of furnaces. In Great Britain, nearly all the principal mines of iron that supply her furnaces, occur in the coal measures; and their product of ore for 1855 was upward of nine million of tons.

origin, but rather that they were deposited in shallow inland seas, fresh-water lakes, or the estuaries of rivers.*

256. **Condition of the Earth during the Epoch represented by the Carboniferous System.**—The great general features of the earth's surface, during the deposition of the rocks which compose the Carboniferous system, can undoubtedly be made out by geologists with a high degree of accuracy.

Thus, during the epoch which represents the close of the Devonian and the commencement of the Carboniferous system, it is not probable that any very considerable part of the surface of our planet was dry land. The rocks which were deposited at this time, and which make up the base of the Carboniferous system, are mainly limestones, sandstones, and shales; and the most superficial observer feels as little difficulty in accounting for their formation, as he would in accounting for the origin of an existing coral reef;—the profusion of marine fossils contained in them clearly indicating that they were deposited at the bottom of an ocean swarming with animal life.†

At a later epoch of the Carboniferous system, the causes favorable to the so abundant production of limestone, and the large population of marine animals in the seas in which it was deposited, decline, while the area of dry land is greatly increased. On this land a vegetation flourished, which for rankness and abundance cannot probably be paralleled by the most favored tropical locality of the present day; and the remains of which, preserved and

QUESTIONS.—What information do the fossils of the coal measures impart concerning the origin of the sediments that inclose them? What was the probable condition of the earth during the early part of the Carboniferous epoch?

* The arrangement of the rocks of the Carboniferous system, as here given, into two groups, is exceedingly general, and in all extensive geological treatises the reader will find that more exact and minute divisions are recognized and referred to. By the Profs. Rogers, who have devoted much attention to the coal formations of the United States, the Carboniferous system is divided into three great groups, viz., the Lower Carboniferous, Middle Carboniferous, and the Coal Measures. The European geologists, while dividing the Carboniferous rocks generally into two series, the "Upper" and the "Lower," also recognize the existence of three well marked groups of strata, viz., The *Carboniferous Slates*, forming the base of the system; 2. The *Carboniferous*, or *Mountain Limestone;* 3. The *Coal Measures.* In Pennsylvania, the exact divisions of the Carboniferous system are as follows: 1. A Conglomerate, 2,660 feet thick, resting upon rocks of the Devonian system; 2. Carboniferous Limestone, or Red Shales and Limestone, which is supposed to correspond with the Mountain Limestone of Europe; 3. A Conglomerate, less than half the thickness of the lower division; 4. The true Coal Measures.

† In this country the Lower Carboniferous limestones are most extensively developed; especially in the western States, where they form high bluffs along many of the rivers, and also abound in caves or caverns, of which the Mammoth Cave of Kentucky is most remarkable. In the northwestern States different portions of this formation of Carboniferous limestone receive various local names: such as the Burlington Limestone, Keokuk Limestone, St. Louis Limestone, Kaskaskia Limestone, etc., etc.

covered up by deposits of sediment, now constitute the great coal beds of our globe. The climate of the earth, during the Carboniferous period, even in the latitude of Baffins Bay (coal being found in these extreme northern regions), was, undoubtedly, similar to that of the torrid zone; and it has also been thought probable that the atmosphere contained a much larger proportion of carbonic acid gas (the food of plants) than it does at the present day.

257. **Animal Life during the Carboniferous Epoch.**—Most of the families of invertebrate animals that flourished during the Devonian era are represented in the Carboniferous system—the species, and with few exceptions the genera, being, however, different. In some of the carboniferous limestones, the abundance of marine shells (univalves, bivalves, and chambered shells) is quite inconceivable to those who have not seen them, and their remains, cemented into rock masses, may be literally said to form mountains. The corals, too, were very numerous and beautiful, and in some instances preserve sufficient of their former color to impart a delicacy of tint to the marbles containing them: while the patterns of their structure are also, in many cases, so ornamental and varied, as to suggest their employment as designs for calico printing. Figs. 146 and 147 represent the patterns afforded by two varieties of fossil corals.

FIG. 146.

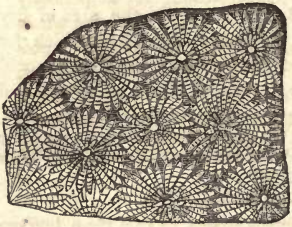
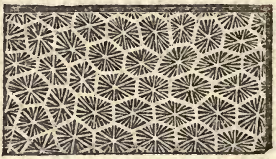


FIG. 147.



258. During this period of the earth's history, that curious family of radiate animals, known as "*Crinoids*," "*Encrinites*," or "*Stone Lilies*," were remarkably developed, and their remains may, in fact, be said to characterize the Carboniferous limestones, in the same manner as the trilobites are especially characteristic of the Silurian rocks, and the bony-plated fishes of the Devonian. The plan upon which these animals were constructed, was that of a cup-like body (something like the calyx of a lily), furnished with numerous flexible arms or branches, and attached to the sea-bottom by a jointed and flexible stalk, or column. Fig. 29, page 74, represents the entire extension of a crinoid, and Fig. 148, plates 1 and 3, the construction of the bodies of different species, with their attachment to their supporting columns. The

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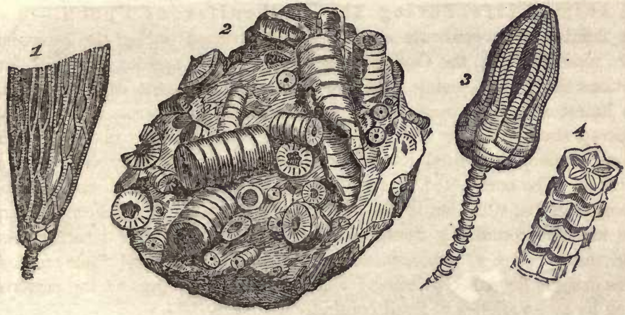
QUESTIONS.—What was the probable condition of the earth during the subsequent period? What types of invertebrate animals flourished during this system? What is said of the abundance of the shells and corals? What class of invertebrate animals was particularly abundant during the Carboniferous period?

stem of the animal, as well as the arms which radiated in every direction from its body, owed their flexibility to the fact that they were composed of an amazing number of little bones, all articulated together like the vertebræ of the spine, and variously grooved and ornamented on their surfaces. Plates 2 and 4, Fig. 148, represent separate joints of the stems of crinoids.

FIG. 148.



In some species, the number of arms was about 1,000, and the number of separate little bones contained in them, at least 100,000; yet so perfectly was each bone articulated with its neighbor, and so firmly were the whole bound together with ligaments, that the arms, when spread, must have possessed the flexibility and tenacity of a seine of stout net-work. "Human ingenuity, with the same purposes to effect, namely, the sweeping of shoals of swarming animals into a central receptacle, would probably construct a similar machine; but it would take half a lifetime to build one equally elaborate."

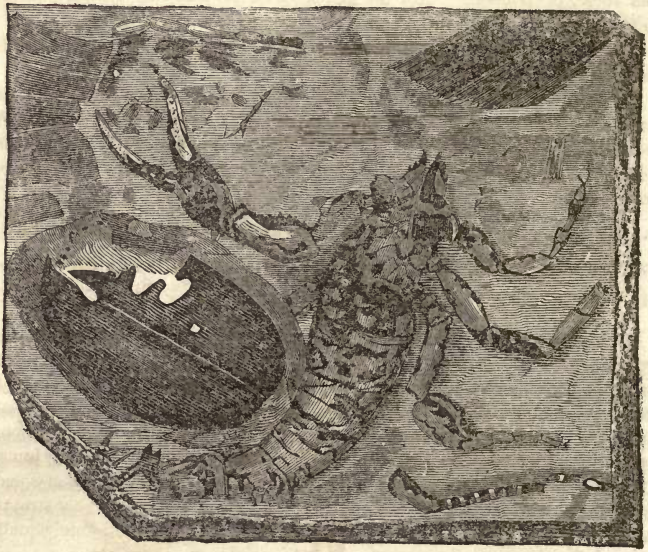
The family of crinoids are represented in almost all the rocks of the geological series, from the Silurian up to the Tertiary systems—105 fossil genera, each of which includes a number of species—having been enumerated. They appear to have attained their greatest development in the Carboniferous system, where their remains form almost the entire mass of some limestones. (See Fig. 148, plate 2.) Two genera only of this curious family are known to exist at the present day; and specimens of these are by no means common.

259. The ancient fishes—the Placoids and the Ganoids—like the Crinoids, seem also to have received their fullest development during the Carboniferous epoch. Their number was very great, and though the class of reptiles had at that time been called into existence, they continued to retain, till the close of the system, a marked reptilian character and organization. The feature which especially impresses an observer who examines their remains is the formidable character of the offensive weapons with which they were furnished, and the amazing strength of their defensive armature. "The

QUESTION.—Describe generally the structure and peculiarities of the crinoids.

teeth of one species of these ganoidal fishes (the *Rhizodus*) were more sharp and trenchant than those of the crocodile of the Nile, and in the larger specimens, fully four times the bulk and size of the teeth of the hugest reptile of this species now living." In the museum of the Royal Society of Edinburgh may be seen the remains of a similar reptilian fish from the Carboniferous

FIG. 149.*



system, which was probably larger than any true fish of the present day, *i. e.*, from thirty to forty feet in length. It was furnished with teeth three times larger than those of the most gigantic living alligator, and was also covered from snout to tail with an armor of enameled bone, that must have been almost impenetrable.*

260. From the very perfectly preserved remains that have been found, we know that over the lakes and rivers inhabited by the reptilian fishes of this

QUESTION.—What is said of the fishes of the Carboniferous system ?

* "I need scarce say," says Hugh Miller (see "Testimony of the Rocks"), "that the geologist finds no trace of that golden age of the world of which the poets delighted to sing, when all creatures lived together in unbroken peace, and war and bloodshed were unknown. Ever since animal life began upon our planet, there existed, in all the departments of being, carnivorous classes, who could not live but by the death of their neighbors, and who were armed, in consequence, for their destruction, like the butcher with his axe and knife, and the angler with his hook and spear. But there were certain periods in the history of the past, during which these weapons assumed a more formidable aspect than at others, and never were they more formidable than in the times of the coal measures."

period, there fluttered several species of insects, furnished with broad, gauze wings, like the dragon flies (Devil's Darning-Needles) of the present day. In the woods, and among the decaying trunks of the Carboniferous trees, there also harbored several species of spiders and beetles, and with these, large, many-eyed scorpions and cockroaches, of types not at all unlike the existing ones. Fig. 149 represents the remains of a fossil scorpion, from the coal rocks of Bohemia. Not an insect, however, has this system yet produced of the now numerous kinds that seek their food among flowers.

The remains of a few small reptiles, akin to frogs and lizards, have also been found in the Carboniferous system.

Among the crustacea, the order of Trilobites, so numerous and varied during the preceding systems, was represented by a few species only, that can be grouped into but one or two genera. This type of animal was, in short, fading away; and with the close of the Carboniferous epoch it became entirely extinct.

261. **Vegetation of the Carboniferous System.**—The forests and thickets of the coal period included no *species* of plants now known upon the earth. They consisted

FIG. 150.

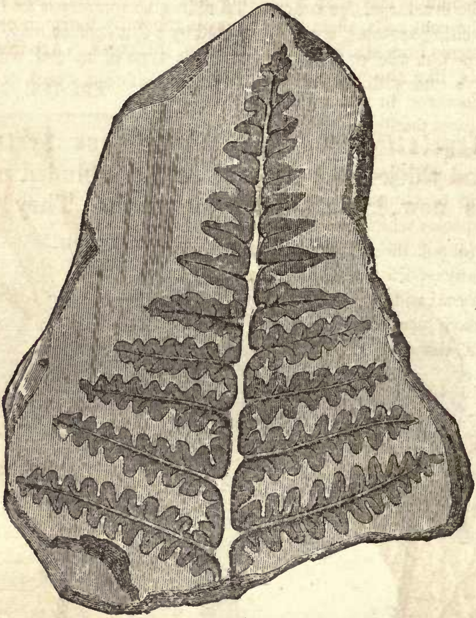
mainly of gigantic shrubs, which are either not represented by any existing types, or are akin to kinds which are now only found in small and lowly forms. The land upon

QUESTIONS.—What higher types of animals existed? What was the character of the vegetation of the coal period?

which this vegetation flourished, is, moreover, supposed to have been flat and marshy, and only slightly elevated above the level of the sea.

The remains of nearly 900 species of terrestrial plants have been obtained from the strata of the Carboniferous system, and of this number, at least two-thirds belonged to the low order of Cryptogamia (flowerless, fruitless plants—see § 194); a proportion which would probably be much increased if we were more fully acquainted with the vegetation of this epoch.

FIG. 151.



The master form, or type of the era, was the *fern*, or brake, of which at least 250 species have been already obtained from the coal measures of Europe. The fern is a plant which thrives best in warm, shaded, and moist situations; and in tropical countries, where these conditions abound, there are many more species than in temperate climes. Some of the family are, in the present tropics, arborescent, or of tree-like size and shape (see Fig. 150), and on the islands of the Indian Archipelago, and in Australia, attain not unfrequently a height of from forty to fifty feet. Now, many of the ferns of the coal measures were of this magnitude, and that, too, without regard to the parts of the earth where they are found. In the Carboniferous rocks of Baffins Bay; of Great Britain; of Pennsylvania; and of the torrid zone alike, fossil arborescent ferns are found, thus indicating that at this era the present tropical temperature existed in very high latitudes. Fig. 151 represents the fossil impression of a fern of the coal period.

In the swamps and ditches of the temperate zones there flourishes an inferior family of plants, termed *Equisctaceæ;* the different members of which bear the common names of horse-tails, cat-tails, scouring rush, etc., etc. They have all an erect, jointed stem, with slender leaves, and an inflorescence at the top. Now, a second large section of the plants of the Carboniferous era were of this kind, but, like the fern, they attained the magnitude of trees. While existing *equiscta* rarely exceed three feet in height, and the stems are generally less than a half an inch in diameter, their kindred, entombed in the coal beds, seem to have been generally fourteen or fifteen feet high, with stems from six inches to a foot in thickness. Arborescent plants of this family, like the arborescent ferns, still grow, however, in tropical countries.

The club-moss family (*trailing pine, Lycopodiaceæ*) are other plants of the present surface, usually seen in a lowly and creeping form in temperate latitudes, but presenting species which rise to a greater magnitude (about three feet) within the tropics. Many species of this family are found in the coal beds, "and it is thought that they have contributed more to the substance of the coal than almost any other variety of plants. But like the ferns and *equisetaceæ*, they attained, in the coal period, a gigantic size. The *lepidodendra* (so the fossil genus is

FIG. 152.

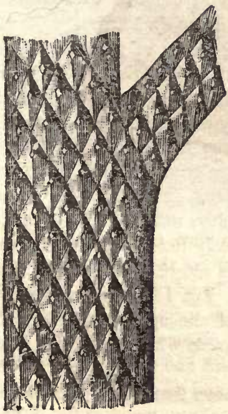
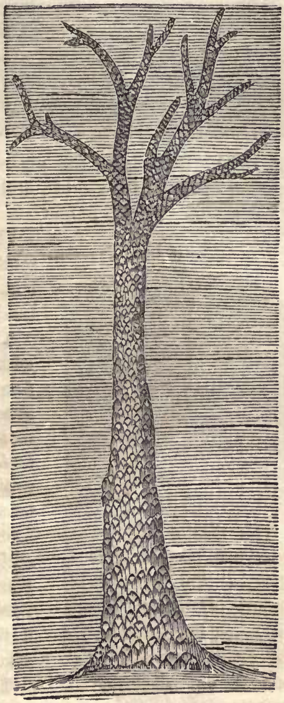


FIG. 153.



called) were probably from forty to eighty feet in height, with a diameter at the base of three feet, and a leaf full twenty inches in length. The exterior of their bark was scaly, and is often found most perfectly preserved. (See

FIG. 154.

Fig. 152.) Sometimes the gigantic trunks of the *lepidodendra* are found standing upright in the mine, and penetrating successive layers of sedimentary deposits. (See Fig. 153.)

FIG. 155.

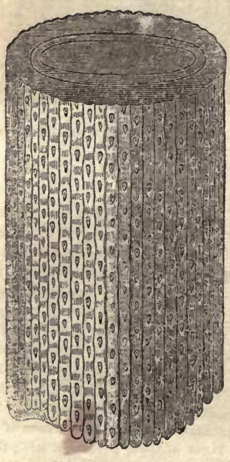


Fig. 154 represents the appearance of an assemblage of great fossil trees, as they occur embedded vertically in cliffs of carboniferous sandstone, at St. Etienne, in France.

The other leading plants of the coal era are without representatives on the existing surface of the earth, and their characters are, in general, less clearly ascertained. Among the most remarkable was a family called "*Sigillaria*," of which large trunks, thirty, sixty, and even seventy feet long, are abundant. These trunks were probably soft and pithy in the interior, and curiously fluted on the exterior surface, with leaves attached in vertical rows along the flutings. Fig. 155 represents a portion of the stem of one species, showing the flutings, and the points where the leaves were attached.

There have also been found in the coal measures a few species of exogenous plants, which probably belonged to the pine family, and appear to have been the highest type of vegetation which existed at this era. Upon sections of their trunks, the concentric rings of annual growth—a record of the changing seasons of these ancient years—are still clearly traceable.*

"Such was the vegetation of the Carboniferous epoch—composed of forms at the bottom of the botanical scale—flowerless, fruitless, but luxuriant and abundant beyond what the most favored spots on earth can now show. The rigidity of the leaves of its plants, and the absence of fleshy fruits and farinaceous seeds, unfitted it to afford nutriment to animals; and monotonous in its forms, and destitute of brilliant coloring, its sward probably unenlivened by any of the smaller flowering herbs, and its shades uncheered by music of birds, it must have been but a somber scene to a human visitant. But neither man nor any other of the higher animals were then in existence to look for such uses or such beauties in this vegetation. It was serving other and equally important ends—clearing (probably) the atmosphere of matter noxious to animal life, and storing up mineral masses, which were, in long-subsequent ages, to prove of the greatest service to the human race, even to the extent of favoring the progress of its civilization."

FIG. 156.

Fig. 156 (designed by Sir R. I. Murchison) conveys some idea of the probable character and appearance of the vegetation of the coal period.

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* The shales which lie immediately above the beds of coal afford the best specimens of coal plants, which occur between every succession of laminæ. The display of interlacing stems and leaves presented by a newly exposed roof of a coal mine is thus graphically depicted by Dr. Buckland, in the "Bridgewater Treatises:"—"The most elaborate imitations of living foliage on the painted ceilings of Italian palaces bear no comparison with the beauteous profusion of extinct vegetable forms, with which the galleries of many of our coal mines are overhung. The roof is covered as with a canopy of gorgeous tapestry, enriched with festoons of most graceful foliage, flung in wild, irregular profusion over every portion of its surface. The effect is heightened by the contrast of the coal black color of these vegetables with the light groundwork of the rock to which they are attached. The spectator feels transported, as if by enchantment, into the forests of another world; he beholds trees of form and character now unknown upon the surface of the earth, presented to his senses almost in the beauty and vigor of their primeval life; their scaly stems and bending branches, with their delicate foliage, are all spread forth before him, little impaired by the lapse of indefinite ages, and bearing faithful records of extinct systems of vegetation, which began and terminated in times of which these relics are the

262. **Formation of Coal.**—It is now universally admitted by geologists, that coal is a mass of compressed, altered, and mineralized vegetation, just as sandstone is consolidated sand, and slate and shale consolidated clay or mud.

The evidence upon which the belief is founded may be briefly stated, as follows:

1st. The enormous profusion of fossil plants, in the form of impressions of leaves, trunks, branches, and barks of trees, found in immediate connection with coal seams. 2d. Coal is composed of carbon, hydrogen, and oxygen, the same elements (though differing in proportion) which enter into the composition of plants. 3d. The substance of coal, when examined under the microscope, affords unmistakable evidence of a vegetable (cellular) structure. 4th. All the stages of gradation between perfect wood and perfect coal may be traced with the greatest certainty.

But granting the vegetable origin of coal, the question immediately suggests itself: Under what circumstances could so great an amount of vegetable matter have ever accumulated?—the magnitude of which may be realized in a degree, from the asserted fact "that all the forests of the United States, if gathered into one heap, would fail to furnish the materials of a single coal seam equal to that of Pittsburg, Penn."

Furthermore, coal is found stratified, laminated, and extended, in horizontal beds, which often cover very large areas, with a nearly constant thickness —the great Pittsburg coal seam, above referred to, for example, having a nearly uniform thickness of from eight to twelve feet, and is estimated to have once covered a surface of 90,000 square miles. Coal, moreover, is ordinarily encased between beds of shale or sandstone, which bear evident proof of having been slowly deposited in quiet waters. In some coal fields, as many as seventy seams of coal, varying in thickness from a few inches to four, six, eight, ten, twelve, and twenty feet, occur thus interstratified with shales and sandstones; and yet, notwithstanding these frequent alternations

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Questions.—What are the principal reasons which induce belief that coal has resulted from an accumulated vegetation? What is said of the vastness of such accumulations? Under what conditions is coal found?

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infallible historians. Such are the grand natural herbaria, wherein these ancient remains of the vegetable kingdom are preserved in a state of integrity little short of their living perfection, under conditions of our planet which exist no more."

of material, the purity of the coal is such, that it rarely contains any considerable admixture of mud, sand, or other foreign mineral substances.*

In explanation of these phenomena, various hypotheses have been suggested, but the general opinion of the best geologists of the present day is, that the vegetable matter constituting coal, must, in the main, have grown and accumulated in immense jungles and peat mosses for many years; that the land must have then sunk, and become the basin of a lake or estuary, into which rivers carried mud and sand; these, covering the vegetable matter, gradually consolidated into shales and sandstones, while the vegetable matter itself underwent the process of mineralization, and was converted into coal. This being done, it is supposed that the area of deposit was again elevated, so as to become once more the scene of luxuriant vegetation; then again submerged, and overlaid by new deposits of sandstone and shale; then once more elevated and covered with plants, and again submerged; and these alternations of submergence and elevation are presumed to have taken place as often as there are beds of coal in any particular coal field."†

QUESTIONS.—What theory of the formation of coal is at present adopted by most geologists?

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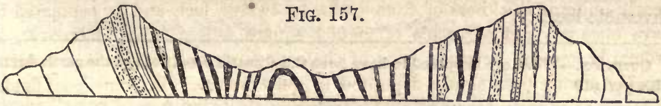
* The student will not fail to observe a striking difference in the modes of occurrence of mineral ores and coal. The former exist in the form of veins intersecting the strata; the latter, in the form of seams parallel with the strata. The former extend indefinitely downward; the latter horizontally. "Ignorance of this simple but radical difference has been the cause of much pecuniary loss. When, for instance, some years since, it was rumored in Philadelphia that the bottom of one of the great Pennsylvania mines had been reached, there was a panic in the market, and the price of stocks in coal mines declined enormously—from a lack of knowledge of the fact, that the continuation of coal seams was to be looked for horizontally rather than vertically." In some instances, where the rocks of the Carboniferous system have been elevated into vertical positions, the coal seams may appear, like metallic veins, to extend downward; but in all such cases it will be observed that the coal beds are strictly parallel with strata, and have been elevated with them. This phenomenon is illustrated by the accompanying sketch (Fig. 157) of the anthracite coal fields of Pennsylvania.

FIG. 157.



† "This sinking process, though persistent in the main, must have been of an intermittent and irregular kind. In some instances, forests seem to have grown on vast platforms, that retained their level unchanged for centuries—nay, thousands of years together; in other cases, the submergence seems to have been sudden, and to such a depth, that the sea rushed in and occupied wide areas where the land had previously been, and this to so considerable a depth, and for so extended a period, that the ridges of coral which formed, and the forests of *Encrinites* which grew, in these suddenly hollowed seas, formed thick beds of limestone, which we now find interstratified with coal beds, shales, and sandstones. Then succeeded an upward movement, and the same area which had been first occupied by a forest, and then by a lake or sea, came to be occupied by a forest again; and though, of course, mere deposition of mud and sand might have filled up the lake or sea to the level of the water, it is not easy to conceive how, without positive up-

263. **Climatic conditions of the Carboniferous Era.**—There is one circumstance in connection with the formation of coal which has given rise to a vast amount of ingenious speculation and hypotheses, viz.: the apparent sameness of external conditions over such extensive areas of the earth as are now occupied by our known coal fields. Thus, the same gigantic ferns and club-mosses are found alike in the coal fields of America, Europe, Melville Island, Greenland, and Australia—regions widely separated, and at once tropical, temperate, and frigid. To account for this luxuriance and homogeneity of vegetable growth various causes have been suggested, as the earth's central heat, a change in the earth's axis, a larger percentage of carbonic acid in the atmosphere, the planetary system moving through warmer regions of space, and the like; but thus far geologists have arrived at no definite conclusions upon the subject.

Deposits of carbonaceous matter have occurred at almost every period of the earth's history, as is evidenced by the fact that thin seams of coal are found in almost all the geological systems; but the coal beds which admit of economical working are almost exclusively confined to the Carboniferous system. The only exceptions are a few coal fields belonging to the Oolitic or Jurassic system, which, in Virginia and some other localities, admit of profitable mining.* It seems, therefore, certain, that whatever may have been the conditions which allowed of so abundant a terrestrial vegetation at this particular epoch of the earth's history, those conditions ceased about the time when the era of the Carboniferous system terminated. A high temperature was evidently not one of these conditions, for there are evidences of it afterwards; and some authorities incline to the belief that the superabundance of carbonic acid gas, which is supposed to have existed during this era, was expended before its close. "There can be no doubt that the infusion of a large amount of this gas into the atmosphere at the present day would be attended by precisely the same circumstances as in the time of the coal epoch. The higher forms of animal life would not have a place on earth. Vegetation would be enormous; and coal strata would be formed from the vast accumulations of woody matter, which would gather in every favorable locality."

Question.—What are supposed to have been the climatic conditions of the earth during this period?

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heaval, for at least a few feet, such surfaces at the water level should have become sufficiently consolidated for the production of the gigantic coal vegetation. But the sinking condition was the general one. Platform after platform disappeared, as century after century rolled away, impressing upon them their character as they passed; and so the coal measures, where deepest and most extensive, consist, from bottom to top, of these buried platforms, ranged like the sheets of a work in the course of printing, that, after being stamped by the pressman, are then placed horizontally over one another in a pile." —*Hugh Miller.*

* The knowledge of this simple fact would have saved the useless expenditure of thousands of dollars both in this country and in Europe. It is worse than useless to expend money and labor in following up signs of coal, unless we are sure we are upon strata of the Carboniferous system.

264. The termination of the Carboniferous system is marked by evidences of volcanic violence. Coal beds generally lie in basins, as if following the curve of the beds of lakes or seas. But there are few basins which have not been broken up; some portions of them being tossed up on edge, while others have been allowed to sink; thus causing the ends of strata to be removed many yards, or even hundreds of feet, from the corresponding ends of neighboring fragments. Fig. 158 illustrates the nature and mode of occurrence of such disturbances (A, B, and C representing three seams of coal). These phenomena are held to have been the results of volcanic movements below, the operation of which is further seen in numerous dikes and intrusions of trap rock, which traverse the coal measures in every direction.

FIG. 158.

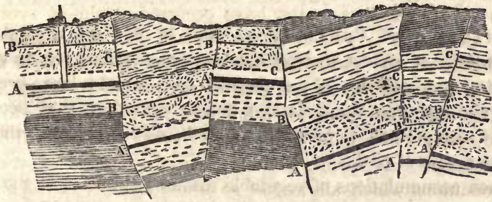
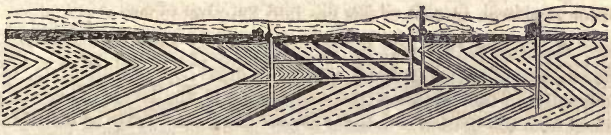


Fig. 159 represents a section of the coal fields of Belgium, and conveys an idea of the manner in which coal seams and their encasing strata of shales, sandstones, and limestones are often flexed, and apparently multiplied. Fig. 157 represents a section of the anthracite coal fields of Pennsylvania.

FIG. 159.



Such disturbances, although often very annoying to the miner, have, however, on the whole, facilitated the discovery and working of coal, by causing a succession of beds to outcrop, or appear, at the surface. Figs. 158 and 159 also show the manner of reaching and working the different coal seams by a system of shafts and subterranean galleries.*

QUESTION.—What phenomena marked the termination of the Carboniferous system?

* Over a large part of the United States it has not become necessary to sink shafts for coal to any very great depth, but the quarrying is commenced at the outcrop of the coal bed; and, till the cover becomes of very considerable thickness, it is found economical to "strip" off the overlying rock rather than to excavate an underground gallery. In Great Britain, however, the excavations for coal constitute some of the deepest mines in the world—*i. e.*, 1,500, 1,800, and 2,000 feet. And in one of these deep pits in Scotland, 400 feet below the surface, Hugh Miller tells us he has seen the rock roof of a gallery completely covered with impressions of the feet of a reptile that walked over it, ages ago, when it formed the immediate (muddy) terrestrial surface.

Other proofs of violence during the Carboniferous epoch are seen in the existence of great beds of conglomerates, which occur in this system. In Pennsylvania two such great formations have been observed—one near the base of the system, 2,660 feet thick; the other higher in the series, and of about one half this thickness. Now, these conglomerates, as usual, consist of fragments of older rocks, more or less worn from being tumbled about in agitated water, and laid down in a mud paste, which afterward hardened. We may legitimately infer, that volcanic disturbances broke up the older rocks, that their fragments were worn in seas; and subsequently deposited with finer particles, in layers.

The close of the Carboniferous system was also characterized by the passing away, or destruction of many forms of organic life previously flourishing—especially in the vegetable kingdom.

265. **Varieties of Coal.**—Wood, and in fact all vegetable tissues, consist essentially of carbon, hydrogen, and oxygen, combined, in very nearly equal chemical proportions. If we abstract from wood a large proportion of its oxygen, and compress the remaining constituents until they become dense and compact, the product formed will differ in no respect from the more inflammable varieties of coal.

Now, when accumulations of vegetable matter are buried in the earth, under favorable circumstances, and decomposition ensues, with an entire or partial exclusion of air, a similar result is produced naturally; or, to speak more precisely, a large proportion of the oxygen, and a small proportion of the hydrogen of the vegetable tissues separate, and leave behind, as a residue, substances rich in carbon and hydrogen—hydrocarbons, as they are technically called. These, variously affected by pressure, or by heat and pressure combined, furnish all the different varieties of coal.

266. *Peat* (see § 163) may be regarded as coal in its incipient stage of formation, and, if submerged and covered to great depths with strata, would, undoubtedly, in time, become true coal. As it is, the layers of ancient peat, obtained from the bottom or interior of peat bogs, can hardly be distinguished from coal, and constitute an excellent fuel.

267. Two principal varieties of mineral coal are recognized—bituminous and anthracite.

Bituminous coal may be considered as a mechanical mixture of carbon and bitumen—the last being a somewhat general name for certain compounds of carbon and

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Questions.—What is the present condition of most coal beds? What is said of the existence of beds of conglomerates in this system? What is the chemical composition of wood? How may wood be theoretically converted into coal? How is vegetable matter actually changed into coal? What relation is sustained by peat to coal? What two principal varieties of coal are recognized? What is the composition of bituminous coal?

hydrogen, the products of the decomposition of vegetable (or animal) substances, which resemble common tar or pitch, and are highly inflammable.

If we conceive a piece of charcoal thoroughly impregnated with pitch or tar, we should have a substance very similar to bituminous coal.

These two ingredients of coal are easily separated from one another by heat, as is constantly done in the manufacture of illuminating gas; the more volatile bitumen being driven off from the coal in the form of gas, or collecting in the pipes as coal tar, while the carbon or coke remains behind.

Anthracite is the name given to a coal whose bituminous or volatile constituents have been mainly driven off by the agency of heat and pressure, leaving the carbon in a dense and nearly pure condition behind.

When bituminous coal is ignited, its volatile constituents, expelled by heat, burn with flame and smoke; while anthracite, from its previous deprivation of bitumen, burns without flame or smoke.

Between these two extremes, coal is found of almost every intermediate variety. The richest, or, as they are technically termed, the "fattest" bituminous coals contain from forty to sixty per cent. of bituminous matter. *Cannel* (*candle*) coal is a highly compact variety of bituminous coal of an even texture, and breaks with a conchoidal or shell-like fracture. It contains a large amount of volatile matter, and, when lighted, burns freely like a candle —hence its name. *Jet* is an extreme variety of cannel coal, of deep black color and brilliant luster; it is capable of receiving a high polish, and is often set as jewelry.

268. The purest coals yield, on combustion, only one or two per cent. of ash, or incombustible matter; ordinary coals, however, yield from five to ten per cent.—an amount that corresponds very nearly with the quantity of saline and earthy substances found in the tissues of plants; others more impure may contain twenty, thirty, or fifty per cent. of ash. At this last point coal loses the property of ready combustion, and also the name of coal, and becomes carbonaceous, or bituminous shale or slate.*

Questions.—Illustrate the composition of bituminous coal? What is anthracite? Why does bituminous coal burn with flame and smoke? Why does anthracite burn without flame and smoke? What is said of the other and intermediate varieties of coal? What is jet? What amount of impurity usually exists in coal?

*** Sulphuret (sulphide) of iron often occurs intermingled with coal, and when present in considerable quantity is a most deleterious impurity; inasmuch as the sulphurous acid gas, generated from it, is not only noxious, but also rapidly corrodes the iron work of the stoves and furnaces with which it comes in contact. When exposed to air and moisture, sulphuret of iron undergoes decomposition, and develops heat; and bituminous coals containing it, are, for this reason, always liable to spontaneous combustion.**

Anthracite coal may be regarded as a metamorphic coal; and is rarely found except in regions very much disturbed by igneous agency, and where the strata are inclined, broken, and contorted.

It often happens, moreover, that in the same coal field the coal is anthracite or bituminous, according as the strata are more or less disturbed and altered. Thus, in Eastern Pennsylvania, where the coal strata are very much contorted and sometimes perpendicular (see Fig. 157), the coal is all anthracite; while in Western Pennsylvania, where the strata are nearly horizontal, the coal is bituminous. In New England coal occurs associated with strata that have been subjected to an extreme degree of metamorphism, or, in other words, "have been more acted upon and hardened by heat than usual," and here the coal is rendered so stony, and approaches so closely in character to graphite or black lead, that it is rendered nearly (or quite) unfit for fuel.

269. **Graphite** (*Plumbago*, or *Black-Lead*) is generally believed to be anthracite coal, which has been subjected to the most extreme degree of mineralization or metamorphism. It occurs chiefly in the older geological systems—very frequently in the neighborhood of igneous eruptions. It consists almost entirely of pure carbon, with a small proportion of iron, as an admixture.

270. **Mineral Oils** (*Naphtha, Petroleum*), **Asphaltum, etc.**—When bituminous coal, or, in fact, any substance of vegetable or animal origin, which is rich in carbon and hydrogen, is subjected to heat in close vessels, certain volatile constituents distill over, and, on condensation, yield gas (carbureted hydrogen), oils, and various pitch-like products. This result which is extensively produced in the arts, for the manufacture of gas, coal oils, etc., appears to have taken place naturally and on a large scale, in the earth; and we accordingly find, in some localities, emanations of inflammable gas (see § 146); or springs of mineral oil (the thinner varieties of which are termed "*Naphtha*," and the more viscid, "*Petroleum*"); or hardened masses of pitchy matter, which are known as "*Asphaltum*," "*Mineral Pitch*," "*Bitumen*," etc.

The product of natural oil springs is often very abundant. In Burmah, Asia, a single group of springs are said to yield regularly 400,000 hogsheads of petroleum annually. In the United States large supplies of mineral oils are obtained in many localities—especially in Western Pennsylvania and Virginia. In Venango County, Penn., where the oil is bored for as in the construction of Artesian wells, subterranean reservoirs have been struck, which are reported to have yielded from 400 to 800 gallons daily.

The most remarkable accumulation of bituminous matter known, is the Great Pitch Lake of Trinidad, West Indies, which is three miles in circumference, and of an unknown depth. It appears to be an immense deposit of petroleum, partially dried and hardened by exposure to the atmosphere.

Mineral oils and bitumen are not, as might be supposed, the product of Carboniferous rocks exclusively; but, on the contrary, they are yielded by

Questions.—Under what circumstances is anthracite coal found? What are illustrations of its occurrence? What is graphite, or plumbago? What is said of the origin of the natural oils? Where is the most remarkable natural accumulation of bitumen?

strata of almost every age which are rich in the remains of plants or animals. In this country some of the most copious oil springs (*i. e.*, those of Pennsylvania) come up through strata which are older than the Coal Measures, and which are almost barren of fossil plants.

271. **Distribution of Coal.**—Coal is very widely distributed over the world, although some countries are more highly favored than others. Available coal fields occur in Great Britain; in Spain, France, Belgium, and Middle Europe; in India, China, and Japan; in the islands of the Indian Archipelago; in Australia and New Zealand; in South America, Chili, and Peru; in Greenland, Melville Island, and in British America. But nowhere is the coal formation more extensively displayed than in the United States, and nowhere are its beds of greater thickness, more convenient for working, or of more valuable quality.

The eastern half of the continent of North America exhibits five great coal fields, extending from Newfoundland to Arkansas: 1. The *first*, or most eastern, is that of the British Provinces, Newfoundland, Nova Scotia, and New Brunswick. Its area is probably about 9,000 square miles, though only one tenth of this surface appears to be underlaid by productive coal seams. 2. The *second*, or Great Appalachian coal field, extends from Pennsylvania and Ohio to near Tuscaloosa, in the interior of Alabama. It is about 875 miles long, and is estimated to contain 70,000 square miles. 3. A *third*, and smaller coal field, occupies the center of the State of Michigan; it covers an area of about 15,000 square miles, but is not very productive. 4. A *fourth* great coal field is situated in the States of Kentucky, Indiana, and Illinois. Its area is estimated at 50,000 square miles. 5. The *fifth*, and most western, occurs in Iowa, Missouri, and Arkansas, and occupies an area of about 57,000 square miles. Besides these great deposits, coal is also found in New England, Kansas, Nebraska, and Texas.

The aggregate space underlaid by the coal fields of North America amounts to at least 200,000 square miles, or to more than twenty times the area which includes all the known coal deposits of Europe.

The amount of coal included in the great coal fields of Europe and America has been approximately estimated by Professor H. D. Rogers, as follows:

Belgium, - - - - -	36,000,000,000	tons.
France, - - - - -	59,000,000,000	"
British Islands, - - - -	190,000,000,000	"
Pennsylvania, - - - - -	316,400,000,000	"
The Great Appalachian coal field, - -	1,387,500,000,000	"
Indiana, Illinois, and Kentucky, - -	1,277,500,000,000	"
Iowa, Missouri, and Arkansas, - -	739,000,000,000	"
All the productive coal fields of North America,	4,000,000,000,000	"*

QUESTIONS.—What is said of the yield of "mineral oil" springs and wells? What is said of the distribution of coal in the Old World? What of the coal deposits of the United States? Where are the great coal deposits of North America located?

* The present annual product of the chief coal producing countries is nearly as follows: Great Britain, 80,000,000 tons; the United States, about 10,000,000; Belgium, about 5,500,000; France, 4,500,000. The total annual consumption of coal in the world is esti-

PERMIAN SYSTEM.

272. This system, as developed in Europe, consists essentially of reddish sandstones and conglomerates, and of common and magnesian limestones, with deposits of marls and gypsum. It derives its name from the Government of Perm, in Russia, where it is extensively developed.

It was formerly supposed that the Permian system was not represented in North America; but within a very recent period deposits of this age have been discovered in Illinois, Kansas, and Nebraska. Evidence has also been adduced by Prof. Emmons showing the existence of Permian strata in North Carolina; and the same geologist supposes that a portion of the red sandstones of the Connecticut River Valley and of the Atlantic slope of the Appalachians also belong to this system.

The organic remains of the Permian system are not very abundant, and do not seem to differ greatly from those of the Carboniferous system.

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273. **Close of the Palæozoic Period.**—With the close of the Permian system the Palæozoic period terminates. The reason for drawing a line of division here is, that there occurred about this time a vast interval, during which the part of the world now occupied by Western Europe (whence our data are chiefly derived) seems to have been more than usually affected by forces of disturbance and destruction. The rocks previously deposited were greatly dislocated, and tilted up in various directions, and large parts of them removed by the action of water. In the United States, the great chain of the Appalachian Mountains, which stretch from New England to the Southern States, is supposed to have been elevated at about this epoch; since the upper strata of the Carboniferous system, in Pennsylvania, are greatly disturbed, while the strata of later ages, which cover them, have not been similarly acted upon. Furthermore, this physical break and discordance in position between the deposits of the Palæozoic and those of subsequent periods was accompanied by a great and apparently sudden change in the organic remains which they contain, and it was even held at one time that there was not a single organism—animal or vegetable—common to both the Palæozoic and Mesozoic periods.

QUESTIONS.—Where is the Permian system principally developed? What is the origin of its name? Does it exist in this country? What period does the Permian system terminate? Why is there a line of division in the geological series drawn here?

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mated at about 100,000,000 tons. At this rate, the coal fields of Pennsylvania alone would meet the demand for 3164 years; and if it were quadrupled—viz., 400,000,000—the productive coal fields of North America would suffice for the world's supply for 10,000 years to come. A survey of these figures, therefore, will serve to dispel any apprehensions of an immediate short supply of coal; and we must also take into consideration that new coal fields are discovered as geological exploration becomes more extensive and exact.

The Palæozoic period was characterized—1st. By the non-existence, so far as is yet known, of birds, or of any mammiferous animals, and by the rarity of all other vertebrate animals, except fishes, which last were all distinguished by the possession of unequally lobed or heterocercal tails. 2d. By the existence of many peculiar types and genera of shells, corals, and crinoids, and by large numbers of trilobites, of which we find no trace afterward. 3d. The vegetation that flourished upon the earth during the Palæozoic ages was remarkably different from that of subsequent periods.

There was, finally, during the Palæozoic age, but little variety among the animals of the different regions of the globe; and this may, perhaps, be explained by the peculiar configuration of the earth at that period. Great mountains did not then exist; the sea covered the greater part of the surface of the globe; and the animals which then existed and whose remains have been preserved, were mostly aquatic. This wide distribution of the waters, furthermore, impressed a very uniform character upon the whole animal kingdom. Between the different zones and continents no such strange contrasts of the different types existed, as at the present epoch. The same genera, and often the same species, were found in the seas of every quarter of the globe; from which we must also conclude that the climate was much more uniform than at the present day.—AGASSIZ.*

QUESTIONS.—What were the principal features which characterized the Palæozoic age? What is said of the uniformity among the races of animals that prevailed at that time in different parts of the globe?

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* The names given to the various stratified groups of rocks included in the Palæozoic period, are, as has already been remarked, derived, for the most part, from the geographical districts where the deposits in question were first studied, or from certain narrow and local mineral or fossil characteristics. (See § 185.) As the study of geology, however, has extended, many of these names have been found to be too local and inexpressive, and, in fact, often inconsistent with the real characters of the formations, as determined by later investigations. To avoid these difficulties, therefore, Prof. H. D. Rogers has proposed to divide the American geological formations, extending from the lowest deposited in the dawn of organic life to those formed at the end of the Coal period (according to certain well-marked fossil or physical peculiarities), into fifteen groups or series of deposits, and to designate them by names significant of their relative ages. To accomplish this, he employs words which suggest, metaphorically, the different natural periods of the day; and which, commencing with the lowest of the series, are as follows:—*Primal*, *Auroral*, *Matinal*, *Levant*, *Surgent*, *Scalent*, *Pre-meridian*, *Meridian*, *Post-meridian*, *Cadent*, *Vergent*, *Ponent*, *Vespertine*, *Umbral*, and *Seral*—meaning, respectively, the formations of the Dawn, Daybreak, Morning, Sunrise, Mounting Day, Climbing Day, Forenoon, Noon, Afternoon, Declining Day, Sunset, Evening, Dusk, and Nightfall. Such a nomenclature of the Palæozoic formations, based on time, is desirable; and, though not at present adopted to any great extent, it may be, ultimately.

MESOZOIC PERIOD.

274. The stratified rocks of the Mesozoic (*i. e.*, the middle period of geological time) are arranged into three systems, viz.: the Triassic (sometimes called the New Red Sandstone), the Oolitic or Jurassic, and the Cretaceous.

TRIASSIC SYSTEM—*New Red Sandstone.*

275. This system derives its name *Trias* (*triple series*) from the circumstance that it is composed, in continental Europe—where it is very fully developed,—of three distinct groups of sandstones, limestones, and marls.

In England, the rocks of this system are principally red sandstones and red marls; and hence the early English geologists gave to them, collectively, the name of "*New Red Sandstone*," in contradistinction to the "*Old Red Sandstone*" (Devonian), which lies below the Carboniferous system. As this system is also noted, in Europe, for containing large deposits of rock-salt, it is sometimes termed, moreover, the "Saliferous" (salt-bearing) system.

Distribution.—In the United States, the Triassic system is probably represented by a part of the shales and sandstones found in the Valley of the Connecticut River, and also in Eastern New Jersey, Virginia, and North Carolina. Deposits referable to this age are also believed to exist in the territory of Utah and New Mexico.

Life of the Epoch.—The *red* sandstones, marls, and shales, which constitute a large proportion of the rocks of this system, are very barren of fossils; and it may be here remarked, that, as a general rule, fossils are always more rare in red rooks than in those of any other color. The matter imparting the red color (peroxyd of iron, etc.) seems to have been either destructive of life in the seas in which it prevailed, or else it was ill adapted to the preservation of the remains of animals that were deposited along with it. In the limestones and other rocks of this system, devoid of a red color, fossils are, however, often very abundant.

As has been already stated, the Triassic system—forming the commence-

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QUESTIONS.—What system constitutes the base of the rocks referred to the Mesozoic period? What is the origin of the name "Trias?" By what other names has this system been designated? What is said of its distribution in the United States? Where is it most fully developed? What is said of the life of this period? What class of rocks are characteristically barren of fossils?

ment of the Mesozoic period—is considered as marking the dawn of a new circle of organic life upon the surface of our planet. "In passing upwards," says Hugh Miller, "from the Permian to the Triassic, we seem to pass not merely from one dynasty to another, but, if I may employ such a term, from one dispensation to another." The singular and typical plants of the Carboniferous system—the lepidodendra, the sigillaria, and the like—have nearly all disappeared, and given place to forms more nearly allied to the tropical plants of the present day. We find, moreover, in the Triassic rocks, none of the curious corals of the Silurian, Devonian, and Carboniferous systems, comparatively few crinoids, no trilobites, no strange-looking, bone-encased fishes; and now, for the first time, we find fishes with homocercal, or equally lobed tails, while the heterocercal, or unequally lobed form, ceased to be the *universal* or common characteristic of this class of animals.

In the rocks of the Palæozoic period the remains of only a few reptiles have been discovered, and it is not probable that this class of animals had, at this age of the world, any great development. During the Triassic epoch, however, we have evidence that reptiles existed in large numbers, and of the most peculiar characters.

FIG. 160.

One of the most remarkable of these was the "*Labyrinthodon*," a strangely formed reptile, unlike anything which now exists. It more resembled a frog or toad than any animal with which we are now acquainted; but, in addition to its frog-like peculiarities, it had the head and teeth of a crocodile, and a size but little inferior to that of an ox. The prints of its feet, which are impressed and preserved on the surfaces of the Triassic sandstones, as clearly as if the animal had traversed the muddy beach of yesterday, very much resemble those of the human hand; but, as in the frog, the hinder paws were fully twice the size of the fore ones. Fig. 160 represents a restored outline of this animal, and the appearance of its tracks.

In the uppermost beds of the triassic system we obtain the first vestiges of the existence, upon the earth, of warm-

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QUESTIONS.—In what respect is the Triassic system particularly distinguished from the systems that preceded it? What class of animals were especially developed during this age? What remarkable reptile then existed?

blooded, air-breathing, vertebrate animals, viz., the teeth and vertebræ of several species of small quadrupeds.

These, from the structure of their bones, it is inferred, must have belonged to the order of marsupalia (pouched animals)—the lowest group of the sub-kingdom, Mammalia.* The most ancient, probably, of these remains have been found by Prof. Emmons, in North Carolina.

It may here be observed, that although no specimens of so large a class of animals as mammalia are found earlier, yet such may, nevertheless, have existed, and the defect may be in our not having found them; but other things considered, the probability is that heretofore none existed. It is also an interesting circumstance, that the first mammals found should have belonged to the marsupialia, when the place of that order in the scale of creation is considered.

OOLITIC, OR JURASSIC SYSTEM.

276. This system is sometimes termed the *Oolitic*, from the oolitic texture of many of the limestones that belong to it (see § 15); and sometimes the *Jurassic*, from the circumstance that it is extensively developed among the Jura Mountains of Switzerland.

277. **Distribution**.—The Oolitic system is typically more developed, and has been more minutely studied, in England, than in any other portion of the globe; and it there consists of three well-marked groups of strata—the "Lias,"† occupying the lowest portion of the system; the "Oolite," the middle portion; and the "Wealden" the upper.‡ In France, Switzerland, and

QUESTIONS.—What is said of the existence of warm-blooded animals at this epoch? What system succeeds the Trias in the ascending order of the series? Give the derivation of the names applied to it? Where is the Oolitic system most extensively developed?

* By marsupial quadrupeds are understood those animals which possess a pouch in which the prematurely-born young are nursed and carried about by the mother until able to take care of themselves. Of these creatures the kangaroo is the best known, and largest representative at present existing. The opossum is the only representative of this group found in North America. All these animals are nocturnal in their habits, so that it rarely happens that the traveler discovers their existence, even in districts in which the smaller kinds may be comparatively abundant.

† This term is said to be a corruption of the word "*liers*," or "*layers*," and was originally applied to the thin beds, which characterize the limestones occuring at the base of the Oolitic system.

‡ So distinct in many respects are the groups of the Lias and Oolite, that they are sometimes treated as independent systems; and it is not improbable that the progress of discovery will ere long compel geologists to adopt this arrangement universally.

Germany, the system is also largely developed; but in these countries the deposits are mainly referred to the groups of the Lias and the Oolite; the Oolite also occurs on a large scale in India.

In the United States the Oolitic or Jurassic system occupies, comparatively, but a very small area. The upper portion of the series of shales and sandstones found in the Connecticut River Valley, and in New Jersey, are now generally believed to belong to this age, as is also a deposit of sandstones, containing workable beds of coal, near Richmond, Va.

Numerous fossils, peculiar to this system, have also been recently brought by the expeditions in search of Sir John Franklin, from extreme Arctic regions.

278. **Characteristics of the Oolitic System.**—This system is mainly composed of limestones, calcareous sandstones, clays, shales, and occasionally seams of coal.* There is no particular appearance of disturbance, so far as has been observed, in Europe, between the strata which mark the close of the Triassic system and the beginning of the Oolitic; but there is, in Europe, a noticeable change in the constituent materials of the rocks of the two systems (*i. e.*, from sand to lime); thus indicating, that while the bottoms of the seas of one epoch were chiefly arenaceous (sandy), those of the latter were chiefly limey and clayey.

279. **Life of the Epoch.**—The organic remains of the Oolitic system are all *Mesozoic*—that is, they belong to genera and species differing from those found in the Palæozoic rocks, and differing also, though less in general aspect, from those found in the rocks of the Cainozoic or subsequent period. They are exceedingly numerous and well preserved—particularly in the department of animals—and more particularly still, in the class of molluscs, which, it has been observed, are always more conspicuous in a system in proportion to the predominance in it of calcareous rocks.

In this system, we likewise find that same uniformity over great space which has been remarked of the fossils of the earlier systems. In the Oolitic rocks of the Himalaya Mountains, of South America, of the region north of the Cape of Good Hope, and in India, fossils have been found, which, as far as naturalists can determine, are undistinguishable from fossils occurring in the Oolite and Lias of Europe.

280. **Vegetation.**—The vegetation of the Oolitic era was extremely varied, but the highest order of plants which

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QUESTIONS.—What is said of its occurrence in the United States? What is the character of the rocks composing the Oolitic system? In what respect do they particularly differ from the rocks of the Triassic system? What is said of the life of this epoch?

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* The light-colored "Caen Stone," which has been of late years extensively imported into this country from the north of France, and examples of which may be seen in buildings in New York City (*i. e.*, the Nassau Bank), and in the interior construction of many churches, is a sandstone of this system. So are also the fine-grained, cream-colored limestones imported from Germany for "lithographic stones."

then existed appear to have been coniferous (cone-bearing); "and as yet no example of a true exogenous timber tree has been detected."

Among the most characteristic forms of this age was a beautiful family of plants, intermediate in character between palms, pines, and ferns, termed Cycadaceæ (single plant, *Cycas*), some of which had short, cylindrical, scaly stems, surmounted by a tuft of elegant leaves, resembling a pine-apple; while others had tall, straight trunks twenty or thirty feet in height. The structure of the cycas is shown at 3, Fig. 161, which represents a restored aspect of the Oolitic vegetation. There were also tree ferns (see Fig. 161, No. 2), but in smaller proportion than in former ages, palms (1 and 4), pines (5), and numerous plants resembling the aloe, the agave, pine-apple, etc. (6, 7, and 8).

FIG. 161.

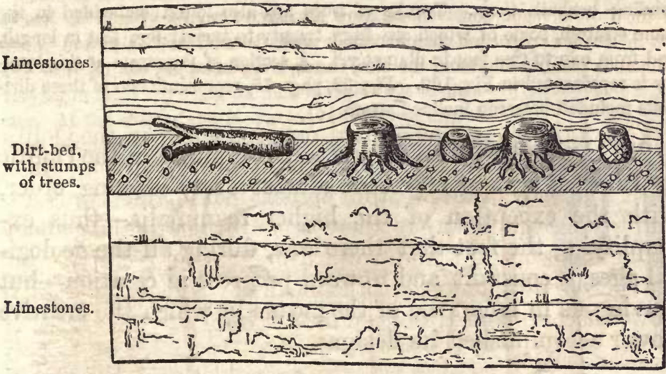
The vegetation, in short, of the Oolite, was generally analogous to that which now prevails at the Cape of Good Hope, and in some of the Islands of the Pacific; and seems to indicate a climate (apparently a universal climate) between the tropical and the temperate. It was also sufficiently luxuriant to produce deposits of coal, which are sometimes workable. One of the most remarkable of these occurs near Richmond, in Virginia; and, although the coal in this locality has been derived from an assemblage of plants, very distinct specifically and in part generically, from those which contributed to the formation of the more ancient or Palæozoic coal, yet it is not surpassed in

QUESTIONS.—What is said of the vegetation of the Oolite? What were some of the most characteristic forms of this age? What is said of the existence of coal in this system? Where does the most remarkable deposit of Oolitic coal occur?

quality, and is abundant in quantity—the main seam in some places being from thirty to forty feet thick, and composed of pure bituminous coal.*

Lignite.—Most of the deposits, however, of vegetable matter, found in the Oolitic system, and in all the other geological systems also more recent than the Carboniferous, have not experienced a sufficient degree of mineralization to convert them into true coal; but they form an imperfect variety of coal, termed *Lignite* (Lat., *lignum*, *wood*), or *Brown Coal*, which, in general, resembles charcoal, and exhibits the ligneous texture of the wood more or less distinctly.

FIG. 162.

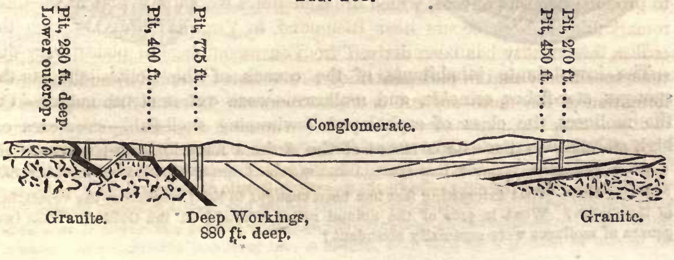


One of the most interesting facts connected with the vegetation of the Oolitic period, is the occurrence, in certain localities in England—interstrati-

QUESTIONS.—In what condition do deposits of vegetable matter generally occur in the systems more recent than the Carboniferous? What is lignite?

* The whole productive area of this Oolitic Virginia coal-field has been estimated at about 185 square miles, or about twenty-six miles in length, and from four to twelve in breadth. "The coal occurs at the base of a series of quartzose sandstones, and shales, and reposes almost directly upon granite. The whole of the central area is covered by conglomerates." Fig. 163 represents a section of this Eastern Virginia coal field, showing the inclined position of the coal seams, and the manner in which the pits or shafts have been sunk to reach them.

FIG. 163.

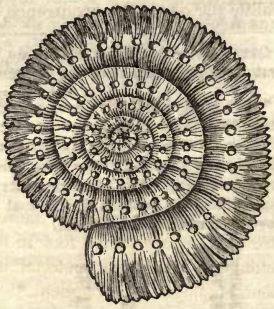


fied with limestones and sandstones,—of dark loam-like strata, locally known as "dirt-beds," which appear, from incontestible evidence, to have been the soils on which grew the Cycadaceæ and other plants of this era. In one locality at the Isle of Portland, on the coast of England, we find, says Mr. Bakewell, "within a distance of two feet, an entire change, from strata containing marine shells, to strata once supporting terrestrial plants; and, should any doubt arise respecting the original place and condition of these plants, there is over the lower dirt-bed a stratum of limestone containing fresh-water shells, and upon this, a thick dirt-bed, in which are stumps of trees, from three to seven feet in height, mostly erect, with their roots extending beneath them. Trunks of trees are also found embedded in the same stratum, some of which are from twenty to twenty-five feet in length, and from one to two feet in diameter." A section of the strata at this locality is represented in Fig. 162. Fig. 32, page 75, represents one of these dirt-beds included between inclined strata.

281. **Animals.**—The animal remains found in the Oolitic or Jurassic system represent almost every existing order, with the exception of the higher mammalia—thus exemplifying the fact that there was, during all the geological ages, a constant and upward progress in creation—but leaving us in ignorance of the means by which the creative power accomplished its designs.

FIG. 164.

FIG. 165.



The invertebrate inhabitants of the oceans of the Oolite—the corals, sponges, star-fishes, crinoids, and molluscs—were extremely abundant. Of the molluscs, the class of cephalopods (swimming shell-fish)—creatures of high standing in their department of the Animal Kingdom, and represented

QUESTIONS.—What interesting fact has been brought to light respecting the vegetation of the Oolite? What is said of the animal remains found in the Oolite? What two genera of molluscs were especially abundant?

at the present day by the nautilus and the cuttle-fish—existed in vast numbers; greater, in fact, at this period of the world's history than in any former, or at any subsequent time.

Two genera, however, were so remarkable and abundant, that they may be almost said to characterize, of themselves, the rocks of the Oolite, viz.: The *Ammonites* and the *Belemnites.* The former had essentially the same chambered structure as the Orthoceratites (see § 240), but instead of being straight, like them, they were coiled up in a plane spiral. (See Figs. 164 and 165, which represent two species of Ammonites.) The range of this genus is from the Triassic to the Cretaceous systems, including the Oolite, where, as already said, it attains its greatest development; and from the strata of these systems more than 500 distinct species have been described—the shells varying in size from a half an inch to three feet in diameter. At the close of the Mesozoic period the genus became extinct, and at present there are no similar shells living.

FIG. 166.

282. The *Belemnite* (Gr., *βελεμνον, a dart*) is a cylindrical shell, terminating at one extremity in a point, and having at the opposite, or largest end, a conical cavity. (See 2, Fig. 166.) Some specimens are several inches in circumference, and from ten to twelve inches in length. They are found in great numbers in the rocks of the Oolitic and Cretaceous systems; and on the continent of Europe there are limestones which are almost wholly composed of them. For a long time it was a question with geologists, what was the nature of the animal to which this singular shell belonged, but it is now known to have been the internal bone of an extinct cephalopod, allied to the squid or the cuttle-fish of our day. Fig. 166, No. 1, shows the restored appearance of the animal, and *a* the position of the belemnite. This creature was furnished with an ink-bag (like the existing cuttle-fish, which furnishes the material for the preparation of the dark pigment known as *sepia*), with which it could muddle the water around it, and thus protect itself against the attack of more powerful animals. In some instances these ink-bags—more than a foot in length—have been found attached to the belemnite, with the ink material in them so well preserved that it has actually been employed as a pigment.*

QUESTIONS.—Describe the structure of the Ammonites? Describe the Belemnites? What is said of the fishes of the Oolite?

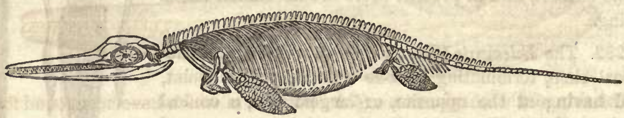
*** Some idea of the richness of the rocks of this system in marine fossils may be gained from the following description of a portion of the lias of Scotland, by Hugh Miller: "It consists of laminæ as thin as sheets of pasteboard, which, of course, shows that there was but little deposited at a time, and pauses between each deposit. Yet never did characters or figures lie closer on a printed page than the organisms on the surfaces of these leaf-like laminæ. We insinuate our lever into a fissure, and turn up a portion of one of the**

283. **Fishes.**—In many of the strata of the Oolitic system, the remains of fish—placoids and ganoids—are abundant. The forms are, however, with few exceptions, different from those found in the strata of any of the preceding systems.

284. **Reptiles.**—But the most striking circumstance connected with the life of this epoch, was a most remarkable development of reptilian forms of life, which existed in such numbers that the Mesozoic period of our earth's history is often spoken of as the "*Age of Reptiles.*"

Some of the most remarkable of these reptiles are known among geologists and naturalists under the generic names of *Ichthyosaurus*, *Plesiosaurus*, *Megalosaurus*, *Iguanodon*, *Pterodactyle*, etc.

FIG. 167.



The Ichthyosaurus (Gr., *fish-lizard*) was a sort of reptile-whale, that attained, in some instances, a length of thirty feet or upwards. Its general bodily form was that of a fish, to which was added the head and

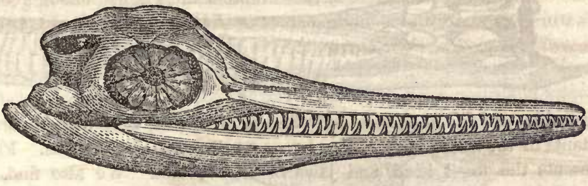
QUESTIONS.—What class of animals was especially developed during this epoch? What name is sometimes given to the Mesozoic period? What were some of the more remarkable reptiles? Describe the Ichthyosaurus.

laminæ, whose surface had last seen the light when existing as part of the bottom of the old Liassic sea, when more than half of the formation had still to be deposited. Is it not one of the parts of Sowerby's "Mineral Conchology" that has opened up to us? Nay, the shells lay too thickly for that, and there are too many repetitions of the same species. The ground of the tablet is of a deep black, while the colors of the fossils stand out in various shades, from opaque to a silvery white or deep gray. *There*, for instance, is a group of large ammonites, as if drawn in white chalk; there, a cluster of minute bivalve shells, each of which bears its thin film of silvery nacre. We turn over another page. It is occupied extensively by ammonites of various sizes, but all of one species, as if a whole argosy, old and young, convoyés and convoyed, had been wrecked at once, and sent, disabled and dead, to the bottom. And here we open yet another page more. It bears a set of extremely slender belemnites. They lie along, and athwart, and in every possible angle, like a heap of boarding-pikes thrown carelessly down a vessel's deck on the surrender of the crew. Here, too, is an assemblage of bright, black plates, that shine like pieces of Japan work—the head-plates of some fish of the ganoid order; and here an immense accumulation of minute, glittering scales of a circular form. We apply the microscope, and find every little interstice in the page covered with organisms. And leaf after leaf, for tens and hundreds of feet together, repeats the same strange story. The great Alexandrian library, with its unsummed tomes of ancient literature, the accumulation of long ages, was but a poor and meagre collection, scarce less puny in bulk than recent in date, when compared with this vast and wondrous library of the lias of Scotland."

breast-bone of a lizard; the paddles of a whale; the snout of a porpoise, and the teeth of a crocodile. Its structure is represented in Fig. 167.

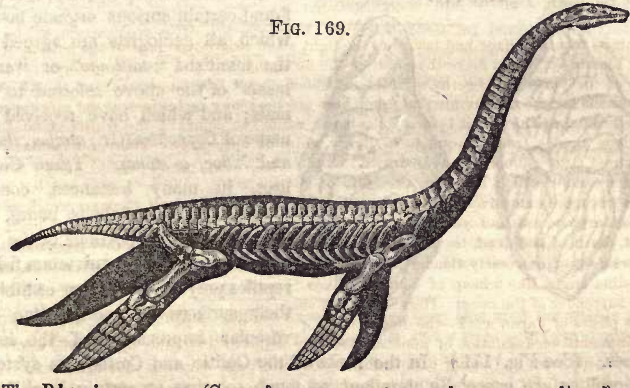
The Ichthyosaurus, however, was a true air-breathing animal, and could do what no whale or porpoise of the present day is capable of accomplishing, viz., it could crawl upon the shore as do the seals and the walrus. It had an enormous eyeball, which was larger, in proportion to the skull, then the eye of any other animal—the orbital cavity in one species being fourteen inches in its longest diameter; and this eye, having no eye-lids, was protected from injury by a casing of numerous thin, and, probably, flexible bones. (See Fig. 168.) The length of its jaws was sometimes upward of six feet, and its teeth were numerous and formidable. (See Fig. 168.)

FIG. 168.



The skin of the Ichthyosaurus (some portions of which have been found fossil) was naked, like that of the whale, and not covered with scales. Owl-like, it probably pursued its prey at night, and must have been exceedingly destructive to the animals with which it was associated. In some instances, the petrified stomach of the Ichthyosaurus has been found in connection with its skeleton, filled with the half-digested fossilized remains of fish, other reptiles, and even with the young of its own species..

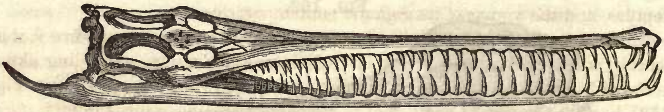
FIG. 169.



The **Plesiosaurus** (Gr., *πλησιος, near to;* .and *σαυρος, a lizard*) was another marine reptile, ranging from ten to twenty feet in length, which has been likened to "a turtle threaded through with the body of a snake." (See Fig. 169. Its head, which resembled a lizard's, was very small; its paddles were large, and like those of a turtle; and its tail was like that of a crocodile. But the most remarkable feature about this animal was the enormous length of its neck. Thus, while the mammalia have not generally more than five cervical (neck) vertebræ, and birds from nine to twenty-four (the swan), the Plesiosaurus had from twenty to forty.

This reptile was carnivorous; but unlike the Ichthyosaurus, which was a deep-sea animal, it was probably a shore creature, and lived in bays and shallow waters; and there, "lurking under marine vegetation, obtained its prey by darting out its long neck, and seizing it with its sharp and formidable teeth."

FIG. 170.



Crocodiles of various species, and often of great size, were contemporary inhabitants of the same seas as the Icthyosaurus and Plesiosaurus. Fig. 170 represents the fossil head and jaws of one species. We also find, in the rocks of this epoch, the bones and the tracks of chelonians or tortoises, and in some instances, what appear to have been the eggs of these animals (clustered together as originally deposited in the sands of the ancient Oolitic seashore), have been found fossil.

285. **Coprolites**.—In connection with the remains of fishes in the Carboniferous system, and with the remains of fishes and marine reptiles in the rocks of the Mesozoic period, there are found certain curious organic bodies, which all geologists are agreed are the fossilized "*voidings*" or "*excrements*" of the above referred to animals; and which have received the name of *Coprolites* (Gr., *κοπρος, dung;* and *λιθος, a stone*). These Coprolites, in many instances, contain scales, fragments of shells, bones, etc, —the undigested portions of the animals on which the carniverous fish or reptiles preyed—and often exhibit on their surfaces the corrugation and vascular impressions of the intestines. (See Fig. 171.) In the rocks of the Oolitic and Cretaceous systems, Coprolites are especially abundant, so much so, that at certain localities in England (which, says Mr. Buckland, would seem to have been *cloaca maxima* of the ancient ocean) they constitute a notable proportion of the strata; and,

FIG. 171.

QUESTION.—Describe the marine reptiles of the Oolite.

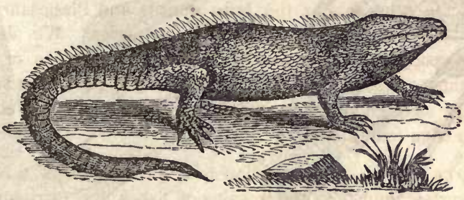
on account of the large percentage of phosphate of lime contained in them, are regularly quarried, pulverized, and used as manure.*

286. **Land Animals of the Oolite.**—But remarkable as were the inhabitants of the Oolitic ocean, the dry land of this epoch must have exhibited forms far more monstrous and gigantic. The most noticeable of these were the so-called "*Megalosaurus*," "*Hylæosaurus*," and "*Iguanodon*," all of which were enormous terrestrial "crocodile lizards," or saurians, covered with scales.

The *Megalosaurus* was about thirty feet in length, and, judging from the sharp, trenchant teeth that still remain implanted in its fossil jaws, was a highly carnivorous and ferocious animal, devouring, in all likelihood, smaller reptiles and the young of its gigantic contemporaries.

The *Hylæosaurus* was a smaller reptile, of from twenty to twenty-five feet in length, which had a row of very large, thin angular spines, extending like a serrated fringe along its back. An existing tropical lizard, the *cyclura* (see Fig. 172), has been supposed somewhat to resemble the Hylæosaurus in *miniature.*

FIG. 172.



The *Iguanodon* is proved, by the form of its teeth and by the partially digested vegetable matter (portions of coniferous and cycadaceous plants) found in connection with its skeleton, to have been an herbivorous (plant-eating) reptile; and in structure and habits probably resembled the Iguana (lizard) of the West Indies, from whence it derives its name. In size, it rivaled the largest elephant in height, and greatly more than rivaled him in length and bulk—its average length being about thirty feet, though some specimens are supposed to have attained a length of from sixty to seventy feet. The limbs of the Iguanodon must have been of proportionate size and strength to sustain and move so enormous a carcass. The hinder extremi-

QUESTIONS.—What was the character of the land animals of the Oolite? What were some of the principal terrestrial reptiles of this epoch? Describe the Megalosaurus. Describe the Iguanodon.

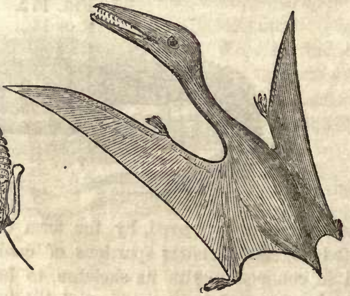
* Under the name of "*beetle stones*" Coprolites have been also used for artistic purposes. Dr. Buckland, the celebrated English geologist, had a table in his drawing-room that was made entirely of these fossils, and was often much admired by persons who had not the least idea of what they were looking at. "I have seen," says his son, "in actual use, ear-rings made of the polished portions of Coprolites (for they are as hard as marble); and, while admiring the beauty of the wearer, have made out distinctly the scales and bones of the fish which once formed the dinner of a hideous reptile, but now hung pendulous from the ears of an unconscious *belle*, who had evidently never read or heard of such productions."—*Buckland's Curiosities of Natural History.*

ties, in all probability, resembled the unwieldy contour of the rhinoceros or hippopotamus, and were supported by short, stout feet. The fore feet appear to have been less bulky, and to have been adapted for seizing and pulling down the foliage and branches of trees; some of its claws which have been found being more than five inches long, and three inches broad. Upon its snout it carried a short, thick horn.

Pterodactyle.—But the most wonderful animal of this, or any other age, was the Pterodactyle (Gr., *wing-fingered*), or flying reptile—a creature which was not altogether unlike the fabled dragon of the Middle Ages. It had the head and neck of a bird, the jaws and teeth of a crocodile, the wings of a bat, and the body and tail of a mammal. It was not, however, a bird, or one of the family of bats, but a true reptile, and, in all probability, could walk, fly, or swim, as its necessities might require. Fig. 173 represents one of the most perfect fossil skeletons of this reptile, and Fig. 174 the supposed appearance of the living animal.

FIG. 173.

FIG. 174.



The size of the Pterodactyle may be inferred from the circumstance that the wings of one specimen which has been found must have had a spread of not less than twenty-seven feet, while the spread of the wings of the great condor of the Andes—the largest of flying birds—does not exceed twelve feet.

287. **The Wealden.**—The most perfect specimens of these huge reptiles of the age of the Oolite have been obtained from that portion of the system which is known as the "*Wealden*"—a deposit of strata typically developed in the southeast of England. In this locality, the group of the Wealden appears to be the fossil delta of an ancient, far-flowing river*—a delta as large as that of the Ganges or the Mississippi. The strata of this delta,

QUESTIONS.—What was the character of the Pterodactyle? What is said of the formation of the Wealden in England?

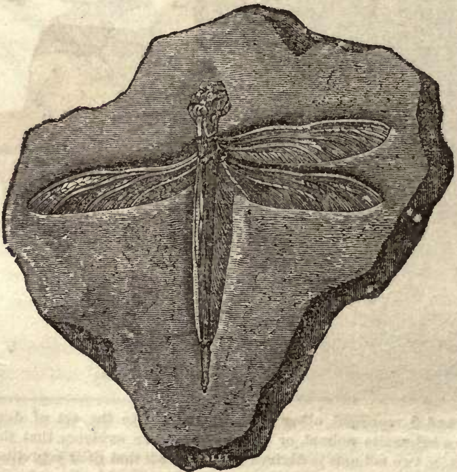
* Fig. 175, designed by the late Sir Henry de la Beche (a distinguished English geologist), and taken from Buckland's "Curiosities of Natural History," represents the condition of things which may be supposed to have existed at the mouth or estuary of this river of the Wealden, or upon the adjacent ocean coast. In the center of the plate, at Fig. 1, is seen the Ichthyosaurus, which has caught and is about to devour a Plesiosau-

FIG. 175.

rus. Figs. 5 and 8 represent other Ichthosauri—one in the act of devouring a fish, and the other a belemnite animal, or cuttle fish.—(The evidence that the Ichthyosauri preyed upon these two animals is derived from the fact that their coprolites often contain the scales of the one, and are, not unfrequently, also colored by the inky secretions of the other.)—Plesiosauri are also figured, one of which has caught a Pterodactyle (see Fig. 4), whose frightened companions are wheeling about in the air overhead. Sailing along the surface of the sea, upon the extreme right of the picture, are seen a fleet of ammonite shells. Fig. 6 represents, growing upon the bottom in great luxuriance, a specimen of crinoid, or stone-lily. The land bears the peculiar vegetation of the Oolite, and is tenanted by terrestrial reptiles. Finally, at the bottom of this primeval sea are strewed the bones and carcasses of its inhabitants—reptiles, fishes, and shells—where they would become, in the reality, gradually covered with mud, and converted into true fossils.

which in some places exceed 1,000 feet in thickness, contain fresh water shells, drift-wood, the bones of the huge terrestrial reptiles above described, and, in short, all the sweepings of a great river, mingled and entombed in sediments with marine shells, crustacea, and the bones of fishes and of gigantic marine reptiles. What part of the earth's surface presented the dry land through which this river held its course no one can tell for certain; but it has been surmised, that it flowed from a point somewhere in the vicinity of the present island of Newfoundland, and across lands now submerged beneath the Atlantic. But through whatever unknown continent this old and nameless river flowed, "we know," says Hugh Miller, "that its banks were covered with forests of coniferous and cycadaceous trees, and with arborescent ferns, and were haunted by gigantic reptiles, rivaling in bulk the elephant and the mammoth. Its waters were inhabited by amphibiæ of the same great class, chiefly crocodiles and turtles of extinct species and types; by numerous fishes of the old ganoid order; and by shells, whose families still exist in our pools and rivers, though the species are all extinct. Winged reptiles, too, occasionally flitted amid its woods, or sped over its broad bosom; and insects, of the same family as our dragon-flies darted over it on wings of delicate gauze, in search of their prey."

FIG. 176.



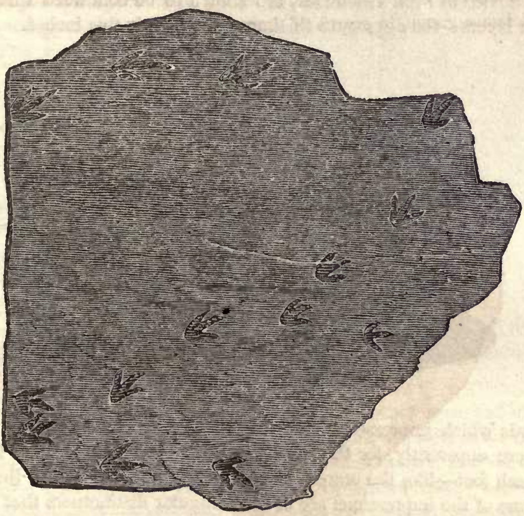
288. **Insects.**—During the Oolitic epoch, the number of insect species greatly increased—so much so, that insects are believed to have formed, in part, the food of some species of the flying reptiles. In certain calcareous strata of the European Lias, remains of insects as wing-cases, etc., occur in such numbers that the deposits in question have received the name of the "In-

QUESTION.—What is said of the insect life of the Oolitic epoch?

sect Limestone;" and Fig. 176, which represents a fossil dragon-fly from the limestone of Solenhofen, Germany, gives some idea of the perfection in which these fossils are not unfrequently found. In addition to dragon-flies, the following other species of Oolitic insects are thus enumerated by a recent authority: "Ants were common, as were also crickets, grasshoppers, beetles, two-winged flies, and, in species distinct from the carboniferous ones, the disgusting cockroaches; and, for the first time, amid the remains of a flora, that seems to have had its few flowers—though flowers could have formed no conspicuous feature in an Oolitic landscape—we detect, in a few broken fragments of the wings of butterflies, a decided trace of flower-sucking insects."

289. **Mammalia.**—Seven genera of mammalia have been described from the strata of the Oolitic system. They were all, apparently, small, rat-like animals, of the class of marsupials, and some of them were undoubtedly insect-eaters. Their remains have been found chiefly in the Oolitic rocks of England.

FIG. 177.



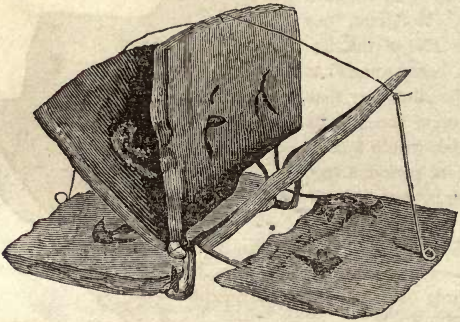
290. **Birds.**—The earliest traces of the existence of birds upon the surface of our planet are obtained from a deposit of red sandstones and shales in the Valley of the Connecticut River, in New England—a deposit formerly regarded as belonging to the New Red Sandstone, or Triassic System, but now generally referred (or at least the upper portion of it) to the age of the Lias or Oolite.

QUESTIONS.—Where do we find the earliest evidence of the existence of birds? What is said of the geological age of the Connecticut River sandstones?

No certain fragments of the skeletons of birds, however, have as yet been found in any geological formation older than the Wealden (the uppermost group of the Oolitic system); but on the successive layers of the deposit of shales and sandstones above referred to (which extends in the Valley of the Connecticut River, from the northern part of Massachusetts, southward for a distance of ninety miles), impressions of the feet of birds and other animals occur in great numbers. The general appearance of these remarkable fossils is represented in Fig. 177.

The aggregate thickness of the successive layers of shale and sandstone, on the surfaces of which these tracks are impressed, has been estimated to exceed a thousand feet. In many instances, the weight of the animal bent downward several layers of muddy sediment—so that now, when the rock, resulting from the consolidation of the sediment, is split open, we find the impressions of its feet preserved, more or less distinctly, on a number of successive layers—the upper surfaces showing the tracks depressed, and the lower the tracks in relief. Fig. 178 represents a curious example of this nature in the cabinet of Amherst College, where the impressions of two tracks, by an ingenious device of Prof. Hitchcock, are shown to be continued through five successive layers—the aggregate thickness of which is five inches.

FIG. 178.

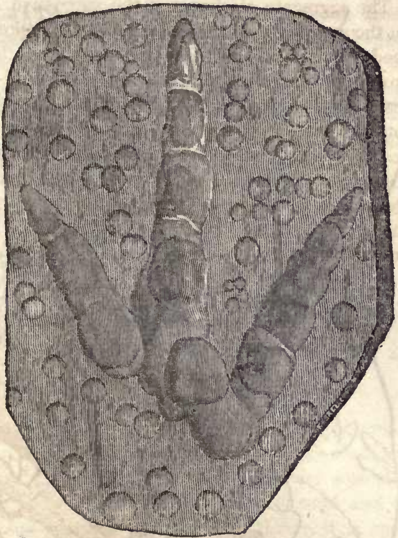


The birds which impressed these tracks (on an original muddy or sandy shore), were apparently, for the most part, long-legged birds, with but three toes on each foot—like the cranes, herons, snipes, or ostriches of the present day. Some of the impressions are of such singular distinctness that not only are the marks of every claw and joint discernible on the stone surface, but even the minute irregularities of the skin on the underside of the foot remain as sharply defined as if the impress had been made upon wax. Fig. 179 represents a track, showing the joints (or phalanges) of the toes, and also the marks of a shower of rain which fell upon the muddy surface about the time the track-making bird passed over it.

QUESTIONS.—What is the thickness of the layers in which the tracks occur? How were these tracks formed? What is said of their distinctness?

291. Tracks, which are believed to have been made by thirty-one different species of birds, have thus far been described by Prof. Hitchcock, from the shales and sandstones of the Valley of the Connecticut River. Some of them are very small, as if made by birds no larger than sparrows, while others are of gigantic size, and equal the footprints of the largest quadrupeds. One slab, in the cabinet of Amherst College, shows footprints which measure eighteen inches from the heel to the end of the middle claw, nearly thirteen inches in greatest breadth, and a stride (judging from the distance of the tracks apart in a straight line) of from three to five feet.

FIG. 179.



When these tracks were first discovered, it was doubted—especially by reason of the great size of some of them—whether they could have been imprinted by birds; but at the present time, most geologists and comparative anatomists are entirely satisfied that they were really made by the class of animals in question. Moreover, our wonder at the size of the impressions has been somewhat lessened, by the discovery that there existed upon the islands of New Zealand, within a comparatively recent period, a race of gigantic birds, but little, if any, inferior in size to those which are believed to have lived in New England during the Oolitic or Triassic ages—some bones having been brought from New Zealand which belonged to birds over eleven feet in height.*

292. Besides the tracks of birds, there are also found upon the strata-surfaces of the same formation, impressions of the feet of many other animals—such as marsupials, lizards, tortoises, batrachians (frogs), and animals that walked upon two legs and yet dragged a tail behind them; together with traces or markings apparently made by insects, worms, and crustacea—in all, eighty-eight different kinds of imprints other than those of the feet of birds.

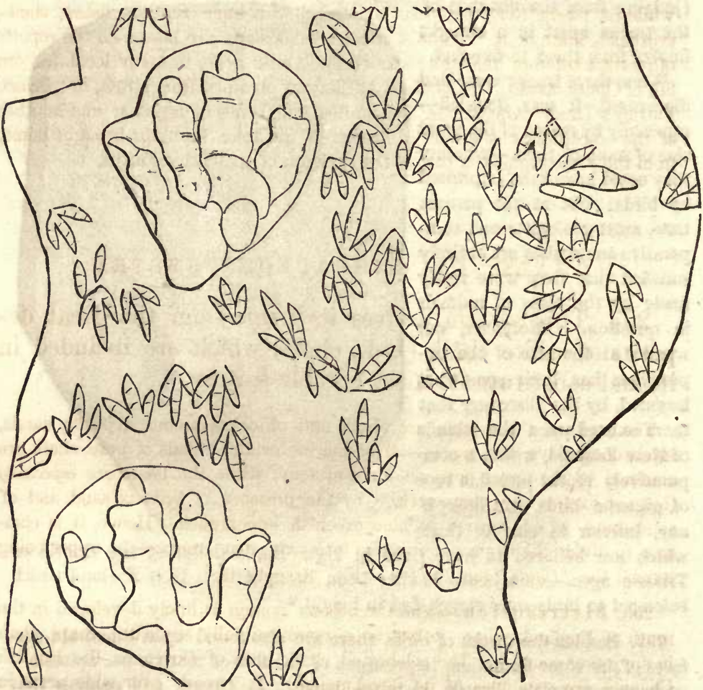
Fig. 180 represents tracks found at South Hadley, Mass., which are the

QUESTIONS.—What of their number? What of their size? What interesting fact respecting the existence of enormous birds has recently been made known? What other impressions besides those of the feet of birds are found upon the strata of the Connecticut River sandstones? What is said of the number and size of these impressions?

* For further notice of these discoveries, see page 317.

largest as yet discovered, and are believed to have been made by a huge frog-like animal. Each track is twenty inches long, fifteen inches wide, and covers upward of a square foot of surface. Upon the same slab—preserved in the cabinet of Amherst College—are also many other smaller tracks (apparently made by birds) crossing each other and crowded, like impressions of feet upon the shores of a muddy pool which ducks and geese have frequented.

FIG. 180.



293. **Condition of the World during the Oolitic Epoch.**—Respecting the condition of the world during the deposition of the strata included in the Oolitic or Jurassic system, everything testifies, as has been already intimated, to the universal existence of a genial, if not of a tropical climate. Indeed, according to Prof. Owen, a close correspondence may be traced between the "land of the Oolite" and the condition of things which *now* prevails in Australia. Thus, the climate of this great "island continent" is semi-tropical; among its plants, the tree-ferns, cycadaceæ, and other Oolitic

QUESTION.—What was supposed to be the condition of the world during the Oolitic epoch?

genera still have representatives; many of the fish and mollusca which inhabit its waters belong to the same families which prevailed in the ocean of the Oolite, and are unlike any which are known elsewhere; while its largest *native* land animals are of the lowest class of mammalia, viz., marsupials (kangaroos, etc.).

During the Oolitic epoch, it seems certain also that a genial temperature prevailed in the Arctic regions; that its lands were covered with plants like those of tropical countries, and inhabited by lizard-like forms and insects; while its rivers, bays, and seas abounded with huge reptiles, fishes, shells, crustacea, and corals. These startling conclusions are based on the reports of recent explorers, that the rocks of the Arctic zone, in many localities, are full of Oolitic fossils. Thus, Capt. M'Clintock obtained from strata, in "Prince Patrick's Land," Ammonites, Belemnites, and bones of reptiles; and another of the expeditions sent out in search of Sir John Franklin brought home, from the same regions, a part of the skeleton of an Ichthyosaurus.

CHALK, OR CRETACEOUS SYSTEM.

294. This system derives its name from the great deposits of white chalk (Lat., *creta*) which are included in it, and constitute its most notable feature.

The rocks of the system are chalk and other calcareous deposits, sands, sandstones, clays, and marls—all of marine origin. Beds of pure chalk are confined to the upper portions of the system; while the lower are *especially* (but not exclusively) characterized by the presence of beds of sand and of sandstones, which have a peculiar greenish appearance. Hence, it is common to divide the Cretaceous system into two great groups—the upper being termed the "*Chalk*," and the lower the "*Greensand*."

295. **Distribution**.—The Cretaceous system is finely developed in the south of England, where it has been more carefully studied, perhaps, than in any other country. The celebrated chalk cliffs of Dover, on the English Channel, are examples of its development. It spreads over wide areas in France and Germany, and forms a part of the great mountain chains of the Alps, Pyrenees, and Carpathians. Cretaceous rocks also occur in India, South Africa, and South America.

In North America, the Cretaceous system occupies a large area of surface. Commencing at the islands of Nantucket and Martha's Vineyard (the cliffs at Gay Head, on the latter island, being probably of this age), it is largely de-

QUESTIONS.—What evidence have we that a mild climate prevailed at this age in the present Arctic latitudes? From what does the Cretaceous system derive its name? What are the principal constituent rocks of the system? How is it usually divided? What is said of the distribution of the Cretaceous system in Europe?

veloped in New Jersey; and from thence it extends continuously along the Atlantic and Gulf Coast—through Delaware, Maryland, Virginia, the Carolinas, Georgia, Alabama, and Texas—to Mexico; "and then covers nearly one-third of the width of the continent, from near the Gulf of Mexico to British North America, with occasional interruptions."

The true chalk, which occurs so abundantly in Europe, has not yet been found among the Cretaceous rocks of North America, but the peculiar greensands of this system are, however, present in some localities, and may be seen especially to advantage in eastern New Jersey.

Near the sources of the Red River there are immense deposits of gypsum ("Plaster of Paris"), which are believed to be of the Cretaceous age, and are probably the largest in the world.

FIG. 181.

296. **Origin of Chalk and Greensand.**—White chalk (well known as a material for marking) is a soft, pulverulent carbonate of lime, and can be converted, like ordinary limestone, by calcination, into quicklime.* In Europe, it constitutes a large part of the Cretaceous system; and has been traced, in one direction, from the north of Ireland to South-

QUESTIONS.—What in North America? Is true chalk found in this country? What is chalk? Under what circumstances does it occur?

* The term "chalk" is often applied to various substances which are in no sense of the word limestones: as "*Red Chalk*," a natural clay containing a considerable percentage of oxyd of iron; "*French Chalk*," a variety of steatite, or soapstone; and "*Brown Chalk*," a familiar name for umber."

ern Russia—a distance of about 1,200 miles; and, in another direction, from the south of Sweden to the southeast of France—a distance of about 900 miles; and there are extensive districts in both France and England where its average thickness is not less than a thousand feet. All geologists are agreed that this immense deposit of this singular variety of limestone was formed at the bottom of an ocean "of a very considerable depth, and of such extent that it must have covered, for many ages, the greater part of what is now Central and Southern Europe;" but concerning the exact manner of its production there is considerable doubt. "The only analogous product of the present day occurs on a comparatively small scale among the coral reefs and islands of the Pacific, where there is constantly forming an impalpable white mud, derived from the coral, which, in dried specimens, cannot be distinguished, by the unassisted eye, from masses of soft chalk." True chalk, however, differs widely from its modern representative, inasmuch as it is composed, to the extent of about one half of its entire bulk, of the shells of microscopic animalcules, so extremely minute, that every cubic inch of chalk has been estimated to contain the remains of over a million different organisms. "If our eyes could be suddenly endowed with a high microscopic power," says Hugh Miller, "the white line which we draw with chalk along a board would resemble a part of a wall of a grotto, covered over with shells." Fig. 181 represents an appearance of chalk, as viewed under a microscope.

The Greensand, which gives name to the lowest group of the Cretaceous system, consists of small, round granules, of a greenish color, which are commonly intermixed with variable proportions of clay and siliceous sand. These granules are mainly composed of silica and iron (forming a silicate of iron) and potash; and owing especially to the presence of the latter ingredient, they possess valuable fertilizing properties.* In New Jersey, where the greensand beds have an aggregate thickness of about 100 feet, it is dug (under the name of marl) from pits during the winter season, and spread upon the fields, preparatory to being plowed in. Twenty loads to the acre are said to produce more valuable results than 200 loads of good stable manure; the effect being experienced with the first crop, and continuing for several years afterwards.

The origin of these greensand grains was for a long time a matter of doubt among geologists, but within a comparatively recent period microscopic investigations have shown that they are, in many instances, the casts (models) of microscopic shells of the order Foraminifera,† and of some other

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QUESTIONS.—Is there any substance analogous to chalk now forming? In what respect does chalk differ from any similar modern products? What is the so-called "greensand?" What is said of its value as a fertilizing agent?

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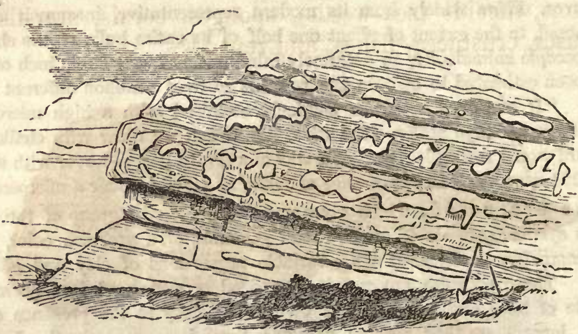
* The average composition of the greensands of New Jersey is as follows: Silica, forty-seven to fifty-one per cent.; protoxyd of iron, twenty to twenty-four; alumina, six to nine; potash ten to twelve. In addition, the greensand strata always abound in organic remains—shells, fragments of bones, etc.—which, by their decomposition, become valuable fertilizing auxiliaries.

† The Foraminifera are an order of animals of low organization, belonging to the class *Protozoa*—see § 200, page 190; and § 68, page 58.

organic bodies. "The shells themselves have disappeared; but the internal form of their cavities has been retained by a silicate of iron, which took the place of the animal bodies, as these decayed, and retained their shapes. So perfectly has this been done, that even the very finest canals of the cell-walls, and all their connecting tubes, are thus petrified and separately exhibited." Recent soundings by the United States Coast Survey have, moreover, brought up from the depths of the ocean—in the Gulf Stream and the Gulf of Mexico—not only grains of greensand, having the form of well-defined casts of foraminifera and minute molluscs, but also perfectly preserved shells of the same species of animals—thus showing that the production of greensand is still going on, in some seas, by the same agencies which produced it in ancient geological periods.

FIG. 182.



Flints.—A remarkable feature of the chalk beds of Europe is the occurrence in them of nodular masses of nearly pure flint (silica), of very irregular and often fantastic forms, and of variable magnitude. These are generally desposited in horizontal layers (see Fig. 182), and, although very numerous, are rarely in contact with each other—each being completely enveloped by the chalk.* The explanation given concerning the formation of these singular masses, is, that they were produced by a chemical aggregation of particles of silica, originally held in solution in the mass of the chalk. But whence the origin of this silica in the midst of a substance so different from it as chalk? Ehrenberg, the eminent microscopist, has suggested that it was derived from the siliceous coverings of microscopic animals; and, in confirmation of his views, he states, that while chalk with flints abounds in the north
41 of Europe, and without flints in the south, silicious animalcules are wanting in the northern chalk, and are present in great quantities in the southern;

QUESTIONS.—What is known respecting its origin? What is said respecting the occurrence of flint nodules in the chalk-beds of Europe?

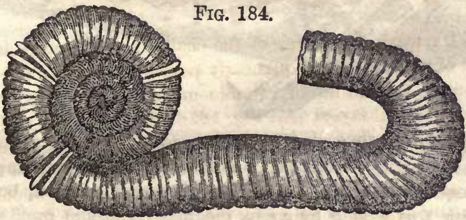
* These flints of the chalk, calcined and ground, furnish the finest material for the manufacture of china ware, porcelain, and flint glass, and, before the invention of percussion caps, were in demand for the manufacture of gun-flints.

thus leading to the conclusion, that in the one case the silicious skeletons have been left in their natural form, while in the other they have been dissolved chemically, and aggregated upon the principle of chemical affinity into nodules of flint. But whatever may have been the source of the silica of the chalk flints, it appears, in almost every instance, to have concentrated upon some organic substance in the ancient ocean; and, consequently, when a flint nodule is now broken open, it is found to inclose the remains of sponges, echinoderms, corals, and other marine organisms, which are often in the most perfect state of preservation.

297. **Life of the Cretaceous Epoch.**—The organic remains found in the rocks of the Cretaceous system are eminently marine; comprising numerous microscopic organisms, fucoids (sea-weeds), sponges, corals, star-fishes, molluscs, crustacea, fishes, and reptiles.

FIG. 183.

FIG. 184.



If we compare, however, the fossils of the upper Cretaceous strata with those found in the Oolitic rocks below, a complete change of species will be noticed. There were ammonites, and belemnites, and many other shells with common generic names in both eras, but the cretaceous species are obviously different from those of the Oolite. And so with the radiata, and the fish, and the reptiles, and all other classes and orders of animals and plants, as far as their remains have as yet been described.

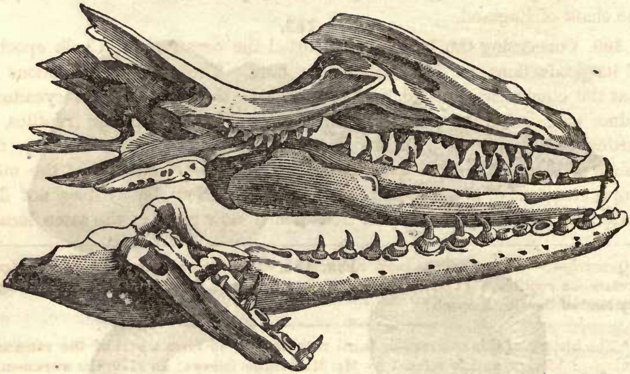
Figs. 183 and 184 represent two of the characteristic shells of the Creta-

QUESTIONS.—What is supposed to have been their origin? What is said of the organic remains found in the Cretaceous system? Are the fossils of the Cretaceous and Oolitic systems alike?

ceous system—Fig. 183 being a *turrilite*, which may be described as an ammonite twisted in a spiral instead of a disc-like form; and Fig. 184, a *scaphite*, in which the coils of the ammonite are partially unrolled and then turned up at the end, so as to give the shell a boat-like form.

298. **Fishes.**—The remains of not less than seventy-eight genera of fishes have been obtained from the Cretaceous system. The majority of these are of the old orders of placoids and ganoids, but during this era the ctenoid and cycloid orders (to which most existing fishes belong) were also ushered into existence—their remains being found, for the first time, in Cretaceous strata. And from this epoch onward, the orders of placoid and ganoid fishes gradually diminish and fade out, while the ctenoids and cycloids rapidly develop, until, at present, they seem to have reached their culminating point, and many times exceed in number and importance all other fishes.*

FIG. 185.



299. **Reptiles.**—The reptiles, so numerous in the two preceding eras, appear to have greatly diminished in numbers during the Cretaceous epoch. The ichthyosaurus and the plesiosaurus continued to exist, but their rule over the ocean was shared by a new gigantic lizard-like reptile—the *Mosasaurus.* This animal was about twenty-five feet in length, and had probably paddles instead of legs, and a tail suited to assist it powerfully in swimming. A perfect specimen of its head, which was found embedded in limestone, at

QUESTIONS.—What is known respecting the fishes of this epoch? What is said of the reptile life of this epoch?

* At the present time the sturgeons and the gar-pikes (of our western rivers) are the most familiar representatives of the ganoid order of fishes; and the skates, dog-fish, and sharks, of the placoid order;—"they are but the inconsiderable fragments of dynasties which were once coextensive with every sea, and predominated during the unreckoned ages which extended from the times of the Lower Devonian until those of the Chalk."

Mæstricht, Belgium (see Fig. 185), measured four and a half feet long, by two and a half broad.* Its teeth are found in the Cretaceous deposits of this country also.

In 1858, there was also found in the greensands of Camden County, New Jersey, the remains of a huge saurian reptile—the *Hadrosaurus*—which was closely allied to the iguanodon, and is proved, by the structure of its teeth, to have been herbivorous (plant-eating). The length of the Hadrosaurus is estimated, by Prof. Leidy, to have been about twenty-five feet; but a better idea of its enormous size may be gained from the statement, that its thigh bone is nearly one-third longer than that of the mastodon. Its hind leg bones, when put together, measure seven feet, upon which the pelvis, back-bone, and upper skin would still go on, making it nine or ten feet high upon the haunches. The animal was probably amphibious. Its bones can be seen at the Academy of Natural Sciences in Philadelphia.

The remains of crocodiles and turtles are also common in the rocks of the Cretaceous system. Fig. 186 represents a specimen of fossil tortoise, from the chalk of England.

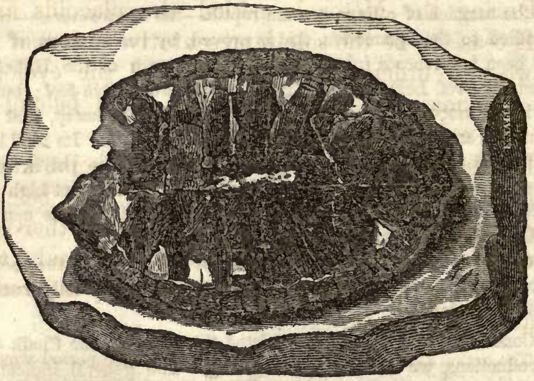
300. Concerning the land which skirted the ocean of the Chalk epoch, or of its productions, we know almost nothing. The general indications are, that the climate was genial, and favorable to the production of cycadaceæ, palms, and coniferous plants, on land, and of corals, gigantic reptiles, and turtles, in the waters. In the Cretaceous deposits of this country, fragments of fossil wood and leaves are by no means uncommon, and the microscopic structure of wood from the greensands of New Jersey does not differ materially from that of the pine trees which now grow in the same locality.

Questions.—What were the most remarkable Cretaceous reptiles? Have any gigantic Cretaceous reptiles been found in the United States? What is known respecting the dry land of the Chalk epoch?

*** The history of this remarkable fossil may be said to form a part of the romance of geological history, and is related by Mr. Mantell, as follows: In 1770, the workmen employed in blasting limestone from some celebrated quarries at Mæstricht, in the Kingdom of Belgium, perceived, to their astonishment, the jaws of an enormous animal attached to the roof of a cavern which they had excavated. The discovery was immediately made known to M. Hoffman, a naturalist of the town, who repaired to the spot, and for weeks presided over the arduous task of separating from the rock the mass of stone containing the remains. His labors were at length repaid by the successful extraction of the specimen, which he conveyed in triumph to his honse. Unfortunately the Dean of the Cathedral claimed the fossil in right of being lord of the manor, and succeeded, by a law suit, in obtaining the precious relic. It remained in his possession for many years, and Hoffman died without regaining his treasure, or receiving any compensation. The French revolution broke out, and the armies of the Republic advanced to the gates of Mæstricht; the town was bombarded, but by desire of a committee of scientific men, who accompanied the French troops, the artillery was not allowed to play on that part of the city in which the celebrated fossil was known to be contained. In the meanwhile, the ecclesiastic, shrewdly suspecting why such peculiar favor was shown to his residence, concealed the specimen in a secret vault; but when the city was taken the French authorities compelled him to give up his ill-gotten prize, which was immediately transmitted to the *Jardin des Plantes*, at Paris, where it now forms one of the most striking objects in that magnificent collection.**

In the Cretaceous strata of Europe, the bones of Pterodactyles and of true birds have been found, and also certain remains which are surmised to be those of monkeys.

FIG. 186.



301. **Close of the Mesozoic Period.**—With the close of the Cretaceous system the Mesozoic period of geological history terminates, and a new order of things begins. So abrupt, indeed, is the break at this point of the geological series, that of all the numerous forms of life found in the Triassic, the Oolite, and Cretaceous systems, hardly a single species crosses the gap, and is found in the strata of the succeeding (Tertiary) system—the exceptions, it is affirmed, being one shell, one coral, and certain microscopic organisms or infusoria. Of these last, fifty-seven species occurring in the chalk, are, according to Ehrenberg, still found living in different parts of the earth, and have been apparently preserved from the destruction which has overtaken other races, by the very humility of their organization and position.

The characteristic features of the Mesozoic period were—

1. The absence of mammiferous animals from the earth, with the exception of a few genera of small size, belonging to the humble class of marsupalia. The remains of Mesozoic reptiles have been often mistaken for those of Cetacea (whales, seals, porpoises, etc.), but it is now generally held that *none* even of this class of marine mammals were called into existence until the dawn of the subsequent period :—

QUESTIONS.—What period closes with the Cretaceous system? What reasons exist for making a division of the geological series at this point?

2. An immense development of reptiles, which tenanted the land and sea in such numbers, that the Mesozoic period is often spoken of as the "reign" or "dynasty" of reptiles:—

3. During the Mesozoic period the placoids and the ganoids cease to be the sole representative orders of fishes; and two new orders—the ctenoids and the cycloids, to which the majority of our present fishes belong—were called into existence:—

4. The beautiful group of chambered shells, known as the ammonites, and the curious family of the belemnites, belong exclusively to this period; while the other prevailing forms of invertebrate life—the coral animals, the crinoids, crustacea, etc.—were characteristically different from the Palæozoic species.

302. The action of igneous forces during the Mesozoic period was frequent and powerful, and was especially manifested in the eruption of many of the great masses and ranges of trap rock of this country and of Europe; the molten matter having risen along extensive lines in the earth's crust, and overflowed and accumulated upon its surface. Such an example of a line of eruption, in this country, is afforded by the belt or range of trap rocks which runs along the Valley of the Connecticut River—entirely across the States of Massachusetts and Connecticut—and which has Mounts "Holyoke" and "Tom," and "East" and "West" Rocks at New Haven, as its most conspicuous elevations. This eruption of trap is known to have taken place during the deposition of those sandstones of the Connecticut Valley which afford the remarkable fossil foot-prints; since the strata of the sandstones have, in some instances, been penetrated and overflowed by the trap, and in others have been deposited upon the igneous rock subsequent to its consolidation; and as these sandstones are, undoubtedly, of Oolitic or Triassic age, we have the geological date of the formation of this trap range and of the above-mentioned mountains, determined with comparative certainty. The trap range, which occupies a portion of the Southern Valley of the Hudson, and appears conspicuously in the bold bluff of the "Palisades," was also probably erupted at the same epoch. In Europe, Mesozoic traps are abundant; and, at about the close of the Cretaceous epoch, immense quantities of basalt were poured out, covering a great part of the North of Ireland, and forming the well-known "Giant's Causeway." (See § 103.)

Concerning the attendant phenomena of these great eruptions, and the changes which they must have produced in the topography, climate, and

QUESTIONS.—What were the characteristic features of the Mesozoic period? What is said of the action of igneous forces during this Mesozoic period?

organic life of the countries affected by them, we can probably form but little idea. The mightiest volcanic eruptions of the historical period are our only materials for comparison, and it would seem as if those portions of the earth, through which the molten trappean rock—now hardened into mountains—rushed in floods to the surface, must have been, for the time being, literally "lands of fire."

CAINOZOIC PERIOD.

303. The Cainozoic, or Recent Life Period, includes the Tertiary system, and all the geological formations of subsequent date, up to the present epoch.

TERTIARY SYSTEM.

304. The earlier geologists divided the stratified crust of the earth into three great formations, viz., the Primary (first), Secondary (second), and Tertiary (third); and regarded as Tertiary all that occurs above the chalk. The term thus originating, is still retained, but the progress of discovery has rendered it necessary to restrict and modify its meaning; and it is now usual with most geologists to consider as Tertiary all those formations which occur above the Cretaceous system, till the close of the so-called Drift deposits; and as "*Post-Tertiary* or "*Recent*," every accumulation which appears to have been formed since the Drift epoch.*

305. **Divisions of the Tertiary System.**—As has been already stated, it is generally believed by geologists that the species of animals and plants inhabiting the earth during the Mesozoic period, with very few exceptions, passed out of existence before the commencement of the epoch represented by the Tertiary system. We accordingly find, in examining Tertiary strata, that the fossils contained in them are not only new, but of *Cainozoic type*, by which expression, we are to understand, that they are all more or less allied to, or even identical with, existing genera. In the oldest Tertiary deposits, or those which lie immediately above the Cretaceous system, there are, probably, no fossils which are exactly the same as any living species; but as we ascend in the series we find, first one shell, and then another, which seems actually of the same species as those which still live;

QUESTION.—What geological formations are included in the Cainozoic periods? What was the origin of the term Tertiary? What are the generally recognized limits of the Tertiary system?

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* Some geologists do not include the "Drift" in the Tertiary system; while others include not only the drift but every other accumulation formed subsequent to the drift up to the present period.

until, finally, in the later deposits of the system, the remains of species of shells still living greatly predominate, and the presence of absolutely extinct species becomes the exception.*

306. In view of these facts, and taking the percentage of living species of shells found fossil in different parts of the system as their guide, geologists have divided the Tertiary strata into four groups; which, commencing with the oldest and ascending in the series, have been designated as follows: 1. EOCENE; 2. MIOCENE; 3. PLIOCENE; 4. PLEISTOCENE.

Each of these names, by its signification, is intended to express the paleontological character of the group to which it applied. Thus—

Eocene (Gr., ἠως, dawn; and καινος, recent) implies the *dawn*, or *commencement* of existing things—about five per cent. of the shells found in the strata of this group being identical with living species.†

Miocene (Gr., μειων, less) implies that the proportion of living species is still less than that of the extinct—about twenty-five per cent. of the shells found fossil in this group being identical with living species.

QUESTIONS.—Where, in the geological series, do we first find fossils which are regarded as identical with living species? In what manner have the strata of the Tertiary system been divided? What is the signification of the names applied to groups of the Tertiary?

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* "Whoever examines a museum containing a pretty complete collection of organic remains, arranged in chronological order, cannot fail of being struck with the following facts: When looking over the Palæozoic fossils, the forms will all appear so strange to him, that he will hardly be able to pronounce to which class of the animal kingdom some of them belong. Even where the class is evident, as for instance with the shells, he will see that they obviously differ from existing shells. There are no oysters, or barnacles, or cockles, or limpets among them. The more familiar the observer may be with our present kinds, the more strange the ancient specimens will appear. When he proceeds to the shells of the Mesozoic period they will seem much more familiar to him. He will say of one, perhaps, 'This is like an oyster,' or 'a Venus (clam);' or, of another, 'This resembles a trochus;' still, if he be well acquainted with recent shells, he will not be able to discover a single specimen to which he can assign not only a generic but a specific name. He will not be able to say, 'This is such and such a Venus, or trochus, of the same species as one that I have in my cabinet of recent shells at home.' When, however, he comes to the fossils got from tertiary rocks, it is no longer the difference between the fossil and the living forms that will strike him, but their resemblance, and, in some cases, their identity. The curious, old puzzling forms have all disappeared; almost every species belongs to a still existing genus, or is very closely allied to it; oysters and barnacles, cockles, limpets, and numerous other kinds now appear in great abundance, and in many varieties. We have, therefore, in these facts, most obvious expression of a great law, that, namely, of the gradual approximation to existing forms, and the gradual appearance of existing species. The first may be traced throughout the series of life, from the earliest to the latest times; the last, which is its necessary conclusion, is only apparent in the Tertiary epoch."—*London Quarterly Review.*

† Some eminent naturalists, among whom we may include Professor Agassiz, are of the opinion that while fossil and living species are often closely related, and apparently the same, yet we cannot in any case prove complete identity.

Pliocene (Gr., πλειων, more) implies that the proportion of living species is more or greater than that of extinct—the number of living forms among the fossil shells of this group ranging from fifty to seventy per cent.

Pleistocene (Gr., πλειστος, most) implies a majority; and in this group the shells found fossil are mostly those of species inhabiting the present seas.

307. **Eocene, Miocene, and Pliocene Groups.**—These *three* groups (which, according to the classification adopted by some geologists, are made to comprise the whole of the Tertiary system) resemble one another so closely in their lithological characters that it is almost impossible to draw any distinct line of separation between them, or to identify them, except by a comparison of their inclosed fossils with living species. "They should, in fact, be regarded as the successive steps or stages of one great and undisturbed formation."

Composition.—The deposits referable to these groups, are, on the whole, much less consolidated than the strata of the older systems; and consist, *for the most part*, of variously colored sands and clays, with interstratified limestones, gypsums, siliceous sandstones, marls, and, not unfrequently, beds of lignite.

308. **Geographical Distribution.**—As far as discovery has gone, there are few countries in which Eocene, Miocene, or Pliocene Tertiary strata have not been detected. In Europe and Asia they occupy well-defined

FIG. 187.

1. River Thames. 2. London. 3. Marine Sands.

tracts or basins, and appear to have been deposited in inland seas or estuaries of limited extent. In some instances the strata are strictly marine, and in others as decidedly fresh water; while in many of the Tertiary basins of Europe they are partly fresh water and partly marine, "as if there had been frequent submergences and elevations, or, at all events, periods when fresh water inundations prevailed over the areas of deposit." The cities of London,

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QUESTIONS.—What is said of the lithological character of the Eocene, Miocene, and Pliocene Tertiaries? What of their composition? What of their geographical distribution in the Old World?

Paris, and Vienna are each situated upon a Tertiary basin. Fig. 187 represents a section of the London basin, which lies in a trough or hollow of the Cretaceous system.

In North America, Tertiary deposits of the groups of the Eocene, Miocene, or Pliocene occur along the Atlantic coast, from Massachusetts to Mexico, and include the whole of Florida and large areas of the States of Alabama, Mississippi, Louisiana, Texas, and Arkansas. They are also found upon the Pacific coast, from Lower California to Russian America; and in the interior of the Continent, upon the eastern slope of the Rocky Mountains, in the region of the head-waters of the Missouri—Kansas and Nebraska—they cover an immense extent of surface. Upon the Atlantic coast, south of Delaware, the western limit of these Tertiary deposits is at the first or lowest falls of the principal rivers, and is generally marked by the long-leaved pine (*Pinus palustris*), whose distance from the shore is said to be limited by these formations.

309. **Life of the Epochs represented by the Eocene, Miocene, and Pliocene Tertiaries.**

Plants.—The vegetation of the earth during the earlier ages of the Tertiary must have presented an aspect widely different from that of any former era. The tree-ferns, the cycadaceæ, and the allied plants, so abundant in the Mesozoic period, sink into their present proportions; while true exogenous trees and shrubs, which had previously few or no representatives in nature, became largely developed.

During the epoch of the Eocene the vegetation appears to have been of a tropical or semi-tropical character, and belonged, for the most part, to species which are now extinct. In the latitude of London there were, undoubtedly, forests of palms; inasmuch as from the strata of Eocene clays, upon which the city of London is built, the fruits of no less than thirteen different species of this family are obtainable.

In the Middle or Miocene Tertiary the fossil vegetation partakes, perhaps, in a nearly equal degree, of a temperate and tropical character but as we rise in the series the temperate forms predominate; and in the Pliocene strata the vegetation closely resembles that which is now found in the temperate regions of North America, Europe, and Japan. In the United States, however, a large number of fruits and seeds of apparently tropical character have been obtained from a deposit of lignite of Upper Tertiary age, occurring as far north as Brandon, in the State of Vermont.*

QUESTIONS.—What of their distribution in North America? What is said of the vegetation of the earth during the earlier ages of the Tertiary? What is known of the vegetation of the Eocene epoch? What of the Miocene and Pliocene epochs? Is there any evidence of the former existence of a tropical vegetation in New England?

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* So far as we can judge, says Hugh Miller, neither flock nor herd could have found support on the greenest and richest plains of the lands of the Carboniferous epoch or of the Oolite; and it is not until we enter on the Tertiary ages that we find floras amid which a man might have profitably labored as a dresser of gardens, a tiller of fields, or a

310. **Amber.**—One of the most curious products of the Tertiary system is the substance termed *amber;* which is now known to be the fossil resin of an extinct species of pine. It is usually found in beds of tertiary clays and sands, and is often associated with the wood of the trees from which it was exuded—the wood being in a state of lignite, and sometimes having the amber adherent to it. The most abundant source of supply of amber is a Tertiary formation on the Prussian coast of the Baltic Sea, where the amber is obtained by digging and mining, and is also found in detached masses upon the sea shore, where it is washed up by the waves from Tertiary strata beneath the ocean. As much as 800 pounds have been thus thrown up on the Baltic coast during a single storm. Amber also occurs in the Tertiary clays of Great Britain, and fine specimens are not unfrequently found while excavating beneath the city of London. In the United States it has been found at various localities (though not in large quantities); as at Amboy, New Jersey; Gay Head, on Martha's Vineyard; and at Cape Sable, in Maryland. The largest specimen of amber known weighs eighteen pounds, and is preserved in the Royal Museum of Berlin.*

But apart from the circumstances of its origin and occurrence, amber has, for the geologist, a peculiar interest, inasmuch as it forms the best of all materials for the preservation of the most delicate organisms of the Tertiary ages. Mosses, fungi, and liverworts are plants of so delicate a structure that they are rarely or never preserved in shale or stone; but specimens of all three have been found locked up in amber, in a state of the most perfect keeping. And, besides containing fragments of the pine which produced it, amber has been found to contain minute pieces of four other species of pine, with bits of cypresses, oaks, poplars, beeches, etc., in all forty-eight different species of shrubs and trees, which must have flourished in the forests where it was exuded, and which, "viewed in a group, may be regarded as constituting," says Prof. Goeppert, "a flora of North American character."

The most remarkable organisms of amber are, however, its fossil insects, which, originally enveloped in the resin as it flowed in a liquid state from the tree, have been preserved in a condition of perfect entireness. In the amber of Prussia alone, upward of 800 different kinds of insects have been determined,

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QUESTIONS.—What curious product is found in the Tertiary system? What is amber? Under what circumstances, and where is it found? What circumstances render amber particularly interesting to geologists? What is said of the organisms inclosed in it?

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keeper of flocks or herds. Furthermore, there are whole orders and families of plants of the very first importance to man, which do not appear until late in even the Tertiary system. According to Agassiz, the order of Rosaceæ—an order to which the apple, the pear, the peach, the raspberry, the strawberry, the almond, and most cultivated fruits belong, together with all the species of roses—was introduced only a short time previous to the appearance of man upon the earth. "And the true grasses—a still more important order, which, as the cereal plants of the agriculturist, feed at the present time at least two thirds of the human species, and in other humbler varieties form the staple food of the *grazing animals*—scarce appear in the fossil state at all. They are peculiarly plants of the human period."

* The value of amber depends much upon the size and purity of the specimen. Pieces of ten or twelve pounds weight command several thousands of dollars; while a piece of a pound weight may not sell for more than fifty dollars.

most of them belonging to species and even genera, that appear to be distinct from any now known; while of the others, some are nearly related to European species, and some seem identical with living forms that inhabit the tropics. Among these insects, the first fossil bee is found, associated with moths and butterflies; a fact which proves the contemporary existence of flower-bearing herbs and trees.

311. **Animals.**—The fossil invertebrate animals of the Eocene, Miocene, and Pliocene groups—infusoria, corals, star-fishes, molluscs, crustacea, insects, etc.—are extremely abundant, both numerically and in point of species.

In this country, deposits, composed almost entirely of the siliceous coverings of infusorial organisms, constitute no inconsiderable part of the Eocene and Miocene Tertiary strata of Maryland and Virginia—some of the beds of infusorial earth near Richmond, Va., being from twenty to fifty feet in thickness. (See § 68, Fig. 21.)

In the Old World the most important member of the Tertiary system is a formation of limestone, of the group of the Eocene, which is almost wholly made up of a class of fossil foraminiferous shells, of the size and appearance of a small coin; and hence termed nummulites, from Latin, *nummus*, a coin (see Fig. 188). In the Alps of Switzerland this nummulitic limestone attains a thickness of several thousand feet, and from thence it may be traced at intervals throughout Southern Europe, and Northern Africa into Asia, as far as the Himalaya Mountains, where extensive beds of it have been recognized at an elevation of 16,500 feet above the level of the sea. It was also largely quarried in Egypt for the construction of the Pyramids and the Sphinx, and the curious organisms that compose it have received from the Arabs the name of "Pharaoh's beans."*

FIG. 188.

QUESTIONS.—What is said of the fossil invertebrate animals found in the Eocene, Miocene, and Pliocene Tertiaries? What of the infusorial deposits of this country? What is the most important of the Tertiary deposits of the Old World? What is said of the distribution of the nummulitic limestones?

* The use of this limestone in the construction of the Pyramids illustrates the fact, that "some of the oldest things in the world, in their relation to human history—erections, many of which had survived the memory of their founders, even in the days of Herodotus—are formed of materials so modern in their relation to the geological epochs, that they had no existence as rock until after the Palæozoic and Mesozoic ages had gone by." Not only the "Quincy granites" and "Berkshire marbles" of New England, but even the red and buff sandstones so extensively quarried in the Valley of the Connecticut River, in New Jersey, and Nova Scotia, are of an antiquity incalculably vast compared with the stone out of which the oldest of the Pyramids was built

Another peculiar formation of the European Eocene is the so-called "*indusial limestone*," a name given to a series of fresh water strata found in Central France, which are almost wholly composed of the cases, or "indusiæ," of the caddis-worms (the larvæ of a species of fly). Great heaps of these cases have been incrusted with carbonate of lime, and have thus consolidated into a species of limestone.

In the Eocene deposits of the United States, east of the Mississippi, only marine fossils have been found; but some idea of their abundance may be derived from the fact, that a formation of the older Eocene, occurring at Clairborne, Alabama, has alone yielded more than 400 distinct species of marine shells, echinoderms, and fishes. Upon the Ashley and Cooper Rivers, near Charleston, S. C., beds of Eocene clays are also exposed in many localities, which are so crowded with marine fossils that a person seeing them for the first time can hardly find words to express his amazement at their number and perfect preservation. The majority of these fossils, however, belong to extinct species.

The Miocene beds of the Southern Atlantic States have thus far furnished about 200 species of marine fossils; and of these, about twenty per cent. of the shells and corals are regarded as identical with living species.

It has, however, been remarked, that of all the numerous organic remains contained in the Eocene and Miocene deposits of the Atlantic States, only two or three species in a hundred are common to both groups—a fact which indicates that a considerable period of time elapsed between the completion of the one and the commencement of the other, during which no strata were deposited in this region.

312. **Fishes**.—The number of fossil fishes found in the Eocene, Miocene, and Pliocene groups is very large—188 genera, embracing several hundred species, having been described.

One of the most celebrated localities of fossil fish known, occurs in a deposit of Eocene limestone at Mt. Bolca, in Northern Italy. Here, within a limited area, the rock contains thousands upon thousands of specimens in a most remarkable state of preservation. The fish are all compressed flat, but the scales, bones, and fins remain; their color (a deep brown) contrasting admirably with the light-colored limestone in which they are embedded. The presence of such immense numbers in one locality is explained on the supposition that the limestone in which they are inclosed was erupted into the ocean in a state of mud, by volcanic agency, and that the fishes were at once suffocated, and surrounded by the calcareous mass. Some idea of the perfection of these fossils may be formed from Fig. 189, which represents a specimen from this locality.

Questions.—What is the "indusial" limestone? What is said of the Eocene fossils of the United States? What of Miocene? Is it probable that any great interval of time elapsed between the deposition of these two groups of strata? What is said of the fossil fish of the Tertiary system? What locality is particularly celebrated for these fossils?

FIG. 189.

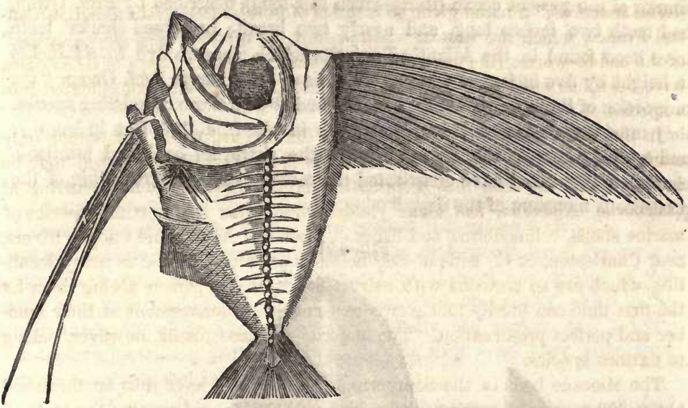

Fig. 190 represents a slab of Tertiary marl, from Central France, which contains a multitude of small fishes, as perfect as if recently enveloped in soft mud.

FIG. 190.

The Squalidæ, or Shark family, have had representative species in the oceans of every geological epoch since the first creation of fishes; but in the seas of the Eocene and Miocene this family appears to have flourished in great numbers; and, in the Eocene and Miocene strata, along the Atlantic coast of the United States, the teeth of sharks are among the most common of marine fossils. Some of these teeth are of immense size, and must have

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QUESTION.—What class of fishes were especially numerous in the seas of the Eocene and Miocene?

belonged to sharks much larger than any living species. One of the largest sharks of the present ocean (thirty-seven feet long), described by Prof. Owen, had teeth two inches long, and nearly two broad; but fossil sharks' teeth have been found in the Atlantic Tertiaries which measure five to six inches in height by five inches in width, at the base. "If," says Prof. Owen, "the proportion of these extinct sharks corresponded with those of existing species, they must have equaled the great whales in size (*i. e.*, 100 feet in length); and combining, with the organization of the shark, its bold and insatiable character, they must have constituted the most terrific and irresistible of the predaceous monsters of the deep."

FIG. 191.

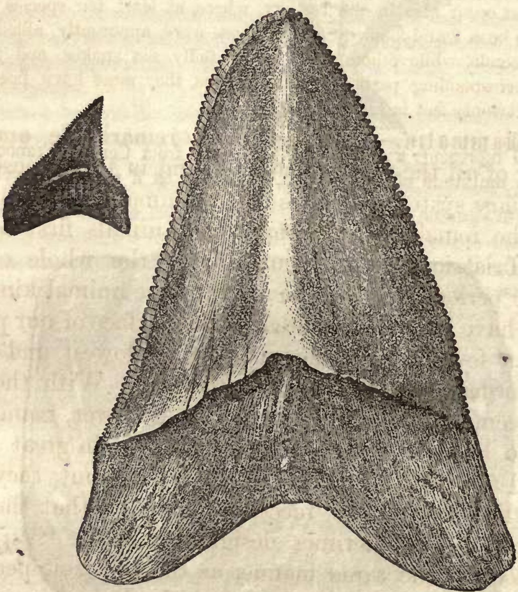

Fig. 191 represents specimens of these fossil teeth of sharks. In most cases their structure, and the serratures along their edges, are as perfect as are the teeth of existing sharks.*

QUESTION.—What is said of the teeth of sharks found fossil?

* The teeth of sharks, both fossil and existing species, all possess one essential character of structure, namely, a base, or osseous root, of variable form, which is implanted in the integuments; and a crown, or external portion, which projects into the mouth and is covered with enamel. These teeth are never embedded in sockets, or united to the solid margin of the jaws; they only adhere to the integuments of the mouth, and possess,

313. **Reptiles.**—The remains of reptiles are abundant in the deposits of the Tertiary epoch, but are not so numerous, comparatively, as in the rocks of the Mesozoic period.

Of crocodiles, eighteen species have been described from Tertiary strata —those found fossil in the Eocene clay, which underlies the city of London, being closely allied to the crocodiles which are now living on the Island of Borneo. Turtles were especially numerous during the Tertiary epoch, and not unfrequently attained to great size—the remains of one individual, found in Tertiary strata, at the base of the Himalaya Mountains, measuring twenty feet across the curve of the shell. The earliest indications which the palæontologist obtains of the existence of Ophidians, or serpents, upon the surface of our planet occur also in the Tertiary, where, at least, ten species of this family have been found fossil. Some of these were, apparently, allied to the boa, or anaconda, while others were, undoubtedly, sea snakes, and judging from the corresponding parts of recent species, they must have been from fourteen to twenty feet in length.

314. **Mammalia.**—But the most remarkable and interesting of all the fossil remains found in the deposits of the Tertiary system are those of Mammalia. As already stated, the remains of mammiferous animals first appear in the Triassic system; but during the whole of the Mesozoic period this great division of the animal kingdom seems to have been represented on the surface of our planet by only a few species belonging to its lowest and most inferior orders,—as the marsupalia, etc. With the very commencement of the Tertiary epoch, however, mammalia appear to have been called into existence in great numbers, and from this time onward, to the present, they constitute the predominant races, so much so, that the Cainozoic period is sometimes designated as the "*reign of mammals*," in the same manner as the Mesozoic period is termed the "*reign of reptiles*," and the Palæozoic period the "*reign of fishes.*"

QUESTIONS.—What is said of the reptilian life of the Tertiary epoch? What varieties of reptiles appear for the first time in the Tertiary? What are the most remarkable fossils yielded by this system? What is said of the development of mammalian life on the earth during the Tertiary ages? What designation characteristic of its life features is sometimes given to the Cainozoic period?

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in most of the sharks, great mobility. They are generally, moreover, disposed in rows; the anterior ones, being first used, fall out, and are replaced by those on the inner series. New teeth are also continually formed behind those which exist, and advance successively toward the anterior rows as the latter are shed, and in their turn occupy the first rank.

The Eocene ages were especially characterized by the existence of large numbers of animals of the order Pachydermata (Gr., *παχυς, thick; δερμα, skin*), an order of mammals which have hoofs, but do not chew the cud, and which are distinguished for the thickness of their skins—as the elephant, rhinoceros, hippopotamus, tapir, hog, horse, etc. The Pachydermata of the Eocene period were, however, so different from any now existing, that new *generic* names have had to be invented for almost all of them.

One variety of Pachydermatous animal, of which eleven or twelve species have been found—varying in size from that of a horse to that of a hog or sheep—had, in its skeleton, the united characteristics of the tapir, the rhinoceros, and the horse. It is named *Palæotherium* (Gr., *παλαιος, ancient;* and *θηριον, wild beast*), and was furnished with a short fleshy trunk, which probably adapted it to live like the South American tapir, in swampy districts, and feed on coarse vegetation. Fig. 102, page 186, will give some idea of its appearance and structure.

Another genus, of which five species have been found, was, in one respect, intermediate between the rhinoceros and the horse, and in another between the hippopotamus, the hog, and the camel. It was especially distinguished by the great length of its tail, which was longer than its body. This animal has received the name of Anoplotherium (*ανοπλος, unarmed*), and varied in size from the dimensions of a pony to that of a hare. (See Fig. 192.)

FIG. 192.

Besides mammals of the order Pachydermata, there have also been found in the Eocene Tertiaries the fossil remains of the dog, hyena, fox, opossum, squirrel, monkey, and bat—all of extinct species; also the bones of many species of birds.

The most interesting collection, probably, of the remains of the animals of the Eocene has been obtained from certain beds of gypsum, which form a part of the Tertiary basin in which the city of Paris is situated. In this formation

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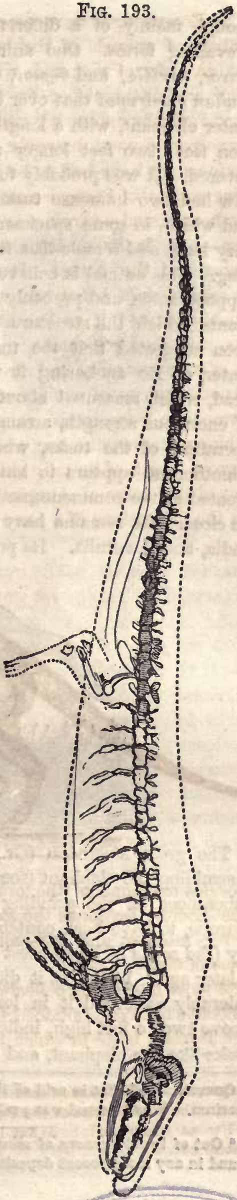
QUESTIONS.—What class of animals especially flourished during the age of the Eocene? What are the peculiarities of the Pachydermata? What were some of the most remarkable Eocene quadrupeds? What locality has furnished the most interesting fossils of the Eocene?

the remains of upwards of fifty species of quadrupeds have been found, four-fifths of which are referable to the order of the Pachydermata. The beds also contain land and fresh water shells, fragments of wood, with numerous bones of fresh water fish, reptiles, and birds. The skeletons of the quadrupeds usually occur isolated, and are often in such a peculiar and partial state of preservation as "to excite the curiosity of even the untaught workmen. Only half the skeleton is present. The limbs and ribs of the under side are found lying in nearly their proper places; while of the limbs and ribs of the upper side usually not a trace can be detected; even the upper side of the skull is often wanting. It would almost seem as if some pre-Adamite butcher had divided the carcass longitudinally, and carried away with him all the upper halves. The reading of the enigma seems to be, that when the creatures lay down and died, the gypsum, in which their remains occur, was soft enough to permit their under sides to sink into it, and that then gradually hardening, it kept the bones in their places; while the uncovered upper sides, exposed to disintegrating influences, either mouldered away piecemeal or were removed by accident."

FIG. 193.



In the Eocene beds of the United States, east of the Mississippi, the remains of no terrestrial mammalia or land quadrupeds have as yet been discovered, but vestiges of Cetacean mammalia* are not uncommon. In Clark County, Alabama, the colossal bones of an animal of this order, termed the "Zeuglodon," are of common occurrence in certain calcareous strata. Mr. Lyell speaks of the vertebral column of one skeleton, more than seventy feet in length, at one locality which he visited, and of another fifty feet long. Fig. 193 represents a restored appearance of the zeuglodon.

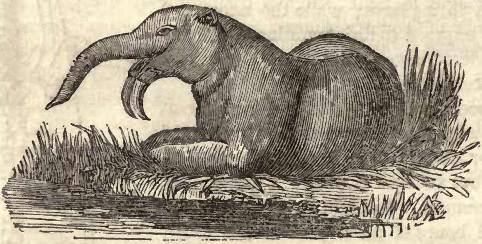
315. In the Miocene Tertiary, Pachydermata,

QUESTIONS.—What mammalian fossils have been found in the Eocene strata of the United States east of the Mississippi?

* The order Cetacea includes the whales, dolphins, seals, porpoises, and other warm-blooded animals inhabiting the ocean.

though mainly of a different type from their predecessors,* are still the prevailing forms. One animal of this kind, called the Dinotherium (Gr., *δεινος, terrible;* and *θηριον, wild beast*), is supposed to be the largest *mammalian quadruped* that ever existed. It seems to have been a kind of great water elephant, with a length of at least eighteen feet, and a height of fourteen feet; two feet longer and higher than the largest mastodon yet discovered. It was probably furnished with a trunk or proboscis, and the lower jaw had two immense tusks, curving downward, like those of the walrus, and which, in some specimens, were three feet in length. Its fore feet were very long, and a mole-like form of the shoulder-blade adapted them for digging. This animal is believed to have lived principally in the water, like the hippopotamus, and probably used its tusks for tearing up the roots of aquatic plants, which the structure of its teeth indicates it fed upon. It has also been suggested that the tusks were used for dragging the animal out of water, or for anchoring it to the shore while it slept in the water. Its head, which measured about three feet across, was provided with muscles of enormous strength, arranged so as to give the most potent effect to the operations of the tusks, whatever may have been their uses. The genus Dinotherium appears to have existed but for a limited time; having been created at the commencement of the Miocene epoch and becoming extinct at its close. Its remains have been found in France, Central Europe, Greece, India, and Australia. Its probable appearance is represented in Fig. 194.

FIG. 194.



The great Mastodon (Gr., *μαστος, nipple;* and *οδους, a tooth*), an animal resembling the elephant (see Fig. 208), and deriving its name from the protuberances on the grinding surfaces of its teeth (see Fig. 195), seems, in Europe, to have been contemporary with the Dinotherium; but in this country (the scene of its greatest numerical development) it appears to belong to a later age. In height it did not surpass the African elephant, but it considerably exceeded it in length—a specimen which could not have stood above twelve feet high, indicating a length of about twenty-five feet. It had tusks like the elephant, and a long, flexible proboscis.

QUESTIONS.—What is said of the animals of the Miocene epoch? Describe the Dinotherium. What animal was probably contemporary with the Dinotherium in Europe?

* Out of twenty genera of mammalia found in the Eocene, seventeen have never been found in any more recent deposits.

Another curious animal of this era, whose remains are found in Tertiary deposits, in India, was the "*Sivatherium*," which was larger than a rhinoceros, and furnished with four horns, and a proboscis. When living, it must have resembled an immense antelope or gnu, with the face and figure of a rhinoceros.*

FIG. 195.

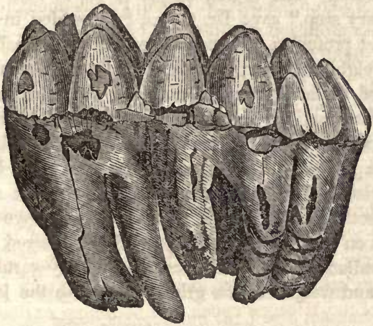


FIG. 196.

Fig. 195, tooth of the American mastodon; weight, 4 lbs.;—
Fig. 196, tooth of the fossil elephant, or mammoth (one-sixth of the diameter of the original).

316. A most extraordinary formation of the age of the Miocene Tertiary has been brought to light within a comparatively few years, in Nebraska, in the district of country known as the "*Mauvaises Terres*," or "*Bad Lands*," of the White River. Its location and geological features are thus described by Dr. Owen, U. S. Geologist, in an official report for 1851:—"From the uniform monotonous open prairie, the traveler suddenly descends one or two hundred feet, into an extensive valley (about thirty miles wide, by ninety in length), that looks as if it had sunk away from the surrounding world, leaving standing, all over it, thousands of abrupt, irregular prismatic and columnar masses, stretching up to the height of from one to two hundred feet, or more. So thickly are these natural towers studded over the surface of this extraordinary region, that the traveler threads his way through deep, labyrinthine passages, not unlike the narrow, irregular streets of some quaint old town; while viewed from a distance one might almost imagine himself approaching some magnificent city of the dead, where the labor of forgotten millions had left behind them a multitude of monuments of art and skill."

QUESTIONS.—What remarkable animal has been found in the Tertiary deposits of India? What extraordinary formation of the Miocene age exists in this country?

* The Tertiary deposit from which the remains of the Sivatherium are obtained lies at the southern base of the Himalaya Mountains, among the Sivâlic hills, in India, and has afforded a greater number of genera, and species of fossil mammalia, than any other region yet explored: such as the mastodon, elephant, hippopotamus, giraffe, camel, monkey, and various carnivorous animals allied to the lion and tiger. Casts of some of the most interesting of these fossils have been presented by the East India Company to the Boston Society of Natural History, and may be seen in their museum.

"On descending from the heights, however, and proceeding to inspect the deep, intricate recesses of this vast labyrinth, the realities of the scene soon dissipate the delusions of the distance. The castellated forms which fancy had conjured up change; and around one, on every side, is bleak and barren desolation."

But the physical features of the *Mauvaises Terres* are of little importance in comparison with its fossil treasures. The region seems to be, in fact, one vast charnel-house, and "at every step," says Dr. Owen, "embedded in the debris, lie strewn, in the greatest profusion, the remains of extinct animals."

In a collection of from six to eight thousand pounds of fossil bones brought from this locality, Prof. Leidy, of Philadelphia, has detected the remains of about thirty species of extinct mammalia. Many of these belonged to huge Pachydermatous animals, such as the hippopotamus (eight species of which have been found), rhinoceros, tapir, palæotherium, anoplotherium, etc. One extinct animal, called the "*Oreodon*," had grinding teeth like the elk and deer, and also sharp-pointed teeth like lions, cats, etc.; and must have belonged to a race that lived both on flesh and vegetables, and yet chewed the cud like the cow. Another, called the *Machairodus*, was wholly carnivorous, and "combined the size and weight of the grizzly bear with the jaws and teeth of the Bengal tiger."

Most of the bones are in a relatively good state of preservation, and are highly mineralized. Dr. Owen saw a nearly entire skeleton of a palæotherium, which measured, as it lay embedded, eighteen feet in length, by nine in height; also a jaw of a similar animal, which measured five feet along the range of its teeth. Besides the remains of mammalia, fossil turtles are numerous. At one point of the valley, which has the appearance of a floor of an ancient lake, they lie embedded by the hundreds; and, in some instances, have an estimated weight of a ton.

All the fossils thus far brought from the Mauvaises Terres of Nebraska are believed to belong to species that became extinct before the epoch when the Mastodon inhabited this country, and their general character indicates that the strata in which they occur embedded was deposited from fresh or brackish waters.

317. Besides the fossil animals enumerated, it is probable that every existing order of mammalia, with the exception of man, had its representatives upon the surface of our planet during the Tertiary epoch.

In former geological epochs, as has been already stated, the plants and animals of every region of the globe appear to have presented a great degree of sameness or identity, but during the later portions of the Tertiary epoch geographical distinctions and separations (life provinces, see § 207) began to prevail. Thus, Australasia is now the exclusive home of the kangaroos, wombats, and all other existing marsupalia, with the exception of the single genus of the opossum; and, very curiously, the bones of the mammalia

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Questions.—Give some description of it and its fossils. What proportion of the existing orders of mammalia are represented in the later Tertiary deposits?

found fossil in the Tertiary deposits of Australasia, have also proved, with very few exceptions, to be those of marsupials.* In like manner, the Tertiary fossil mammalia of South America resemble the sloths, armadillos, anteaters, and other animals which are now restricted to that continent. In New Zealand, before the arrival of Capt. Cook's ships, no mammal existed larger than a rat, and among the fossils of the Tertiary of these islands a like restriction of animal forms has also been discovered to prevail. Some genera of mammalia, however, have always had a much wider range than others, and the bones of the mastodon and horse, especially, have been found fossil in the Tertiary deposits of almost every quarter of the globe.†

318. **Pleistocene Group.**—In the present state of geological knowledge it is impossible to define the limits of this most recent group of the Tertiary system with precision, but upon one point all geologists are agreed, namely, "that while the Eocene, Miocene, and Pliocene strata were gradually, and during a long series of ages, deposited in seas, estuaries, and lakes, surrounded by land that enjoyed a high and genial climate, some immense changes—physically and geographically—took place over these areas, which brought the Pliocene to a close, and heralded the advent of the Pleistocene era. The distribution of Pliocene lands and seas was violently broken up, the climate was changed, and the huge mammalia that browsed in thousands in the jungly valleys, or roamed over the wooded plains, met with a rapid and all but total extinction."

QUESTIONS.—What remarkable difference is manifest on comparing the fossils of the Tertiary with those of the earlier systems? What is said of the limits of the Pleistocene group? What circumstances appear to have attended the advent of the Pleistocene era?

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* Recent geological explorations in Australia have put us in possession of many interesting facts respecting the animal life that prevailed on this great island continent during the Tertiary epoch. Nearly all the principal orders of terrestrial mammalia existing in other parts of the globe were represented, but with very few exceptions they were all marsupials, or pouched animals. Thus, for example, there was a large carnivorous quadruped, equaling, probably, the largest existing lion or tiger in size and ferocity, and yet was a pouched animal like the kangaroo or opossum. It was contemporary with, and probably preyed upon, kangaroos four or five times larger than any now existing, and also upon another herbiverous pouched animal (the Diprodon), which had a head and face somewhat like a kangaroo, and the proportions of a rhinoceros; the size of the Diprodon may be inferred from the circumstance, that its fossil skull measures three feet long, by one foot eight inches broad.

† At the time of the discovery of the American continent the horse was unknown to the natives, and probably did not then exist in the New World—the horses now found wild in North and South America being, undoubtedly, descendants of subsequent European importations. Yet the bones of the horse are found fossil in the very latest Tertiary deposits of the United States, and seem to warrant the inference that the species, after having been called into existence upon this continent, died out, and was then renewed from the Old World by the agency of man.

According to Prof. Owen, no unequivocal fossil remains of the sheep have as yet been discovered; although the bones of the goat are found fossil in deposits of the Pliocene and Pleistocene epochs. The inference from this negative evidence, therefore, is, that the sheep is not, geologically, more ancient than man.

319. **Physical Geography of the Tertiary Epoch.**—At the commencement of the Tertiary epoch many of the most extensive mountain ranges of the globe—as the Alps, Pyrenees, Carpathians, Himalayas, etc.—were not in existence. We know this from the circumstance, that strata of unmistakably Eocene age, filled with the remains of marine animals, are now found high up on their flanks or summits. (See Fig. 15.)* In this country, the great chain of the Rocky Mountains had also not attained its present elevation. Sir R. I. Murchison considers that the Alps, at the commencement of the Tertiary epoch, were represented by merely a long archipelago of islands, slightly raised above the surface of the ocean.

Some of the other marked geographical features of the globe, during the earlier ages of the Tertiary, as made known by geological investigations, were as follows: The Mediterranean, or another great and corresponding inland sea, covered the deserts of Sahara, Lower Egypt, and a part of Arabia. The Straits of Gibraltar, probably, did not then exist, and the waters of the Mediterranean mingled through the channels of the Red Sea and the Persian Gulf with the Indian Ocean. The islands of Great Britain were, probably, connected together, and also with the continent, the English Channel not having been excavated. The North Sea and the Baltic spread over the plains of Northern Europe, and another ocean stretched from Siberia and joined with the Mediterranean by the Black Sea. India was then a great triangular island. In North America, the Gulf of Mexico covered a great part of the territory of the Gulf States, and penetrated into the interior of the country, as far as the head waters of the Missouri; while a deep trough or channel of ocean water divided the continent along the line of the St. Lawrence and the present chain of the great lakes. South America at this epoch was, probably, represented by three great islands, the Isthmus of Panama not existing.

During the whole of the Tertiary epoch the mountain chains, above referred to, appear to have been gradually uplifted, and to have attained their present elevation at about the commencement of the Pleistocene era. In the case of the Alps, the final elevatory movements must have been of terrific violence, and amounted, according to Sir R. I. Murchison, "to a total inversion, in many places, of entire mountains."

320. **Glacial Epoch.**—During the early part of the Pleistocene era also, large portions of Europe, Asia, and North America, appear to have gradually subsided; and in connection with these vast oscillations of the crust of the earth, and, probably, as a consequence of the changes occasioned

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QUESTIONS.—What were some of the geographical features of the globe at the commencement of the Tertiary epoch? What changes of land and of climate took place over the northern hemisphere at the commencement of the Pleistocene era?

* Any one, says Sir R. I. Murchison (Proc. Royal Soc., 1851, p. 57), who will climb peaks of the Alps rising 8,000 or 9,000 feet above the level of the sea, in the vicinity of Lake Lucerne, may satisfy himself, that the crystalline schists and slates forming their summits were once mere mud, deposited from water, at the same time as the slightly consolidated clays which underlie the city of London.

by them in the distribution of land and water, the climate of the temperate parts of the northern hemisphere, which was before genial, experienced a great reduction of temperature.

This epoch of the earth's history is often spoken of as the "*glacial*" epoch or period, from the circumstance that glaciers appear to have then formed on almost all the mountains of the northern hemisphere; and it is even the opinion of many geologists that almost the entire surface of this hemisphere, north (at least) of the 40th or 50th parallels of latitude was covered at this epoch with ice of great thickness.

The traces of the existence of ancient glaciers, of great extent, in the northern part of the United States, and in Northern and Central Europe, are among the most interesting of geological phenomena. They are the same in every respect as now result from the action of existing glaciers, and comprise rocks grooved, striated, and polished, large masses of rocks disrupted and transported, and the peculiar glacial accumulations or ridges of detritus, which are technically known as *Moraines.* (See § 142.) In the Alps, unmistakable evidence exists that the extent of glacial action once reached full fifty miles beyond the limits of the existing glaciers. Scandinavia, in Europe, appears, moreover, to have been a sort of center from whence enormous glaciers, like those which now exist in Greenland, once radiated in all directions over the continent. In Great Britain nearly all the principal mountains of Wales and Scotland, none of which now reach the limits of perpetual snow, have been also the seat of glaciers.

In North America most distinct traces of glaciers have been discovered in numerous localities, upon the Green Mountain range of Vermont, Massachusetts, and New York, upon the Catskills, and upon the Laurentian Mountains of Canada. Upon the Green Mountains of Vermont and Massachusetts, where the phenomena have been very carefully examined by Prof. Hitchcock, the glaciers appear to have filled up and moved down the valleys opening into the present valley of the Connecticut River, and the valleys contiguous to its tributaries; and their course, following the sinuosities of the valleys, is made clearly manifest by the deep furrows and striæ which they have left upon the sides of the adjacent mountains.* In some instances

QUESTIONS.—What name is often given to this epoch? Do we find evidence of the existence of former extensive glaciers in the temperate zones of the northern hemisphere? What is the nature of this evidence?

* According to Prof. Hitchcock, the following are among the localities in New England, where traces of ancient glaciers are especially noticeable: In Massachusetts, on the Westfield River, in Russel; near Huntington; at Sodom Mountain, in Granville; and on the Deerfield River and its branches. In Vermont, at Windham and Grafton, on Saxton's River; on a branch of West River, in Jamaica; on the Otta Queechee, in Plymouth and Bridgewater; on the White River and its branches; and at Hancock, on the west side of the Green Mountain range.

also, the remains of immense moraines, crossing the valleys and indicating the termination of the glaciers, are still visible. The length of one of these ancient glaciers of Vermont has been ascertained by Prof. Hitchcock to have been at least eighteen miles.

321. **Drift.**—The subsidence of land in the northern hemisphere, already spoken of as occurring during the early part of the Pleistocene, or Glacial epoch, appears to have continued until a great part of Northern America, Northern and Central Europe (including the British islands), and Northern Asia, were submerged beneath the ocean. In Northern America the extent of this subsidence has been estimated at from 2,000 to 4,000 or 5,000 feet, or sufficient to submerge nearly all the mountains of Canada, New York, and New England. In Europe, the amount of subsidence has been estimated, for different localities, at from 1,000 to 3,000 feet.

The evidence upon which geologists have arrived at these conclusions is substantially as follows:—

Spread out over a great portion of the northern hemisphere, and resting upon rock formations of every system, there is found to exist a vast accumulation of abraded material, such as clay, sand, gravel, and detached fragments of rock, termed bowlders; the latter being sometimes scattered loosely over the immediate surface, and sometimes inclosed in beds of clay or gravel, without regard to gravity or any other law of arrangement. These accumulations, in some places, exhibit a stratified arrangement, but, in general, their appearance suggests at once the idea, that they have been transported and confusedly piled up by some unusual and extraordinary operation of water.

By the early observers, the origin of these deposits was referred to the Noachian deluge, and the general name of Diluvium (Lat., *a deluge*) was applied to them; but as the subject came to be better understood, this opinion was abandoned, inasmuch as it was apparent that no transient deluge could have produced the effects exhibited; and, at the present time, the whole formation is believed to be mainly the result of the long-continued and joint action of water and of ice, at a time when the lands in question were partially or wholly beneath the ocean.

The name also by which the formation is now almost universally recognized is DRIFT, although the terms "*Diluvium,*" "*Diluvial Drift,*" "*Glacial Drift,*" "*Bowlder Formation,*" and "*Erratic Block Group,*" are frequently used as synonyms.

QUESTION.—To what extent did the subsidence of northern lands probably proceed? What is mainly the evidence which has led geologists to these conclusions? What name has been given to the accumulations of abraded material spread over the northern hemisphere?

Fig. 197 represents drift (*b*), confusedly blended, and resting upon highly inclined strata of the Silurian age (*a*), and covered with deposits of the same material regularly stratified (*c*). Fig. 198 represents a section of a drift accumulation of coarse gravel, sand, and bowlders, which also contains deposits of fine clay.

FIG. 197.

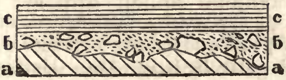
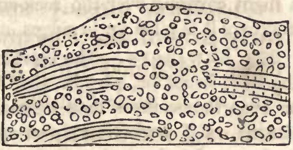


FIG. 198.



322. **Limits of the Drift.**—In America the Drift extends from the polar regions as far south as about latitude 40°. "Its southern limit of *continuous deposit* in the United States is a line drawn from Long Island, through Central Pennsylvania, to the Ohio, with occasional extensions southward in the valleys of the Delaware, Susquehanna, and Mississippi."* In Europe all traces of it are lost in the countries bordering on the Mediterranean. In South America deposits similar to the northern Drift have been recognized in Terra del Fuego, and Patagonia.

The vertical range of the Drift in this country can be inferred from the fact "that all the mountain peaks of Northern America, east of the Rocky Mountains, are covered by its water and ice-worn materials, with the exception of several hundred feet of the conical summit of Mount Washington, in New Hampshire, which is covered with angular fragments of rocks that have never been disturbed except by frost." In many localities in New England, New York, and Canada, beds of clay containing marine shells occur, in some instances, at an elevation of over 500 feet above the present sea level, and are then overlaid by Drift deposits of sand and gravel of varying thickness. In England and Scotland, moreover, marine shells, mingled with the Drift, have been found at elevations as high as 2,300 feet above the present ocean. According, also, to Sir Charles Lyell, the shells occurring in the Drift deposits of Canada and of Scotland, are of an Arctic type, and indicate a colder climate than now prevails in those countries. In 1849, during the construction of the Rutland and Burlington railroad, in Western Vermont, an almost entire skeleton of a whale was found embedded in blue clay, of the Drift formation, from ten to fourteen feet below the surface.† A similar

QUESTIONS.—What are the horizontal limits of the Drift? What is its vertical range in this country?

* The traveler, starting from Northern New England, and passing south along any of the great lines of railway, can obtain, from the excavations on the sides of the road, many excellent views of sections of Drift accumulations; and can form a good idea of the nature and arrangement of the Drift material. He will also observe, that south of the line above indicated, the gravel banks and bowlders, which are so characteristic of New England, with occasional exceptions, entirely disappear.

† This skeleton is preserved, and may be seen in the State Geological Collection of Vermont, at Burlington.

skeleton has been also found in a clay-pit near Montreal, fifteen feet below the surface, associated with various species of marine shells. At Gardiner, and Augusta, Maine, beds of clam and muscle shells, scarcely distinguishable from those now existing on the adjacent coast, occur beneath deposits of sand and gravel sixty feet in thickness.

The Drift material is diffused very unequally. In some localities it forms only a slight covering over the rock-surface, or it may be entirely wanting, while in others it is piled up in ridges and hills of several hundred feet elevation.

323. **Bowlders.**—The bowlders, which are everywhere characteristic of the Drift formation, vary in size from a few pounds to masses of hundreds or even thousands of tons weight. They are generally more or less rounded in form, as if water-worn, and are unlike the rocks in place which underlie them. In short, the whole physical condition of these loose masses is such that the most superficial observer could hardly fail of arriving at the conclusion, that they are foreign to the localities where they occur, and must have been transported from a distance by some powerful agency.

FIG. 199.

In some districts the bowlders are strewn so thickly that they almost continuously cover many square miles of surface. This is especially true of many parts of New England. Fig. 18, page 49, represents the appearance of the

QUESTIONS.—What other unmistakable proofs of the former submergence of this country beneath the ocean have been obtained? What is said of the diffusion of the Drift material? What is said of the occurrence of bowlders in the Drift formation? What of their number?

country at Squam, on the coast of Massachusetts, near Gloucester. In other districts, only single bowlders, separated by long intervals, or a few "perched blocks" reposing on some height, will be met with.

The size of these transported blocks is often enormous. At Fall River, Massachusetts, on the south side of the bay, at the mouth of the Taunton River, a bowlder of conglomerate rock was uncovered in a gravel ridge, which originally weighed 5,400 tons, or 10,800,000 pounds. The ledges of this conglomerate are met with only on the other side of the bay. This remarkable bowlder has been entirely destroyed for building purposes.

Fig. 199 represents a bowlder (figured and described by Dr. Hitchcock), located upon a mountain in Whitingham, Vermont, which is forty feet long, thirty-six feet wide, twenty-seven feet high, and is estimated to weigh 3,400 tons. This bowlder has, unquestionably, been transported across a valley 1,000 feet deep to its present position.

FIG. 200.

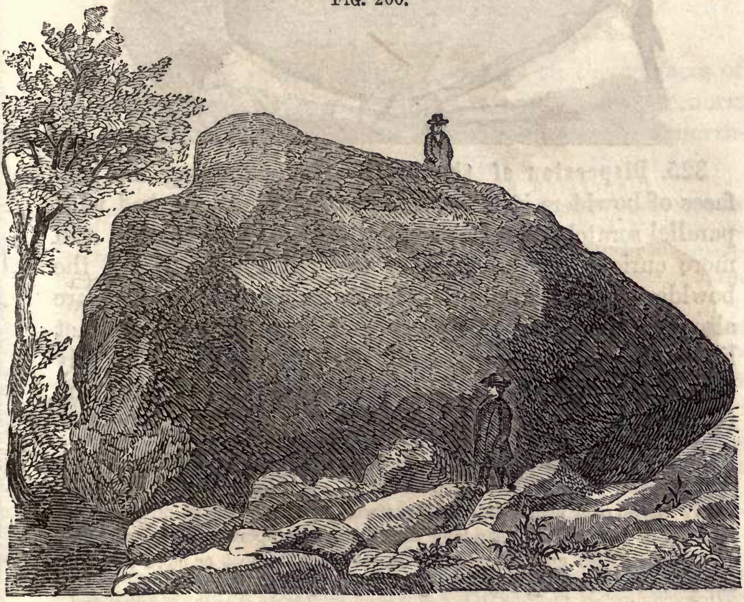


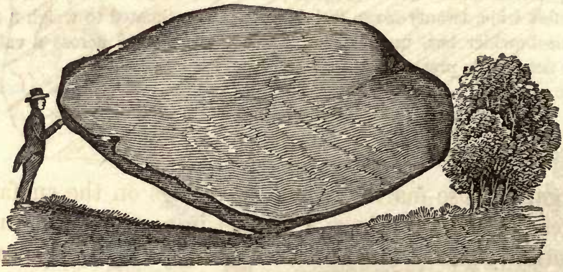
Fig. 200 represents one of the largest known bowlders in New England, located at Danvers, Mass. It is the property of the Essex County Society of Natural History, and is carefully preserved from spoliation, as a geological curiosity. On Hoosic Mountain, in the town of Adams, Mass., is a bowlder

QUESTION.—What of the size of some bowlders?

of granite, weighing 500 tons, which has been transported from a ledge on an opposite mountain across a valley 1,300 feet deep, and at the same time elevated about 1,000 feet.*

324. **Rocking Stones.**—Bowlders of many tons weight are sometimes met with so nicely poised and balanced upon other rocks that they may be easily made to oscillate by the hand, though an immense force would be required to dislodge them. Such examples are termed "rocking stones." Fig. 201 represents a rocking stone in Fall River, Mass., poised upon granite, and weighing 160 tons.

FIG. 201.



325. **Dispersion of the Drift.**—On examining the surfaces of bowlders it is common to find them marked with parallel scratches (striæ) and groovings; and what is still more curious, the surfaces of the rocks upon which the bowlders, gravel, and other Drift accumulations rest, are also more or less smoothed and marked with distinct linear striæ and furrows, as if the Drift had been forcibly carried forward, and had scratched and worn them during its passage.

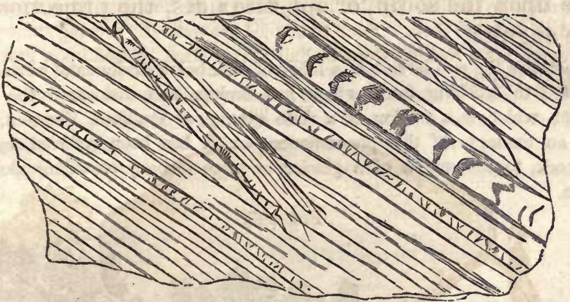
It has been conjectured that if the rocks of the northern portion of this country could be laid bare, the traces of this abrading action would be distinctly visible over nearly half their surface. Rocks, however, of slight consistency, or which have been long exposed to atmospheric influences, rarely exhibit it. These grooves, or striæ, are sometimes a foot or more in width, and several inches deep, but most generally they are a fraction of an inch in depth, and from a quarter of an inch to two or three inches in width. Some-

QUESTIONS.—What are rocking stones? What may be commonly observed upon the surfaces of bowlders? What curious fact has also been noticed respecting the rock surfaces upon which the Drift rests? What is said of extent and size of the Drift markings?

* The action of ice in transporting similar large blocks of stone, has been already noticed, and may be advantageously reviewed in this connection. (See § 142, 143.)

times the striæ assume the form of the most delicately cut parallel lines, so fine that the aid of a lens is requisite for their examination. Fig. 202 represents examples of Drift striæ on black limestone, from near Lake Champlain, Vermont.

FIG. 202.



Again, these markings and groovings on the surfaces of ledges, or rocks in place, all trend in one general, uniform direction, namely, from north to south, varying from northeast to southwest, and from northwest to southeast.

"In general," says Prof. Hitchcock, "they do not alter their course for any topographical feature of the country; but cross valleys at every conceivable angle, and even if the striæ run in a valley for some little distance, when the valley curves the striæ will leave it and ascend hills and mountains, even thousands of feet high."

In New England, New York, and Canada, Drift striæ have been observed upon the summit of rocks of most of the highest mountains, and from the size and extent of the furrows, it seems certain that the agency which produced them, was nearly, or quite as energetic, as at lower levels."*

Another remarkable circumstance connected with the phenomena of the Drift striæ is, that they are never found

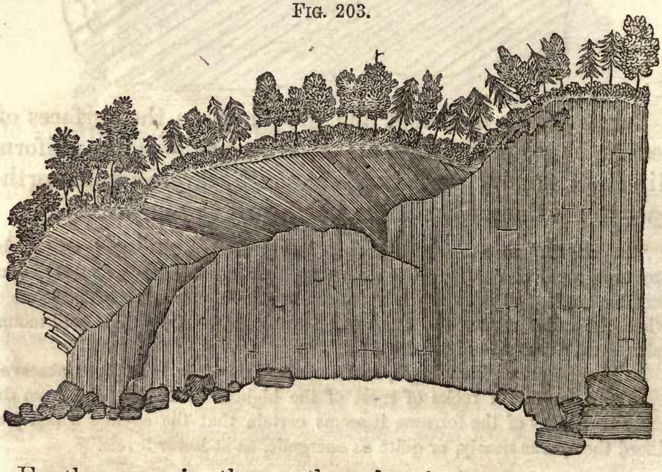
QUESTIONS.—Do the Drift striæ run in any uniform direction? At what elevations have they been observed?

* On the White Mountains of New Hampshire Drift furrows exist, at an elevation of 5,000 feet above the sea—the greatest elevation at which they have been found in North America. Above 6,000 feet the summit of Mt. Washington appears to have entirely escaped the effects of the drift agency. On Jay Peak, at the Northern extremity of the Green Mountain range, 4,025 feet, above the ocean, Drift striæ exist abundantly. On Mt. Holyoke, in Massachusetts, furrows exist a foot wide and two inches deep. Upon the Catskills the striæ have been observed at an elevation of 2,850 feet, running horizontally north and south, as if a succession of icebergs had grated along the slopes of the mountains during their submergence. Fine examples of these striations may be seen while ascending the Catskills by the route to the Mountain House.

upon the south sides of mountains, unless for a part of the way where the slope is small. The north, northwestern, and northeastern sides of mountains, which have been exposed to the drift agency, are also universally worn and rounded, while upon the south, or opposite sides, the projections are more angular.

Sometimes the end or side of a ledge of rock bears evidence of having been subjected to crushing force, which has broken and dislocated the strata. Fig. 203, which is a section of a slate quarry, at Guilford, Vermont, represents an example of this phenomenon, which has been referred, by Prof. Hitchcock, to the action of a glacier or huge iceberg crowding along the surface.

FIG. 203.



Furthermore, in the northern hemisphere the bowlders are always of some variety of rock which occurs in solid ledges in a direction north of their present position ; and, in most instances, by proceeding north in the direction of the Drift striæ in the vicinity, the localities from which the bowlders of a particular district are derived, can be found at a greater or less distance.

In such cases the blocks will usually be found to increase in size and number as we approach the "parent ledge."

QUESTIONS.—What other remarkable circumstances have been observed in connection with the Drift phenomena? Are we able ever to determine the location from whence bowlders have been transported?

The distance to which bowlders of great size can thus be proved to have been transported is often very great. "Plymouth Rock" is a bowlder of sienitic granite, ledges of which are found in the vicinity of Boston. The north shores of Long Island are strewn with bowlders of red sandstone, granite, and other rocks, arranged in groups which correspond with the position of the same ledges in Connecticut, across the Sound to the north. Most of the other islands on the New England coast are also covered with bowlders derived from the continent. Upon the bare granite summit of Mt. Katahdin, the highest mountain in Maine, at an elevation of 3,000 feet or more above the surrounding valleys, pieces of limestone containing fossil shells are found, though no ledges resembling them are known, except many miles to the northwest, and at a much lower level. In Russia bowlders have been identified with ledges more than 800 miles distant, in a northerly direction.

FIG. 204.

Upon the prairies of the northwestern States granitic bowlders of great size (significantly called *lost rocks*), which have, undoubtedly, come from the region of the great lakes—a distance of 300 to 600 miles—are very common. Fig. 204 represents the appearance of a bowlder of porphyritic granite on the prairies of Iowa, west of the Mississippi (figured by Dr. D. D. Owens, U. S. Geologist), the portion of which above ground measures fifty feet in circumference and twelve feet high. This and other isolated blocks upon these prairies appear to have been dropped rather than rolled into their present position, and, in the opinion of Dr. Owen, they have been brought from extreme northern regions by icebergs.

QUESTION.—What are some of the facts which have been ascertained respecting the transportation of bowlders?

326. **Theories of the Drift.**—Taking all these phenomena into consideration, we become impressed with the idea that powerful currents have swept, from north to south, over all the region occupied by the drift material—carrying with them clay, sand, gravel, and rock-masses—which have furrowed the rock-surfaces as they passed along, abraded and rounded the northern slopes of mountains, and piled up vast accumulations and ridges of detritus.

It is not easy, however, to refer such effects to any ordinary operations of water. We can conceive of no current sufficiently powerful to transport bowlders of tons' weight up steep acclivities, over mountains, and from one valley to another. We know, moreover, of no sedimentary conditions that would permit bowlders, sand, clay, and gravel to be piled up in one indiscriminate mass; while the extent of the erosion and smoothing of rock-surfaces that has taken place clearly indicates long-continued action. Geologists, therefore, have almost universally agreed, that ice as well as water was concerned in producing these phenomena, and, in the opinion of many, the physical changes at present occurring in Arctic latitudes, where the land is worn and wasted by glaciers and avalanches, and where icebergs and icefloes transport and distribute the eroded material over the bed of the ocean, afford a sufficient solution for all the geological problems presented in the Drift formation. (See §§ 142, 143.)

The theory of the Drift, which has been originated by Lyell, Hitchcock, and other authorities, and which is now accepted by most geologists, is substantially as follows: It is supposed that about the close of the Tertiary epoch a subsidence of land took place in the northern hemisphere, which was accompanied by a great reduction of temperature; and that, as a consequence of this access of cold, glaciers formed upon most of the northern mountains, and, as in Greenland at the present day, extended to the sea. Large islands and bergs of floating ice, laden with detritus, were also moved southerly from the polar regions by oceanic currents; and these, as they grounded on the submerged lands, pushed along all loose materials of sand and pebbles, smoothed and rounded the northern sides of ledges and mountains, and, when fragments of hard stone were frozen into their lower surfaces, grooved and polished the rocks with which they came in contact. When the icebergs and floes melted, their burdens of detritus—including fragments of rock, both large and small, which had been frozen into them as parts of glaciers or as coast-ice—would fall to the bottom of the ocean, and, in this way, bowlders, as well as finer materials, would be scattered over extensive areas. As the land also continued to sink, the glacier and coast-ice would

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QUESTIONS.—What general idea is acquired from a consideration of the various Drift phenomena? Is it possible to refer all the effects of the Drift to the agency of water? What theory in explanation of the Drift has been advanced and generally accepted?

be lifted higher and higher along the shores, and, finally, be urged by the northerly currents over hills and mountains, carrying a great amount of abraded material along with them. Finally, it is supposed, a gradual elevation of the submerged lands took place, and that, during their reëmergence, the materials which cover them were still further modified (modified Drift) by exposure to the disturbing and stratifying action of waves, ice, tides, and currents.

Other theories explanatory of the Drift phenomena have been proposed by geologists from time to time, but no one of them is universally accepted as fully adequate to explain all the facts recognized.*

327. **Duration of the Drift Period.**—How long the Drift period lasted it is impossible to determine, but from the changes on the surface of the earth, which appear to have been made during its continuance, it seems to have been considerably protracted.

Thus, in the Valley of the Connecticut River, Prof. Hitchcock finds evidence that about 1,000 square miles of surface have been denuded of sandstone strata to the depth of at least 1,000 feet; while in other localities of Vermont and Massachusetts, rock formations, of three, five, and even ten thousand feet in thickness, have been removed by erosion. In the north part of Berkshire County, Massachusetts, according to Prof. Emmons, a formation of slates and limestone, equivalent to more than three-fourths the present elevation of the peak "Graylock" (3,600 feet above sea-level), has been worn away and transported to a distance.

328. **Ancient Sea-Beaches and River-Terraces.**—The evidence of the gradual elevation of the lands of the northern hemisphere above the ocean, at the close of the Drift period, is hardly less marked than that which indicates their prior submergence.

QUESTIONS.—What is said respecting the duration of the Drift period? Have we any distinct evidence of the reëlevation of land during the Drift period?

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* A theory advanced by the Profs. Rogers, and supported by some eminent European authorities, supposes the Drift phenomena to have resulted from the movement of a series of stupendous and rapidly moving "waves of translation," excited and kept in motion by the uplifting of the floor of an Arctic sea, and by undulations of the earth's crust during an era of earthquake commotion. These waves moving southward over a considerable portion of the lands of the northern hemisphere, and driving before them, with great velocity, vast masses of detritus, are considered to be agents adequate to produce the results exhibited in the phenomena of the Drift formation. Dr. Whewell, who has instituted a mathematical examination of the mechanical effect of such convulsions, arrives at the conclusion that if a sea-bottom 450 miles long, 100 miles broad, and 500 feet below the surface of the water, were raised either at once or by paroxysmal lifts, waves of translation would be produced sufficiently powerful to effect the dispersion of the whole northern Drift.

Ancient Sea-Beaches.—Along the shores of every sea or ocean there exists a level margin, more or less covered with sand and gravel, which constitutes the existing beach, or sea margin; but in many countries there are also found, at various heights above the present sea-level, and following the bays or recesses of the land, similar margins or terraces, which are known as "*ancient*," or "*raised beaches.*" These give evidence of either an elevation of the land or a depression of the ocean, and point to times when the sea and land maintained successively different levels.

In Scotland fifteen such ancient coast-lines have been enumerated; at some of which the sea remained sufficiently long to excavate lines of deeply hollowed caverns in hard granitic rocks. One such ancient coast-line, or escarpment, has been traced around nearly the whole of Great Britain and Ireland, at a nearly uniform elevation of thirty feet above the present sea-level, and presents marks of greater attrition, *i. e.*, deeper wave-hollowed caves, etc., than the modern line. "It therefore seems certain," says Hugh Miller, "that however long the sea may have stood against the present coast, it must have stood for a considerably longer period against this ancient one."

In New England the remains of ancient sea-beaches have been pointed out by Prof. Hitchcock at elevations above the present sea-level, varying from less than 100 to between 2,000 and 3,000 feet. One such beach occurs upon the east side of Mt. Washington, New Hampshire, at an elevation of 2,020 feet; another in the vicinity of the Franconia Notch of the White Mountains, at a height of 2,665 feet. The most distinct beaches, however, are usually less than 1,200 feet above the sea level; and, according to Prof. Hitchcock, they are often in such a state of preservation "that they cannot be distinguished from recent beaches, except that they are sometimes much mutilated by erosion." Many of them also wonderfully correspond in height over very extensive areas, thus indicating that they were formed contemporaneously. Fossil shells have been observed in these beaches in this country at an elevation of over 500 feet above the present ocean; but in Great Britain beaches containing species of shells that now only inhabit high northern latitudes—as the shores of Iceland and Spitzbergen—are found at much greater elevations.

River Terraces.—Indications of rivers having formerly run at much higher levels than at present, or in places where no river could now exist, are common in many parts of this country. Thus, along the course of

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QUESTIONS.—What is said of the existence of ancient sea-beaches? Do such beaches occur in this country?

most of our rivers a succession of terraces may be observed, one above the other—each successive terrace being removed further back from the present water level than the one below it. The number of these terraces varies from two or three to ten, and they appear sometimes on both sides of a stream, and sometimes on only one side. On the Connecticut River the terraces in some places attain an elevation of over 200 feet above the present surface of the water; and on the Genesee River, N. Y., of over 300 feet. Remarkably distinct and parallel terraces or ridges of sand, gravel, etc., containing recent shells, may also be traced along the borders of some of the great American lakes, at a considerable distance back from their present shores, and at elevations of from 100 to 200 feet above them.

These terraces give unmistakable evidence of former water levels, and are believed to be mainly the result of the natural drainage of the continent, during the period of its gradual elevation, subsequent to the Drift epoch.

329. Examples of river action, where no river or stream now exists, are also not uncommon. At Orange, New Hampshire, on the summit level, between the Connecticut and Merrimack Rivers, there are pot-holes worn by the action of water in solid granite, at an elevation of over 600 feet above the waters of the Connecticut River. Similar phenomena, at even greater elevations (1,600 feet in one instance), have been noticed in many other localities in New England. At Niagara, from the Falls for four miles down, there is spread over the surface, on both sides of the river, reaching to the edge of the cliffs, a deposit of fluviatile (river-like) character, containing fresh water shells of the same species as those now found in rivers above the Falls. It is forty feet in thickness, and its bottom is 250 feet above the present channel of the river. Now, these layers of sand and gravel could have been deposited only by water running at their level; and, consequently, this action must have been before the deep gorge, which at present constitutes the channel of the river, was excavated through them.

330. **Antiquity of the Drift.**—The Drift formation is regarded as marking the last of great geologic changes which have taken place upon the surface of our planet; and some attempts have been made by geologists to calculate the *absolute* time that has elapsed since its termination. The most favorable data for this purpose have probably been obtained from the study of the Falls of Niagara. Thus, various circumstances (such as the cutting of the gorge through the fluviatile deposits above noticed) clearly indicate that the Falls did not commence until about the close of the Drift epoch; and that, since their commencement, they have receded—and eroded a deep rock gorge—from Queenstown, on Lake Ontario, to their present location, a dis-

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QUESTIONS.—What are river and lake terraces? Where do they exist in this country? What do they indicate? Are there any examples of river action at high elevations in this country? Enumerate some of them? What is said of the antiquity of the Drift?

tance of seven miles. The time required for this recession and erosion, judging from the most exact data that can now be obtained respecting the present excavating action of the Falls, cannot, in the opinion of Mr. Lyell, be estimated at less than 35,000 years; and, accepting this calculation as approximately correct, then the close of the Drift epoch cannot approach within some 25,000 or 30,000 years of the time commonly assigned for the creation and first appearance of man upon the earth.

Fossils of the Pleistocene Epoch.—Besides marine shells (which are generally crushed and broken), the Drift deposits in many localities—especially in the Old World—abound in the remains of large terrestrial mammalia. From the Drift of Great Britain alone, there have been obtained the bones of two species of elephant, two species of rhinoceros, of the hippopotamus, hyena, tiger, bear, and of gigantic species of the elk, deer, and ox. Some of these animals we now know only as inhabitants of the tropics, but during the Pleistocene era (and probably before the epoch of the Drift), it seems certain that a species of elephant (*Elephas primigenius*), known as the mammoth,* and a species of rhinoceros, roamed over the lands from Siberia to Britain, and that they were fitted to endure the rigors of a severe climate by a covering of long hair and closely felted wool. We know this from the wide distribution of their teeth and bones, and also from the circumstance, that in Northern Siberia, where the soil is permanently frozen, entire carcasses are not unfrequently found buried in the Drift, in a high state of preservation. The most remarkable instance of this kind, was the discovery, in 1799, of the entire carcass of a mammoth embedded in an ice-cliff on the borders of the Arctic Sea, near the River Lena. When first seen by a Tungoos fisherman it was but partially exposed to view, but in 1803 the ice melted to such an extent that the enormous carcass became entirely disengaged, and fell down from the ice crag upon a sand bank. In 1804 the discoverer removed the tusks, which weighed 360 pounds, and sold them, while the people in the vicinity carried away large quantities of the flesh of the animal to feed their dogs. In 1806, when the remains were taken possession of by an agent of the Russian government, the head was still covered by the skin, the pupil of the eye was distinguishable, the brain remained within the skull, and a long, shaggy mane hung from the neck. It was also ascertained that the skin of the body had an abundant covering of hair and reddish wool, indicating that the animal was fitted to resist a

QUESTIONS.—Are there any data which allow us to approximately estimate the time that has elapsed since its termination? What fossils have been found in the drift deposits? What extinct animals inhabited Northern Europe and Asia during the Pleistocene era? What evidence have we in relation to this point?

* The mastodon and the mammoth, which are often confounded by those not familiar with geological researches, were distinct animals. The former was an animal allied to the elephant, yet differing from it in some respects—especially in the form of its teeth; the mammoth, on the contrary, was a true elephant, but of a different species from the elephant of the present epoch. (See Figs. 195, 196.)

cold climate. This skeleton, with portions of the skin and hair, was transported to St. Petersburg, and may now be seen in the museum of the Imperial Academy of that city. Other similarly preserved carcasses of mammoths, and of a species of woolly rhinoceros, have since been found in Siberia, and in many localities in that country the bones and tusks of the former animal are so abundant, that the collection and sale of fossil ivory constitutes a regular business.*

Some idea of the number of mammoths that formerly roamed over the land of the British Islands may also be formed from the circumstance, that the fishermen engaged in dredging for oysters on one limited tract of the English coast (that of Norfolk), brought ashore, in the course of thirteen years (from 1820 to 1833), no less than 2,000 grinders or teeth, besides great tusks and numerous portions of skeletons.

331. **Ossiferous Caverns.**—This name has been given to caverns—found in almost every quarter of the globe—which contain accumulations of fossil bones embedded in hardened mud, or in layers of stalagmite which have been deposited upon them by water dripping from the roofs of the caverns.

These bones have been derived, in part, from animals that lived and died in the caverns, or from carcasses of animals that were dragged thither and devoured by carnivora, or were possibly drifted in by waves and currents, while the sea and land stood at variable levels.

In Europe many remarkable caverns of this character have been discovered, and their exploration is a subject of high geological interest. From a cave at Kirkdale, in Yorkshire, England, parts of the skeletons of between 200 and 300 hyenas have been obtained, besides bones of a species of tiger, bear, ox, deer, horse, mammoth, rhinoceros, and hippopotamus. In fact, the cave

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QUESTIONS.—What are ossiferous caverns? What is the assumed origin of the bones found in them?

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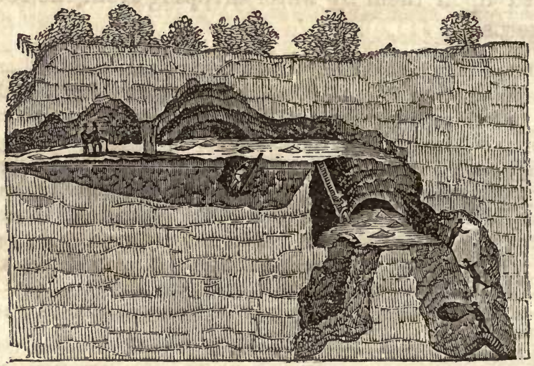
* The cliffs of frozen clay and gravel, that line the Arctic coast of Siberia, are described by explorers as being the repositories of vast quantities of bones of extinct animals. Capt. Kellet, who commanded one of the expeditions in search of Sir John Franklin, states that at Eschscholtz Bay—a locality a short distance south of the Arctic circle—which he visited in 1850–51, the fossil bones of animals are so abundant that huge tusks and horns not unfrequently project up through the soil, while the soil itself, when turned over, "exhaled a strong and disagreeable odor, like that of a well filled cemetery." Capt. Kellet obtained from this locality the remains of the mammoth, horse, moose-deer, reindeer, bison, musk-ox, the big-horned ram, and of some cetacea (whales, etc.).

The theory in explanation of these facts, advocated by Sir John Richardson and other geologists, who have given the subject attention, is, "that Arctic Siberia was once warmer than now, and actually produced a vegetation sufficient to support a vast creation of herbivorous animals, such as we now find the remains of; and that by some catastrophe—some vast deluge or wave of succession—they were suddenly engulfed on the shores of a sea where they had their pasture-grounds."

seems to have been a den of hyenas for ages previous to the Drift, during which epoch its entrance was choked up by detritus and remained unnoticed until the year 1821. Another similar cave, at Torquay, England, which seems to have been successively the den of hyenas, bears, and smaller carnivora, has yielded the remains "of more wild beasts than would have peopled all the menageries in the world." From one compartment of this cave some thousands of teeth of the hyena, the bear, and the horse, have been gathered; in another, the floor, for several feet in depth, is composed almost exclusively of gnawed fragments of bone; while bones projecting above the stiff soil of the cave have been actually worn smooth by contact with the feet of the hyenas passing in and out. Other remarkable caverns have been discovered in France, Germany, Italy, Australia, New Zealand, etc., and from caves in the vicinity of Palermo, Sicily, especially, the bones of the elephants and hippopotamus have been obtained in such numbers that ship-loads of them have been sent to foreign countries for agricultural purposes. Fig. 205 represents a vertical section of a famous bone-cave, at Gailenreuth, in Germany, the floor of which is literally paved with fossil bones and teeth, embedded in layers of stalagmite.

FIG. 205.



Many of these caves are certainly of vast antiquity, inasmuch as their lower floors often contain the remains of Pliocene animals; the middle deposits, the remains of true Pleistocene species; while the upper layers of mud and stalagmite, not unfrequently inclose charred wood, rude stone implements, and bones of the human race. Their epoch, therefore, as respects their organic remains, must be regarded as partly Tertiary and partly recent.

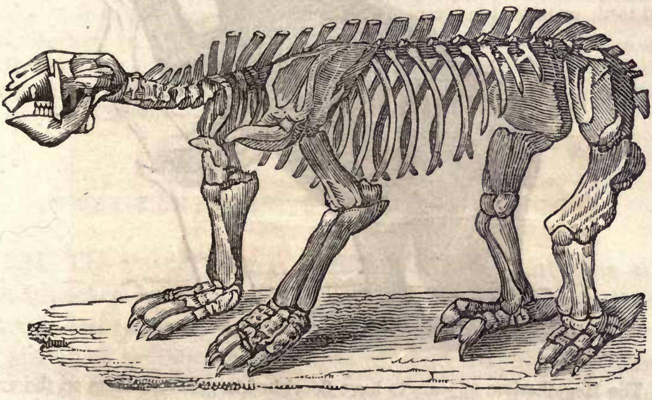
332. In tropical and sub-tropical countries, where the influences which produced the Drift formation of the

QUESTIONS.—What are examples of remarkable bone caverns? To what periods of geological time are the origin and bone accumulations of these caverns referred?

North did not prevail, the deposits of the Pleistocene era form an uninterrupted series with those of the preceding Tertiary ages, and are similarly characterized by the presence of numerous and varied fossils, and especially by the remains of extinct mammalia.

In South America the deposits of fine sediments spread over the great plains known as the "Pampas" (which appear to have been submerged during the Pleistocene era) have yielded the remains of many colossal extinct quadrupeds, the majority of which appear to have belonged to the order *Edentata*—an order which is represented at the present day by the sloths, armadillos, ant-eaters, etc. The largest and most remarkable of these extinct animals was the so-called *Megatherium* (Gr., *μεγας*, *great*; and *θηριον*, *animal*), which resembled, in many respects, the sloth, but was perfectly

FIG. 206.



colossal in its proportions—its body being from eight to twelve feet long, seven to eight feet high, and having a breadth across the haunches of at least five feet. Its thigh bone was three times as large as that of the elephant; its tail, nearest the body, was six feet in circumference; and its spinal marrow, judging from the opening in the vertebræ, must have been a foot in circumference. Its fore-feet were a yard in length, by twelve inches in breadth, and were terminated by gigantic claws, set obliquely to the ground, like those of the mole—a position which would render them digging instruments of great power. Fig. 206 represents an entire skeleton of this animal, found in 1789 near Buenos Ayres, and now preserved in the Royal Museum

QUESTIONS.—What is said of the deposits of the Pleistocene era in countries not exposed to the Drift agency? What remarkable fossils have been obtained from the "Pampas" of South America? Describe the Megatherium.

of Madrid, Spain. Notwithstanding its great size and strength, the Megatherium is shown by the structure of its teeth to have been an herbivorous animal, and, probably, like the present sloths, fed on the tender stems, leaves, and roots of trees. As its weight and structure would not allow it to climb trees like the sloth, or burrow like the mole (which it also resembles in some respects), it is supposed that the animal loosed and cut the roots of trees with its powerful claws, and then, supported on its haunches and enormously thick tail, pulled them down with its fore limbs, aided by the great weight of its body.*

FIG. 207.

The Megatherium appears to have flourished in great numbers on the vast plains of South America, and some traces of it have even been found as far north as Texas, Georgia, and South Carolina. It was associated with a number of other colossal animals of a similar character; one of which, called the *Mylodon*, was but little inferior in size. Fig. 207 represents a restored appearance of the Mylodon.

QUESTIONS.—Have we any evidence that animals allied to the Megatherium existed at this epoch in North America?

* This supposition has received a degree of confirmation, from the curious circumstance of the finding of a skull of one of the great Megatheroid animals (the Mylodon) in South America, which had been fractured longitudinally in two places, one of which fractures was entirely, and the other partially healed. As there was probably no animal then living in the country of the Megatherium, which had the ability or will to make such a wound, it has been ascribed to the falling of a tree, which the Mylodon probably undermined and overturned upon itself.

Towards the close of the last century ex-President Jefferson called attention to the occasional discovery, in the limestone caverns of Western Virginia, of huge bones, which, from the large size of the claws attached, he supposed must have belonged to a carnivorous animal. Since then other bones of similar character have been discovered in Kentucky, Tennessee, Mississippi, Alabama, and Brazil, and a scientific examination of them has shown that they are the remains of an extinct sloth-like, herbivorous animal, to which the name Megalonyx (Gr., *μεγας*, *great*; and *ονυξ*, *claw*) has been given. It is supposed to have resembled the Megatherium in form, and to have been of about the size of a large ox,—using its claws (some of which were about seven inches in length) to loosen and pull down trees, in order to feed upon their leaves. It was contemporaneous with the Mastodon and Mammoth in the Valley of the Mississippi, and possibly survived them.

333. As has been already stated, the Drift formation in North America does not extend as far south as the Southern or Gulf States; and this section of the country, during the submergence of the more northern portions of the continent, appears to have been the home of a great number of extinct species of quadrupeds, as the horse, bison, hippopotamus, elephant, mastodon, megatherium, megalonyx, and others; since we now find the bones of all these animals in the latest Tertiary strata of Georgia and South Carolina mingled with shells of the same species with those at present living in the neighboring waters.

POST-TERTIARY, OR RECENT EPOCH.

334. The Post-Tertiary, or Recent system, embraces all the superficial geological accumulations and changes that have taken place since the close of the "Drift" formation, or since the present distribution of land and sea has been established. It, therefore, carries forward the geological history of the earth to the present time, and introduces us to the existing order of things.

It is, however, difficult, perhaps impossible, to draw any distinct line of severance between the deposits of the Pleistocene and those of the Post-Tertiary epochs. Both formations insensibly grade into each other, and no sudden and decided changes in the forms and conditions of life took place at the termination of one or the commencement of the other, as occurred, apparently, in the transitions between the older systems. These facts are strikingly

QUESTIONS.—What geological accumulations are included in the Post-Tertiary or Recent system? What is said of the connection of the Post-Tertiary deposits with those of the preceding eras?

illustrated in the clay cliffs, or "bluffs," which border the Mississippi River from Baton Rouge, in Louisiana, as far north as Kentucky, and rise to an elevation of from 50 to 250 feet. Here we have a gradually varying succession of strata which unite deposits of the Eocene age, containing bones of the palæotherium, at the base of the cliffs, with those of the Pleistocene, containing bones of the extinct mastodon, near the summit; while these last, again, are covered by, and blend into, modern fluviatile deposits, which entomb the bones of buffaloes, bears, raccoons, opossums, beavers, and other animals still existing upon the Continent.

335. The accumulations of the Post-Tertiary epoch, although superficial and scattered indiscriminately over the surface without any determinate order of superposition, assume, nevertheless, when taken in the aggregate, a geological importance not at all inferior, so far as amount is concerned, to any of the older stratified formations.

They consist mainly of clays, sands, gravels, and marls—which, as the products of the ordinary operations of water, are often collectively termed Alluvium*—of peat-mosses, infusorial deposits, calcareous and silicious tufas, coral-reefs, shell-beds, and volcanic accumulations. The "raised beaches" and "river terraces," described in connection with Pleistocene deposits, are also probably referable in part to the Post-Tertiary system.

With the exception of volcanic lavas, limited deposits of calcareous and silicious springs, some consolidated sands, shell-beds, and coral-reefs, the Post-Tertiary system does not include any solid (or rock) strata.

It should be also here remarked, that many of the deposits of this system, which we term "*Recent*," are only so in a geological sense, or as compared with those of the epochs already described, inasmuch as the time represented by their formation undoubtedly extends over a period of many thousand years. Thus, we include in this system the "*delta* formations" of existing rivers (see § 154), which are often of great thickness—as, for example, the Delta of the Ganges, which, in the vicinity of Calcutta, has been ascertained (by boring) to consist of successive layers of clay, marl, and vegetable matter, of at least 480 feet in thickness, and all abounding with the bones and shells

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QUESTIONS.—What is said of the importance of the accumulations of the Post-Tertiary system, so far as their relative amount is concerned? Of what do they mainly consist? Do they include any solid strata? In what sense do we use the word "*recent*," as applied to the formations of this era?

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* Some authorities (as Hitchcock) consider and designate all aqueous deposits formed subsequent to the Tertiary epoch as alluvial. Others (as Emmons) restrict the term to the "washed" accumulations of sand, gravel, and earth, found upon the banks and mouths of rivers. Lyell defines *alluvium* to be "earth, sand, gravel, and other transported matter, which has been washed away and thrown down by rivers, floods, or other causes, upon land not permanently submerged beneath the waters of lakes and seas."

of animals still living in the vicinity. Again, the amount of sediment brought down by the Mississippi to the Gulf of Mexico has been shown, by Mr. Forshay, an eminent engineer, and Dr. Riddell, of New Orleans (from observations extending through thirty years), to be between three and four thousand million cubic feet annually; and yet at this rate it must have required, according to Mr. Lyell, a period of at least 60,000 years for the river to have built up the great accumulations of alluvium which make up its Delta.*

336. **Life Features of the Post-Tertiary Epoch.**—With the exception only of man, we know of no remarkable living generic animal forms that may not have been in existence upon the surface of the earth at the commencement of the Post-Tertiary epoch.

Some species of animals, however, which are known to have been abundant at the commencement of this era, have since become *universally* extinct, while others have experienced, as it were, "*local extinctions*," or, in other words, have entirely disappeared or removed from countries and areas that were formerly inhabited by them.

337. **Epoch of the Mastodon in North America.**—The most interesting of the animals, that have recently (in a geological sense) become extinct, is, probably, the great American Mastodon (*mastodon giganteus*), which, in connection with the Mammoth, or fossil Elephant (*elephas primigenius*), appears to have attained a great numerical development upon this continent at about the close of the Pleistocene, or the commencement of the Post-Tertiary epoch. Geologists are enabled to determine with certainty the age at which these colossal herbivorous animals existed in this country, from the circumstance that their bones are found in a partially petrified, or subfossil state, in superficial deposits, lying above the Drift formation—as, for example, in peat-bogs, or the mud and marl deposits of existing ponds and lakes, the origin of which, it would seem, cannot extend far back of the introduction of man upon this continent.†

QUESTIONS.—What facts prove the great antiquity of some of the Post-Tertiary deposits? What is said of the life features of the Post-Tertiary epoch? What interesting animals have become extinct in this country within this epoch?

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* The area of the Delta of the Mississippi is estimated at 13,600 square miles, and borings have been made in it to the depth of 600 feet.

† Some have thought that the mastodons and mammoths did not become entirely extinct in this country until after the advent of man, and find a support for their opinion in various traditions of the North American Indians, which represent their ancestors as warring against certain colossal animals, which are described as "tree-eaters," and as never lying down, but leaning against a tree when they slept. Sir Charles Lyell, however, after a review of all the facts in the case, has arrived at the opinion that the period of the extinction of the mastodon, although geologically modern, must have been many thousand years ago.

The age of the European mastodons was probably earlier than that of the American, Judging from the distribution of their bones, the mastodons appear to have existed most numerously in the valleys of the Ohio and Mississippi, and from thence, to have roamed as far to the northeast as New York and New England. Their remains, however, have been but rarely found in New England, and it has been conjectured that the Hudson River may have acted as a barrier to their migrations. The mammoth (or fossil elephant) appears to have roamed over the same territories contemporaneously with the mastodon, but in much smaller numbers.

In the Western States the bones of these animals are found most commonly in the low places around the salt licks—spots that are still frequented by deer and other wild animals that come to "lick" up saline waters. At one such locality, in Kentucky, known as the "Big-Bone Lick," about twenty miles southwest of Cincinnati, it is estimated that the bones of 100 mastodons and twenty mammoths have been dug up, together with the bones of the megalonyx, buffalo, deer, and other animals.

The most complete skeletons of the mastodon have, however, been found in swamps and peat-bogs, in the States of New York and New Jersey, in which the animals were probably accidentally mired and suffocated.* The finest and largest skeleton in existence was discovered by some laborers engaged in digging marl from a swamp in Newburg, N. Y., in the summer of 1845. It occupied a standing position, with the head raised and turned to one side, and the tusks thrown upwards—the position natural to a quadruped when sinking in the mire. In the place where the stomach lay, and partially inclosed by the ribs, there were found about seven bushels of vegetable matter—*i. e.*, bruised and chopped twigs and leaves—which, without doubt, represented the food last eaten by the animal. Some of these twigs, subjected to microscopical examination, proved to be those of a coniferous tree, probably the white cedar. This skeleton (represented in Fig. 208) was purchased by the late Dr. John C. Warren, of Boston, and is now preserved in that city. Its dimensions are as follows:—Length, twenty-five feet; height, twelve feet; length of tusks, ten feet. The total weight of the bones is 2,000 pounds, and so slightly changed are they, that they still retain a large proportion of their animal matter.

QUESTIONS.—What geological evidence enables us to accurately determine these facts? In what portions of this country do the mastodons and mammoths appear to have existed in the greatest number? In what localities are their bones usually found? Describe the circumstances of the discovery of the great Newburg mastodon.

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their remains, as before stated, having been found somewhat abundantly in Tertiary strata, as low down as the Miocene. The remains of the European and Siberian mammoths are also found embedded in the Drift formation, while the remains of the American mammoths, according to Prof. Rogers, are invariably found above the Drift. It may also be here remarked, that it is generally conceded that the American mastodon (mastodon giganteus) was of a species peculiar, and restricted to this country.

* Elephants at the present day in Africa become frequently entangled and suffocated in the swamps and mud-holes which they have entered for the purpose of wallowing. At a recent meeting of the Boston Society of Natural History, an instance of a considerable number of elephants having been thus swamped and buried, was communicated by one of the American missionaries stationed at Gaboon, West Africa.

In some instances there have been found, in connection with the skeletons of the American mastodons, tufts of hair, of a dun brown color, varying in length from two to seven inches—thus indicating that the animal, like the Siberian mammoth, might have been fitted to endure a climate considerably colder than that in which the present elephants live.

FIG. 208.

338. **Dinornis, or Extinct Birds of New Zealand.**—Another interesting example of the extinction of a race of animals, within a comparatively recent period, has been afforded us by recent discoveries in New Zealand, the history of which furnishes a beautiful illustration of the law first elaborated by Cuvier, that all the parts of an animal's structure correspond and are mutually dependent upon each other. (See § 203.) Thus, in 1839, Professor Owen, the eminent English comparative anatomist, received from New Zealand a fragment of bone, six inches long, and broken at both extremities, which had been dug from a deposit of river-mud. Applying to this fragment the principles of comparative anatomy, he arrived at the conclusion that it once formed part of the leg-bone of a gigantic and unknown bird, somewhat resembling the ostrich, but larger and heavier. This opinion, which was at first received somewhat doubtingly, was, in 1843, confirmed by the discovery of a large number of similar bones; and it is now fully proved that there existed, in New Zealand, within a comparatively recent period, great numbers of birds, whose tracks would have been as large as, or larger, than the largest fossil bird-tracks found in the Valley of the Connecticut River, and whose height, in some instances, must have been ten, and possibly fourteen or sixteen feet.* From the bones already collected

QUESTIONS.—What is known respecting the recent extinction of a race of birds in New Zealand?

* At the time of the first discovery of the large fossil foot-prints of birds on the sandstones of the Valley of the Connecticut River, some geologists urged, as an argument against their genuineness, that it would be impossible even to imagine the existence of a bird of such stupendous size as would be required for the production of the largest impressions.

(and within the last few years entire skeletons have been found) Prof. Owen has determined the former existence of eleven species of these birds, of various sizes, which he has referred to one genus, under the name of *Dinornis* (Gr., *δεινος*, *terrible;* and *ορνις*, *a bird*). They appear to have been destitute of wings, to have had a powerful adze-like beak, leg-bones as large as those of an ox, and toe-bones nearly equal to those of an elephant. It is also a curious circumstance that the natives of New Zealand recognize these bones as those of a bird, which they call the *Moa;* and from the fact that the bones

FIG. 209.

are usually found slightly buried in the mud of rivers, or in caves, and are sometimes associated with charred wood, and the bones of man, it seems almost certain that they lived during the human epoch. Prof. Owen infers, from the form of the skull, and some other points of their structure, that they were sluggish, stupid birds, living on roots, and without the instinct, or perhaps the ability, to escape, or defend themselves. Fig. 209 represents the appearance of a skeleton of one of the largest species of the Dinornis.

QUESTION.—Describe the Dinornis.

339. **Extinct Bird of Madagascar.**—Since 1850 there have been received in Europe, from the Island of Madagascar, the bones of another gigantic bird, which was quite as large, and possibly larger, than the largest Dinornis of New Zealand; and what is still more curious, there have been also found in connection with these bones, in a deposit of recent alluvium, a number of enormous eggs, which are believed to belong to the same bird. Two of these eggs, and the fragments of a third, are now in the museum of the *Jardin des Plantes*, at Paris. The dimensions of one of them are as follows:—Largest circumference, two feet nine inches; largest diameter, one foot, one and three-fourth inches; smallest diameter, eight inches. The thickness of the shell of this egg is about an eighth of an inch; its capacity, about eighteen English pints, or six times the gross volume of an ostrich's egg, or 148 times that of an ordinary hen's egg.*

FIG. 210.

340. **Dodo.**—When the Island of Mauritius, in the Pacific, was discovered, in 1598, a bird called the Dodo, considerably larger than a swan, and weighing about fifty pounds, was so abundant that it constituted an important portion of the food of the inhabitants, but within the course of a few years it became entirely extinct, and its bones are now found only in the recent alluvial deposits of that island. Two heads, a foot, some feathers, and a few paintings, have, however, been preserved in the museums of Europe, and these now constitute the only proofs of the existence of a large bird, which was certainly living within the last 200 years. Fig. 210 represents the appearance of the Dodo.

QUESTIONS.—What is said of the extinct birds of Madagascar? What were the circumstances of the extinction of the Dodo?

*** M. St. Hilaire, an eminent French naturalist, considers it quite probable that this bird, which he calls the Æpyornis, may have had an existence within the historic period, and have given origin to the famous Eastern story of the *Roc*. (See "Arabian Nights.")**

According to Prof. Owen, we possess ample evidence also of the existence, in England, at the time of the invasion of Julius Cæsar (2,000 years ago), of three distinct species of animals—*i. e.*, two gigantic species of ox, and one of the reindeer—all of which are now, however, extinct. In Ireland a large species of elk became extinct, probably not long after the island was inhabited by man.

341. Examples of the local extinction of animals, or their entire disappearance from areas formerly inhabited by them, are common and familiar. In Great Britain the wolf and the beaver have become extinct within the last 200 years. The "Great Auk," or Northern Penguin, which was formerly abundant on the coasts of Iceland, Greenland, and Norway, is not certainly known to have been seen since 1844. In this country, every one is familiar with the fact, that with the removal of the forests many wild animals have almost entirely abandoned the regions formerly frequented by them, and have moved westward. According to Prof. Owen, some animals, occupying circumscribed provinces, which are being broken in upon by new conditions, may also be regarded as rapidly tending to extinction—as, for example, the musk-ox, or Arctic buffalo, the beaver, kangaroo, ostrich, and possibly the elephant. It is thus evident, that while the inorganic materials of our planet are being worn down, shifted and reconstructed into new arrangements, its vitality is also undergoing corresponding modifications, redistributions, and even extinctions.

342. **Epoch of Man.**—It is from the superficial deposits of the Post-Tertiary, or Recent epoch—namely, the peat-mosses, alluvial sands and clays, cave deposits, coral and shell conglomerates—that the geologist first obtains unmistakable evidence of the existence of the human race upon the surface of our planet.

As regards the exact time, however, when the creation and first appearance of man took place, geology gives us no definite information; but this much may be safely stated, "*that the scriptural record, in which man is represented as the last born of creation, is opposed by no one geologic fact.*"

Furthermore, the fair presumption, reasoning from geological evidence alone, is, that man was not called into being until after the commencement of the present geological era, and until after the time when, in the northern hemisphere, the sea and land had received their present configuration, and were peopled by those genera and species which yet inhabit their lands and waters.

Questions.—What other instances of the total or partial extinction of animals, within a comparatively recent period, can be cited? In what geological formations do we first find evidence of the existence of man? What inference can be fairly drawn from geological investigations respecting the comparative antiquity of the human race?

Many interesting examples of the discovery of the remains of man in a truly fossilized state, or under conditions which give them an antiquity anterior to that of any *definite* period of history, are on record. Thus, on the site of the city of Glasgow, there have been dug up, since 1781, from a considerable depth, three rude canoes or boats, one of which reposed on a bed of sea-sand, a quarter of a mile from the river Clyde, and twenty-six feet above its present high-water level. Mr. Robert Chambers, of Scotland, who investigated the circumstances of these discoveries (the last being in 1854), states "that we have scarcely an alternative to the supposition, that when these vessels foundered, and were deposited where in modern times they have been found, the Firth of Clyde was a sea, several miles wide at Glasgow, and covering the site of a portion of the city."*

Fig. 211.

Within the present century there have been obtained, from the coast of Guadaloupe, one of the West India islands, embedded in hard, compact limestone, a number of fragmentary human skeletons, one of which (see Fig. 211) now constitutes a conspicuous feature of the geological collection of the British Museum, while portions of others are preserved in the Museum of the *Jardin des Plantes*, at Paris, and in the Museum of the Medical College of Charleston, S. C. When these fossil skeletons were first discovered, they were regarded by some, as constituting of themselves, ample evidence of the existence of the human race during a remote geological epoch; but a careful examination of the rock inclosing the bones, has since shown, that it is of very recent origin—of a variety, in fact, that is even now continually in the process of formation (see § 66)—being composed of minute fragments of shells and corals, of species now inhabiting the adjacent seas, ground down by the waves and consolidated along the sea margin. The fact that the same rock has been also found to inclose fragments of pottery, stone arrow-heads, and pieces of carved wood in a high state of preservation, further identifies the age of these bones as historically recent, and renders it certain that they are the remains of the ancient Indian inhabitants of the island.

QUESTION.—Are the remains of man ever found in a fossil state?

* One of these canoes—still preserved in a museum at Edinburgh—contained, when discovered, a beautifully shaped and polished stone hatchet; which circumstance would seem to indicate that the use of iron was unknown to the builders of the vessel.

In Europe the works and bones of man have been often found in caverns, embedded in mud or layers of stalagmite, and in such close proximity to the remains of fossil animals that some have supposed that representatives of the human race must have lived contemporaneously with the extinct species of the Tertiary epoch. A careful investigation of all the phenomena has, however, in almost every case, entirely dissipated any such conclusions, or at least rendered them extremely doubtful.

343. **Economic Products of the Tertiary and Post-Tertiary Systems.**—In an economic point of view, the materials of the Tertiary and Post-Tertiary systems are of vast and universal value.

They include, for example, most of the clays used for pottery, bricks, and other fictile purposes; the supplies of silicious sand used for glass-making, the preparation of mortar and the molds of metal-smelters; and the gravels used for road making. In this country nearly all the fine clays suitable for pottery and modeling, are obtained from Eocene and Miocene Tertiary deposits along the Atlantic coast—especially from Martha's Vineyard, Long Island, and New Jersey—while the coarser clays of the northern and interior portions of the country, which are extensively used for brick-making, are, for the most part, referable to the Drift formation. Great accumulations of coarse sand and gravel are also almost everywhere characteristic materials of the Drift formation.

In California, Australia, and the Ural Mountains, drift, or fluviatile sands and gravels, are the main repositories of gold; and in Brazil and India, of gems and precious stones. Peat and marl are other familiar economic products of the latest geological formations.

CONCLUSION.

344. In the sketch of the geological divisions of the earth's crust, embraced in the foregoing chapters, not a thousandth part of what might have been told respecting the ancient history of our earth and its inhabitants has been given. Sufficient, however, it is believed has been stated, to enable the student to obtain a general and comprehensive idea of the most important facts and theories which have resulted from geological studies and explorations, and which are now recognized as constituting the fundamental elements of geological science.

Turning back the record of the earth, as revealed to us in the successive groups of strata which compose its crust, one cannot fail to be impressed with the idea that there has been a continual progress in the condition of

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QUESTIONS.—What is said of the economic products of the Tertiary and Post-Tertiary systems? Enumerate some of these products.

our planet, whereby its surface has become gradually fitted for the existence and development of higher forms of animal and vegetable life, and that these have appeared at successive epochs, as if by special acts of creation. Thus, at one stage of the earth's history—the era of the Metamorphic rocks—plants and animals do not appear to have existed. It is true, that the evidence on this point is merely negative, and the geologist *cannot say with certainty* that life was not coeval with the globe itself; but the fair presumption, from a great number of facts is, that the earth, anterior to the epoch of the deposition of the Huronian or Cambrian rocks, was not in a condition to support life under any of its forms.

As we ascend higher, however, in the series of strata, we find vestiges of organic beings—first, in the rocks at the base of the Silurian system. Among plants, we have first sea-weeds, and afterwards, in the Devonian and Carboniferous systems, land plants;—ferns, club-mosses, and gigantic endogens predominating in the coal-measures; palms, cycadaceæ, and pines in the Oolite; and exogenous or true timber trees in the Tertiary and current eras.

In the animal kingdom, we find evidence that zoophytes, radiata, mollusca, and articulata existed for ages in the broad seas of the Lower Silurian epoch, before there were any higher forms;—all, however, being perfect of their kind, and as admirably constructed as any representatives of the same orders now peopling existing seas.

Next to these invertebrata appear, in the deposits left by the waters of the Upper Silurian and Devonian epochs, the first vertebrate animals, in the form of fishes. After these come land animals, of which the first were reptiles, universally allowed to be the type of animal life next in advance from fishes, and to be connected with the latter by the links of an insensible gradation. From reptiles we advance to birds and mammals, which last appear to be represented in the commencement by the lowest forms of their class, viz., the Marsupalia. In the Lias and Oolite, reptiles attain their greatest development, and are the predominant forms. In the Tertiary epoch, however, huge mammalia prevail, and these, in time, give place to other and existing species, with Man, the highest representative of their class, and the crowning form of created existences.

According, moreover, to the testimony of the most eminent geologists and anatomists, the human form is that, toward which, as to their archetype, all other organic creatures have been tending. Oken, the eminent German anatomist, says, "Man is the sum total of all the animals." Prof. Owen of England, "supreme in his own especial walk as a comparative anatomist," asserts that "the recognition of an ideal exemplar for the vertebrated animals, proves that the knowledge of such a being as man must have existed before man appeared. For the Divine mind that planned the archetype also foreknew all its modifications. The archetypal idea was manifested in the flesh, under divers modifications, upon this planet, long prior to the existence of those animal species that actually exemplify it."

The same idea is also recognized by Prof. Agassiz, who expresses himself as follows:—"It is evident that there is a manifest progress in the succession of beings on the surface of the earth. This progress consists in an increasing similiarity to the living races, and, among the vertebrates, especially, in their increasing similarity to man. But this connection is not the consequence of a direct lineage between the races of different ages. There is nothing like parental descent connecting them. The fishes of the Palæozoic age are in no respect the ancestors of the reptiles of the secondary age, nor does man descend from the mammals which preceded him in the Tertiary age. The link by which they are connected is of a higher and immaterial nature; and their connection is to be sought in the view of the Creator himself, whose aim in forming the earth, in allowing it to undergo the successive changes which geology has pointed out, and in creating successively all the different types of animals which have passed away, *was to introduce man upon the surface of the globe. Man is the end toward which all the animal creation has tended from the first appearance of the first Palæozoic fishes.*"

345. The study of the systems and periods of the geologist also leads to the conclusion, that in all times past the agencies which have operated to change and modify the rock materials of the globe have been the same; that then as now, sands and sandstones, gravels and conglomerates, shales and clays, vegetable and animal debris, were accumulated and consolidated in precisely the same way and by similar agencies. Some geologists (who have been termed Catastrophists) incline, however, to the opinion that geological agencies, in order to have produced the results recognized, must have acted in the earlier epochs of the world with greater intensity, and also simultaneously over wider areas, than at the present day; while another class (who have been termed Quietists) consider the movements now going on upon the surface of the earth, and coming under the observation of men, as sufficient, if extended through indefinite periods of time, to account for all the phenomena presented in the crust of the earth, without the necessity of attributing to the forces any greater intensity of action than they now exhibit. This latter belief (which is especially advocated by Sir Charles Lyell in his great work, "Principles of Geology") is certainly in accordance with the spirit of right philosophy, though many problems in geology seem to find a solution only through the admission of the former hypothesis.

346. **Geology and the Bible.**—It is sometimes urged against the study of geology, that its teachings are inconsistent with, or opposed to, those of inspiration. To enter into any discussion of this subject, with a view of proving to the contrary, would be foreign to the object of the present work; but it may not be inappropriate to call the attention of those, who have neither the time nor opportunity for examining the points at issue sufficiently to arrive at an independent opinion, to the circumstance, that many of the leading authorities, at the present day, in geology—Dean Buckland, Hugh Miller, Whewell, Sedgwick, Hitchcock, Emmons, and many others, are men whose Christian faith and character has never been questioned; and if these persons can find no serious inconsistency between the teachings of science and religion, the presumption is a fair one that none in reality exists. "No truths established by studying the works of God can interfere with truths revealed by His Word."

APPENDIX.

Although geology may be taught exclusively from a text-book, yet in no way can a knowledge of the science be gained so readily and so pleasantly as by combining with the lesson of the book an examination of actual specimens, the inspection of geological plates and illustrations, and by excursions to natural sections and to examples of rock formations.

It is an error to suppose that an expensive cabinet of geological and mineralogical specimens is necessary to illustrate efficiently a course of geological study. On the contrary, every teacher and student can readily, and with little or no expense, collect specimens of almost every important variety of rock and of many of the fossils which characterize the great geological groups and systems. Every section of country affords an abundance of some classes of specimens. Thus, the coast of New England abounds in granites, syenites, quartz-rocks, trap-rocks, and porphyries; and the country adjacent to the Green and Appalachian range of mountains, in metamorphic rocks, namely, clay-slates, talcose, mica, and hornblende schists, and many varieties of quartz, and crystalline limestones or marbles. In the Valley of the Connecticut, in New Jersey, Eastern Virginia, and North Carolina, we have shales and sandstones of Mesozoic age; among the Catskills of New York, sandstones and fossils of Devonian age; along the Atlantic coast, from Martha's Vineyard to Texas, Tertiary strata and fossils; in Western New York and throughout the Western States, Silurian rocks and fossils; while Pennsylvania, Virginia, North Carolina, and almost every State West, afford magnificent examples of the coal formation, with its characteristic fossils. In all these sections of country, moreover, there are always numbers of persons who will gladly and freely exchange suits of specimens from their own localities for those of other and remote districts.

As a guide for collecting, it is suggested to teachers and students that they should first endeavor to obtain, and render themselves thoroughly familiar with, the following specimens:—

Rock Specimens.—*Granite; Syenite; Gneiss; Clay-Slate; Clay-Shale; Mica-Schist; Talcose-Schist; Hornblende-Schist; Quartz-Rock; Porphyry; Greenstone; Basalt; Lava; Serpentine; Limestone, crystallized, earthy, and magnesian; Sandstones, red, white, and brown; Marl; Calcareous Tufa, Stalactite or Stalagmite; Conglomerate; Coal, anthracite and bituminous; Lignite.*

Minerals, which are the essential components of important rocks, or are frequently embedded in them:—*Quartz, crystallized and massive; Agate;*

Chalcedony; Jasper; Garnet; Hornblende; Feldspar; Mica; Augite; Talc; Steatite; Tourmaline; Calcareous Spar; Sulphate of Lime, or Gypsum; Sulphur; Plumbago; Bitumen; Bituminous Shale; Baryta.

ORES OF THE METALS.—*Iron Pyrites (sulphide, or sulphuret of iron); Magnetic Oxyd of Iron; Red and Brown Hematite; Bog-Iron Ore; Ores of Manganese; Galena, or Sulphuret of Lead; Native Copper; Carbonates and Sulphurets of Copper; Red Oxyd of Zinc; Blende, or Sulphuret of Zinc.* Ores of other and rarer metals, as of Tin, Gold, Silver, Platina, Cobalt, Nickel, Antimony, etc., can be added if convenient.

Those who would prefer to purchase rather than collect their specimens, can obtain elementary geological and mineralogical collections of dealers in New York City, at moderate prices.* At the same time, the personal collection of specimens is to be recommended whenever practicable, as the information obtained in so doing is of the most lasting and practical character.

Collections of characteristic fossils of the different geological systems are much more difficult to obtain than collections of characteristic minerals and rock specimens. Deficiencies in this respect may, however, be supplied in a great degree by reference to the plates and figures given in most of the extended works and reports on Geology and Palæontology. Thus, the Reports of the Geological Survey of the State of New York figure, with great minuteness, the fossils of the Silurian and Devonian rocks found in that State; the Report of the Survey of Pennsylvania, the fossils of the Carboniferous system; and that of North Carolina, the fossils of formations of the Mesozoic period. No difficulty, however, will be experienced in obtaining specimens illustrative of all the conditions in which fossils occur; as true petrifactions, incrustations, casts, impressions, etc.; and also of specimens of rock-masses which have been formed by the aggregation of particles or fragments of organic structures, as of shells, corals, encrinites, etc.

Whatever may be the text-book used, the teacher will find it very advantageous to have other books on the subject of geology at command, from which he may, from time to time, illustrate any particular subject under consideration, by reading or quoting examples or descriptions of phenomena, or by exhibiting plates and diagrams additional to those included in the lesson. In this way, the recitation may be made to partake of the character of a familiar lecture, and the interest of the student is encouraged and sustained; and unless, in the study of the natural sciences, the interest is awakened, all routine instruction will profit but very little. Among the books especially worthy the attention of teachers and students, the following may be recommended:—First, the Report of the Geological Survey of one's own State. In most of the States such reports have been published, and can often be procured gratuitously. They furnish local examples of geological phenomena, information respecting the age and character of the rocks in one's immediate vicinity, and the localities where specimens of particular rocks, minerals, and fossils are obtainable. Within the last few years many reports of Geological

* Further information on this subject can be obtained of the Publishers of this work, Messrs. IVISON, PHINNEY & Co., 48 & 50 Walker-street, New York.

Surveys of the U. S. Territories have been also issued and distributed gratuitously by the National Government. Many of these are readily accessible in every section of the country, and contain much valuable information, with numerous Maps, Sections, and Illustrations.

From the following list of leading, and for the most part inexpensive geological treatises, selections can be made according to one's inclination and ability:—Lyell's "*Elements of Geology*;" Lyell's "*Principles of Geology*" (this work is a storehouse of facts relative to current geological events); De La Beche's "*Geological Observer*;" Mantell's "*Wonders of Geology*;" Mantell's "*Medals of Creation*" (an elementary English work on Palæontology); Hugh Miller's "*Testimony of the Rocks*," "*Popular Geology*," "*Old Red Sandstone*," "*Footprints of the Creator*;" Hitchcock's "*Outlines of the Geology of the Globe*;" Hitchcock's "*Illustrations of Surface Geology*;" Emmons's, Hitchcock's, Jukes, and Ansted's *Elementary Treatises on Geology* (the last two, English publications); Page's "*Hand-Book of Geological Terms*" (English); Taylor's "*History and Statistics of Coal*;" Buckland's "*Bridgewater Treatises*;" Dana's "*Elementary Mineralogy*," etc. A popular account of all the new facts and theories in geology, reported for each successive year, will also be found in the volumes of the Annual of Scientific Discovery.

Geological excursions to localities of interest afford an opportunity for obtaining much practical information, conjointly with healthful outdoor exercise and recreation. It is not necessary either to travel miles or days to find such localities. Sea-cliffs, river-channels, the sides of ravines, mountain precipices, road and railway cuttings, stone-fences, clay-beds, sand and gravel banks, quarries, and mines, all these are geological localities of interest; and although one may have seen them every day for years, yet when examined for the first time, from a geological point of view, they will be found expressive of many varied and interesting truths.

"In a new and progressive science like geology, which has still such a wide field of exploration before it, and which calls in the aid of so many of the other sciences, there is ample scope for the energy and industry of the most talented and enthusiastic. One individual may devote himself to the mineralogy of geology; another to its physical problems; a third to fossil plants; a fourth to fossil animals; a fifth to the economic relations of the science; and a sixth endeavor to find expression for the general laws which it indicates; while all may go on as one great brotherhood in the elucidation of the history of the marvellous world we inhabit. And whether in collecting data among the hills and ravines, by the sea-cliff or in the mine, or in arranging and drawing from these data the warranted conclusion, the earnest student will find geology at once one of the most healthful and exhilarating, as it is, intellectually, one of the most expanding of human pursuits. And even when *no* professional object is aimed at, the man of business, the health-seeker, and the holyday tourist, will find it an endless source of recreation—one that need never interfere with the comfort of a neighbor, or bring to the observer one pang of mortification or regret."

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FINIS.

Petrified Forest.—The San Francisco *Alta* offers the following theory as to the formation of the famous petrified forest near Mount St. Helena, Cal.: During one of the periods of St. Helena's volcanic activity—we assume that St. Helena was the one—it poured out a great abundance of ashes, some of which, whether dry or wet, in the form of mud, filled in what was then a valley, ten miles southwest of the summit of the mountain. This valley has its redwood trees, which are buried to a distance of twenty or thirty feet above their roots. The ash or mud hardened into rock; the trees died, and the tops, exposed to the air, decayed away and disappeared. The buried portions of the trunks also decayed; but as they did so the water, trickling down, carried with it sand and soluble minerals, which crystallized in the place of the disappearing fiber until the vegetable had been replaced by a mineral trunk, with the form, the size, the structure, the vertical grain, the knots, and even the concentric rings, showing the annual growth of the original tree. This petrifaction was harder than the surrounding sandstone, which, in the course of centuries, was washed away, leaving the stone trees standing, but when the erosion got down to the lower end of the petrifactions a little unevenness in the surface deprived the trees of their proper support, and they fell, breaking into short, transverse pieces, as we now see them. The fracture is of a kind that could not be made in a vegetable fiber, and that we should find very difficult to make in stone while lying down in a solid surface. The concussion of a fall of a brittle material explains it. There is, we believe, no known instance of petrifaction in open water. Petrifaction requires decay of the organic material, and wood is preserved, not injured, by water. The condition most favorable for petrifaction is an inclosure in a sandstone mold, with a mild temperature favoring slow decay, an outlet through the sandstone for the decayed material, and a continuous but slow infiltration of a fluid saturated with lime or other crystallizing minerals. These were the conditions at the Petrified Forest.

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