THE GEOLOGICAL STORY

JAMES D. DANA

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THE

GEOLOGICAL STORY

BRIEFLY TOLD

BY

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GEOL. STORY.

PREFATORY SUGGESTIONS.

GEOLOGY is eminently an out-door science; for strata, rivers, oceans, mountains, valleys, volcanoes, cannot be taken into a recitation room. Sketches and sections serve a good purpose in illustrating the objects of which the science treats, but they do not set aside the necessity of seeing the objects themselves. The reader who has any interest in the subject should therefore go for aid in his study to the quarries, bluffs, or ledges of rocks in his vicinity, and all places that illustrate geological operations. At each locality accessible to him he should observe the kinds of rocks that there occur; whether they consist of layers or not; and their positions, whether the layers are horizontal,— the position they had when made; or whether inclined, — a slope in the beds being evidence of a subterranean movement like that which takes place in mountain-making.

Geology teaches that much the larger part of the rocks that consist of layers were made through the action of water; and if such rocks are accessible, it is well, after learning the lessons of the book, to look among them for evidence of this mode of origin, either in the structure of the layers, in the nature of the material, in markings within the beds, or in the presence of relics of aquatic life, such as shells, bones, etc. If some of the layers in a bluff consist of sandstone, others are pebbly, others clayey, and one or more are of limestone, the kinds of changes in the waters that took place to produce such varied results should be made a point for investigation.

If an excavation for a cellar is opened near an accustomed walk, it is best to look at the sections of the earth or sands thus made; for these sands are very often in layers, and, in that case, they bear evidence that even there the loose material of the surface had been arranged by water, either that of the ocean or that of a river or lake.

When the layers contain fossils, a collection should be made for study; for they show what living species populated the waters or land when the rocks were forming; and in the height of a single bluff there may be records thus made of several successive populations different from one another.

If a beach or a cliff along the ocean is accessible, the action of the waves in their successive plunges may be watched to great advantage; for they are thus grinding up the stones and sands of the beach and eroding and undermining the cliff. While viewing such work on a seashore, it will be a good time to consider that this battering goes on almost incessantly through the year, and year after year, and has so gone on along coasts and about reefs for indefinite ages. The cliff and the rocky ledges in the surf at its base should be closely examined, that the amount and kind of wear may be appreciated; and the action of the water over the beach should be studied in order to understand why, after so much grinding, coarse sands and often pebbles are still left.

If there are sand-flats exposed off the shores at low tide, there is a chance to discover by what currents or movements of the water they were formed, and whence came the sands that compose them, which should be taken advantage of; for these modern sand-flats are identical in kind and mode of origin, although not in extent, with the sand-flats of ancient time out of which sandstones have been made; the only possible difference being that in the earlier ages the waters were everywhere salt, and rivers gave little aid. And if the sandy surface is left rippled as the tide goes out, note this, for ancient sandstones often contain such ripple-marks over their layers; or if the muddy portions are marked with the tracks of Mollusks, note this also, for in many rocks just such tracks occur.

If coral reefs or shell rocks are forming along the shores, as in the West Indies, these formations should receive special study; for many of the old limestones of the world were made in the same way.

If a heavy rain has gullied a side-hill or proved disastrous to roads, here is a fruitful field for study; for the gullies are miniature valleys, and they illustrate how most great valleys were excavated, — the latter being as truly the work of running water as the former. The same gullied slope may exemplify also the formation of precipices and waterfalls, of crested ridges, table-topped summits, and groups or ranges of mountain peaks.

These are some of the points of easy observation. Many others will occur to the reader after a perusal of the following pages.

A few labeled specimens of minerals and rocks are absolutely indispensable for even a partial understanding of the subject, and the student should buy or beg them, if not able to do the better thing — to collect them himself.

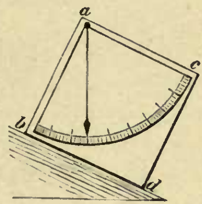
Of MINERALS: 1, crystallized quartz; 2, two or three quartz pebbles of different colors; 3, the variety of quartz called hornstone or flint; 4, common feldspar; 5, mica; 6, black hornblende; 7, a black or greenish-black crystal of augite, and better if in a volcanic rock; 8, garnet; 9, tourmaline; 10, calcite (carbonate of lime), a cleavable specimen; 11, dolomite, or magnesian carbonate of lime; 12, gypsum, or sulphate of lime; 13, pyrite (sulphide of iron); 14, magnetite, or magnetic iron ore; 15, hematite, or specular iron ore; 16, limonite, the common iron ore often called "brown hematite"; 17, siderite, or spathic iron ore; 18, chalcopyrite, or yellow copper ore; 19, galenite, or lead ore (sulphide of lead); 20, graphite.

Of Rocks: 1, 2, 3, common compact limestone of three different colors, one, at least, of these specimens with a fossil in it; 4, chalk, a variety of compact limestone; 5, 6, white and clouded granular or crystalline limestone, of which the ordinary architectural marble is an example; 7, 8, red and gray sandstone; 9, conglomerate, called also pudding-stone; 10, shale, such as the slaty rock of the coal-formation, and other shales of the Silurian and Devonian; 11, slate, or argillyte, that is, common roofing-slate, or writing-slate; 12, 13, coarse and fine-grained grayish or reddish granite (to be obtained, like marbles and sandstones, in many stone-yards); 14, red or gray quartz-syenyte, of which the Scotch "granite" and Quincy "granite" are good examples; 15, gneiss, a piece that has the mica distinctly in planes, and hence is banded on a surface of transverse fracture; 16, mica schist; 17, trap, an igneous rock; 18, trachyte, an igneous rock; 19, lava, a cellular volcanic rock; 20, a piece of diatomaceous or infusorial earth.

The above-mentioned minerals should at least be accessible to a class, if not in the hands of each student; and it would be well if the collection were larger. Moreover, the instructor, if not a practical geologist, should have by him the writer's Manual of Geology, or some other large work on the science, in order to be ready to answer the questions of inquisitive learners, and add to the examples and explanations.

The student should possess a hammer and a chisel. The best hammer has the face square, flat, sharp-angled, and the opposite end brought to an edge; this edge should have the same direction with the handle (as in the figure), if it is to be used for getting out rock-specimens, but be transverse to this, and thinner, if for obtaining fossils. The socket for the handle should be large, in order that the handle may stand hard work. The chisel should be a stone-chisel, six inches long. Rock-specimens should be uniform in size, with straight sides; say two inches by three, or three inches by four. Fossils had better be separated from the rock if it can be done safely.

For measuring the dip, that is, the slope, of layers, an instrument called a clinometer is used, which can be had of the instrument makers. It is a compass having a pendulum hung at the center, the extremity of which swings over a graduated arc. In the best kind the compass is three inches in diameter and has a square base.



A clinometer apart from the compass may be easily extemporized by taking (see figure) a piece of board, *abcd*, cut to an exact square (three or four inches each side), hanging a pendulum on a pivot near one angle (*a*), describing on the board, with one leg of the dividers on the pendulum-pivot, an arc of 90° (*b* to *c*), and then dividing this arc into nine equal parts, each to mark 10°, and subdividing these parts into degrees. Such a clinometer, well-graduated, is sufficiently accurate for good work.

Field work of the kind above pointed out makes the facts in the science real. It also teaches with emphasis the great lesson that existing forces and operations are in kind the same that have formed the rocks, the valleys, and the mountains. It thus prepares the mind to appreciate geological reasoning and comprehend the march of events in the earth's history.

NEW HAVEN, CONN., April 1, 1895.

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PART III.

GEOLOGY.

THE word *Geology* is from two Greek words signifying *the story of the earth.* As used in science it means an account of the rocks which lie beneath the surface and stand out in its ledges and mountains, and of the loose sands and soil which cover them; and also an account of what the rocks are able to tell about the world's early history. By a careful study of the nature and positions of rocks, and the markings or relics they contain, it has been discovered how the rocks themselves were made; and also how the mountains and the continents, with all their variety of surface, were gradually formed. And, further, it has been ascertained not only that the earth had plants and animals long before Man appeared, but what were the kinds that existed in succession through the long ages.

The subjects, therefore, of which geology treats are:—

I. The KINDS OF ROCKS.

II. The ways in which the rocks, valleys, mountains, and continents were made,—or GEOLOGICAL CAUSES, AND THEIR EFFECTS.

III. The events during the successive periods in the earth's history; that is, what making of rocks was going on in each period, what making of mountains and valleys, and what species were living in the waters and over the land in each, and how the world of the past differs from the world as it now is,— all of which subjects, and others related, are treated under the general head of HISTORICAL GEOLOGY.

PART I.

ROCKS, OR WHAT THE EARTH IS MADE OF.

Rocks consist of minerals; the ores and gems they contain are some of the minerals; and throughout the earth, to its center, the solid rocks have a crystalline structure.

The most abundant element in minerals and in the earth's constitution is *Oxygen*. It makes part of the atmosphere, is one of the two constituents of water, and is an essential part of all rock-making minerals. Owing to its strong attractions for other elements, iron rusts, — that is, becomes oxidized; and most iron-bearing minerals in the rocks oxidize, wherever exposed to air and moisture. This oxidation produces the decay of the rocks, and promotes the conversion of them into gravel, sand, and soil.

Of next importance in the constitution of rocks is *Silicon* (named from the Latin for *flint*). All the rocks excepting limestones contain silicon in combination with oxygen, and also usually other elements.

Next comes *Carbon* (named from the Latin for *coal*). It is the chief ingredient of coal and one of the constituents of limestone and of mineral oil and gas. It is a chief constituent also of all animal and vegetable tissues. In its pure crystallized state it is *diamond*, the hardest of all minerals, and also *graphite* or *plumbago* (the material of lead pencils), which is among the softest of minerals.

Aluminum (so named from the Latin for *clay*), combined with oxygen and other elements, is a chief constituent of clay, and also of very many of the rocks and hard minerals.

Calcium (from the Latin for *lime*) is a chief constituent of limestone. *Magnesium, potassium, sodium,* are other common elements of rocks.

Sulphur occurs pure in nature, especially in volcanic regions. It is a constituent of many ores, and also of gypsum among rock-making materials. *Arsenic* is an ingredient of many ores, but not of any rock.

Hydrogen (named from the Greek for *water-producer*) is the element that is combined with oxygen to form water. It is an essential constituent also of animal and vegetable tissues. It forms, with carbon, mineral oil and gas.

The crystalline structure of the earth's minerals and rocks is universal. A mineral shows it often in having symmetrically arranged facets over its surface, which are generally brilliant in luster. Some of these forms are shown in the figure of quartz on page 17, of garnet, hornblende, and augite on page 22, and of calcite on page 24.

The crystalline structure is commonly shown also in the presence of planes of easy fracture or cleavage in one or more directions; and when in two or three directions, in causing many crystals to break into fragments of symmetrical form when struck with a hammer. The planes of fracture of a broken bar of iron are surfaces of angular points because of this cleavage, each grain being an imperfect crystal with cleavage planes; and so is the plane of fracture of white marble, the grains in the surface being angular and lustrous. So it is in granite, and through all the earth's deepest foundations wherever the rocks are not melted.

The crystalline structure is assumed on consolidation, whether this takes place from a state of fusion, or of solution, or of vapor. The vapor or moisture of the air is changed to crystals of water, or to flakes, which are aggregations of crystals, with every snowstorm; and the water of ponds crystallizes in becoming ice. Even the sand of the seashore is crystalline; for every grain is a fragment of a crystal.

If conditions are favorable for very slow, quiet consolidation, single crystals of large size may form; but if too rapid, the solid snow becomes an aggregation of crystalline grains. This is the condition of granite and of all other igneous rocks except the glassy ones; for glass, like animal and vegetable tissues, is an exception to the general rule, in being non-crystalline. Even glass becomes crystallized if melted again and *slowly* cooled; but it is then turned into stone.

It is thus manifest that the principle which gives to the gem its beauty of form and brilliancy pervades the whole system of material existence. The elements of beauty are everywhere.

I. MINERALS.

Minerals are distinguished by their chemical composition. But, in general, the kinds may be determined by an examination of their color, hardness, luster, specific gravity, and fusibility.

When distinctly crystallized, minerals may be distinguished also by their crystalline characters; for besides symmetry in the general arrangement of the faces, there is, in the same mineral species, a like angle between corresponding faces, and also between like cleavage directions.

1. Consisting of Silica.

Quartz. — Quartz is the most common of the materials of rocks. It is well fitted for this first place; for (1) it is one of the hardest of minerals, the point of a knife-blade or edge of a file making no impression on it; (2) it does not melt in the hottest fire; and (3) it is not dissolved by water, or corroded by either of the common acids. Its durability is its great quality. With a piece of quartz it is easy to write one's name on glass. Another quality of it, distinguishing it from many minerals it resembles, is that it breaks as easily in one direction as another; that is, its crystals have no cleavage.

It is of various colors and kinds. *Flint* and *hornstone* are dark-colored, massive quartz. The smooth-surfaced stones of a pebble bank, whether white, brown, yellow, or black, if uniform (not speckled) in color, are almost all quartz. Mountains thousands of feet high are sometimes made of quartz rocks. The sands of a seashore are mostly quartz, because the grinding of particle against particle which goes on under the heavy dash or swift flow of the waters wears out all other materials, and leaves only the hard quartz particles behind.

Quartz is often found in crystals. The figure annexed shows the form of one of them. It is a regular six-sided prism (*iii*), with a six-sided pyramid at each end; and it is often as transparent as glass. Frequently the crystals are attached by one end in great numbers to a surface of rock, so that this surface is brilliant with little pyramids of quartz set crowdedly over it, or with pyramids raised on prisms. The inclination of the face of the prism to the adjoining face of the pyramid is always the same (141° 47′), wherever the quartz crystal may come from. These glassy crystals are wholly natural productions, having their forms perfect and luster brilliant when first taken from the rocks.

FIG. 1.

Quartz.

While some quartz crystals are clear and colorless, others have a purple color, and these are the *amethyst* of jewelry. Others have a light-yellow color, looking like topaz, and are called *false topaz;* and others a clear smoky-brown color, and these are the *cairngorm stone* of Scotland.

Agate is quartz in which the color is arranged in thin bands or layers of different shades of color, as white, smoky-brown, red, etc.

Quartz, called in chemistry *silica*, is a compound of silicon and oxygen, in the ratio of 1 atom of the former to 2 of the latter, and the chemical formula is therefore SiO_2.

Quartz, while so enduring, if pulverized and heated, after mixing it with soda, potash, lime, magnesia, or oxide of iron, fuses easily and forms glass. Ordinary glass is made by melting together quartz sand and soda. Again, hot waters containing soda or potash in solution will dissolve out the silica of silica-bearing minerals, and on cooling will deposit it again. The waters of hot springs often contain silica, which they have taken, along with soda or potash, from some rock with which they have been in contact. Through deposits from such solutions (1) agates have been made; (2) fissures in rocks have been filled with quartz, and the fractures thus mended; and (3) the sands of sand beds and gravel of gravel beds have often been cemented into the hardest of rocks.

Opal is also silica, but it differs from quartz in being softer, of less specific gravity, and never crystallized, and it is dissolved much more readily by hot alkaline waters; the precious opal has a beautiful play of colors arising from internal reflections. The silica of Diatoms and of the deposit made by geysers (called *geyserite*) is in the state of opal.

2. Silicates.

Silica, while existing in rocks abundantly as quartz, also makes, on an average, a third of all their other minerals, limestones excepted; that is, it exists combined with other substances, making various common minerals. These minerals containing silica are called *silicates.*

Some of the substances that are combined with silica in the common silicates are the following:

1. *Alumina.* — Consists of aluminum and oxygen in the ratio 2 : 3, and has therefore the formula Al_2O_3.

In the pure state it constitutes the mineral *corundum* (a blue variety of which is the blue gem, sapphire, and a red variety, the ruby). It is infusible, like quartz, and harder than all other minerals excepting the diamond. Because so hard, it is ground up to make emery, for grinding and polishing hard stones and metals.

2. *Lime.* — A constituent of all limestone, as well as of many silicates. Quicklime, which is used for making mortar, is more or less pure *lime.* Consists of one atom of calcium and one of oxygen, and has therefore the symbol CaO.

3. *Magnesia.* — A constituent of Epsom salt. Consists of magnesium and oxygen in the proportion 1 : 1, and has the symbol MgO.

4. *Potash.* — An ingredient of wood ashes, hence the name. Consists of potassium (or *kalium*) and oxygen, in the proportion 2 : 1; its symbol is K_2O.

5. *Soda.* — An ingredient of the ashes of seaweeds. Consists of sodium (or *natrium*) and oxygen in the proportion 2 : 1; its symbol is Na_2O. Sodium and chlorine constitute common salt, the symbol being NaCl.

6. *Iron oxides.* — Consist of iron (*ferrum*, in Latin) and oxygen; one oxide has the symbol FeO, and another Fe_2O_3.

Some of the more common silicates are the following:

1. **Feldspar.** — A feldspar contains, besides silica, the elements of alumina, and of potash, soda, or lime. It is fusible, and is therefore a constituent of most volcanic or igneous rocks.

Feldspar has usually a white or flesh-red color, and sometimes might be mistaken for quartz. But (1) it is not quite so hard as quartz, though too hard to be scratched easily with a knife; and, besides, (2) it melts when highly heated; (3) it cleaves in one direction with a bright, even surface, brilliant in the sunshine, and also in another direction but less easily, at right angles or nearly so to the former. While quartz has no cleavage, feldspar has cleavage in two directions transverse to each other.

Common feldspar (called *orthoclase* in mineralogy) is a *potash feldspar*, containing the elements of potash along with those of alumina and silica; another form is a *soda feldspar*, and is called *albite*, from its usual white color; others are *soda-and-lime feldspars*, and one of these, called *labradorite*, is a constituent of trap, basalt, and other igneous rocks; and another is a *lime feldspar*.

2. **Mica.** — Mica (often wrongly called *isinglass*) splits very easily into leaves, thinner than the thinnest paper, which are tough and elastic, and frequently transparent. It does not melt easily, but fuses on the thin edges with high heat. It is the transparent material commonly used in the doors of stoves. Some mica is white, or gray; it is oftener brownish, and very frequently black. Like feldspar, it contains the elements of silica and alumina, with potash. The common light-colored kind is free from magnesia and is called *muscovite;* the black kind contains magnesia and iron and is called *biotite.*

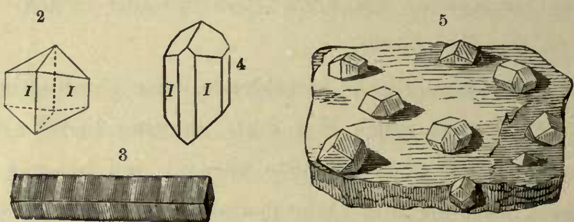
3. **Hornblende.** — Black hornblende, when occurring in rocks, often looks much like mica, showing lustrous cleavage surfaces; but it is a brittle mineral, and hence cannot, like mica, be split into thin, flexible leaves or scales with the point of a knife. It makes very tough rocks, hence the first part of the name, *horn;* the rocks are heavy and sometimes look like an ore of iron, hence the second part, *blende,* a German word meaning blind or deceitful. It is a *silicate,* that is, it contains silica, but with it there are iron oxide, magnesia, and lime without potash. Hornblende also occurs of green, brown, and white colors. A green radiated kind is called *actinolite;* a white kind, *tremolite;* a finely fibrous kind having the fiber flexible, *asbestus.*

4. **Augite or Pyroxene.** — Augite is black or dark-green *pyroxene,* having the same composition as hornblende, and differing only in the shape of its crystals. It is named

from a Greek word signifying *luster*, because its crystals are often bright, though not more so than those of hornblende.

Two of the crystals of hornblende are represented in Figs. 2, 3, and one of those of augite in Fig. 4. The angle of the prism of augite (or that between *I* and *I* in Fig. 4) is about 87°; while the angle of the prism of hornblende (between *I* and *I* in Fig. 2) is $124\frac{1}{2}$°; it is mainly owing to this difference that hornblende and augite have distinct names.

FIGS. 2–5.



Minerals.

Figs. 2, 3, Hornblende; 4, Augite; 5, Garnet in mica schist.

5. **Garnet.**—Usually in dark-red crystals, but often also black, and occurring imbedded in mica schist and other rocks, as represented in Fig. 5. The crystals, here represented, have 12 rhombic faces, or are dodecahedrons. Another common form has 24 faces, and is called a trapezohedron. The most common varieties of garnet contain silica, alumina, iron oxide, and lime. When transparent it is used as a gem.

6. **Talc.**—A very soft mineral, feeling greasy in the fingers, consisting of silica, magnesia, and water. A granular kind is *soapstone*.

7. **Serpentine.** — A soft mineral or rock, usually greenish, of the same constituents as talc, but in different proportions.

8. **Chlorite.** — A soft dark-green mineral, having the elements of talc, along with alumina, and often some iron oxide. It is sometimes mica-like in structure.

Other common silicates are *staurolite*, whose crystals are often crosses; *cyanite*, usually in bluish bladed forms; *epidote*, commonly of a yellowish-green color; *tourmaline*, often in 3- to 9-sided prisms of a black color, the luster pitch-like on a surface of fracture; *chrysolite* or *olivine*, a greenish glass-like silicate of magnesia and iron, common in some igneous rocks, especially basalt.

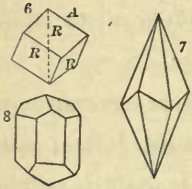
3. Carbonates.

Carbon has been described as one of the constituents of limestone, mineral coal, charcoal, mineral gas, and mineral oil. One atom of carbon combined with 2 of oxygen forms carbon dioxide, often called *carbonic acid;* its symbol is CO_2. Carbonic acid is the gas that escapes from ordinary effervescent waters, such as soda water. It is present in the atmosphere, constituting 3 volumes in every 10,000. Compounds of carbonic acid are called *carbonates.*

1. **Calcite.** — Calcite is *carbonate of lime*, also called *calcium carbonate;* its formula is $CO_2 + CaO$ (or $CaCO_3$). It occurs in crystals that break easily in three directions, affording forms with rhombic faces, like Fig. 6; the angles between the faces are 105° 5′ and 74° 55′. A very common form is called *dog-tooth*

spar; the shape is shown in Fig. 7. Another kind is a 6-sided prism with a low pyramid at either end (Fig. 8).

Figs. 6–8.



Calcite.

Calcite is easily scratched with the point of a knife. Most limestone is more or less pure calcite. When calcite or limestone is burnt, carbonic acid escapes as a gas, and the lime is left. This lime is the so-called *quicklime*, for making mortar. When a grain of calcite is put into dilute hydrochloric acid, carbonic acid gas is given off freely, producing a brisk effervescence, and the calcite, if it is pure, becomes wholly dissolved. By means of (1) its effervescence with acid, (2) its low degree of hardness, (3) its infusibility in the hottest fire and its burning to quicklime instead of fusing, calcite or limestone is easily distinguished from feldspar and other minerals. The cleavages in crystals of calcite also separate it from feldspar; for the number of directions is three, and the angle between them is about 105° instead of about 90°. Limestone is mostly massive calcite, more or less impure, but partly dolomite.

2. **Magnesian Limestone, or Dolomite.** — Limestone sometimes contains magnesia in place of half of the lime, and it is then called in mineralogy, *dolomite,* after Dolomieu, a French geologist of the last century. Dolomite, or magnesian limestone, does not effervesce freely unless the acid is heated, and in this respect it differs from calcite. In aspect, calcite and dolomite are closely alike.

4. Sulphates.

Sulphur, when combined with oxygen in the proportion 1 : 3, forms, along with water, the strong acid, *sulphuric acid*, called often *oil of vitriol*.

Gypsum. — Gypsum is a *sulphate of lime* (or *calcium sulphate*) containing water. It is one of the ingredients deposited by sea water on evaporation. Occasionally it forms large rock masses. The mineral crystallizes in rhombic and arrow-head forms, and has an easy cleavage in one direction. It is soft, pearly in luster, and white to gray and black in color. When fine granular, and fitted for making vases or for other ornamental use, it is called *alabaster*.

No other sulphate occurs in rock masses. *Barite*, or *barium sulphate*, also called *heavy spar*, is a frequent associate of ores in veins. *Copperas*, or *green vitriol*, is an iron sulphate, — a common result of the decomposition of iron ores containing sulphur.

5. Ores.

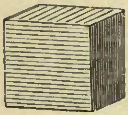
Ores include those metal-bearing minerals that are of economical value. The metal in many ores is in combination with sulphur or oxygen, but in some with arsenic, antimony, and other elements, or with carbonic acid, sulphuric acid, phosphoric acid, and other acids.

The following are a few of the common ores: —

1. **Pyrite.** — Pyrite has nearly the color and luster of

brass. It is so hard that it will strike fire with steel (whence its name, from the Greek for *fire*), and in this it differs from a yellow ore of copper, called *chalcopyrite* or *copper pyrites*, which it much resembles. It is very often in cubes, like Fig. 9. It consists of sulphur and iron, nearly 48 parts by weight in 100 being iron; the chemical symbol is FeS_2. Both of the constituents have a strong affinity for oxygen; and consequently pyrite often changes to vitriol or an iron sulphate, or to the oxide of iron called *limonite*. It is of no use as an ore of iron, because of the difficulty of separating the sulphur; but it is often employed for the making of vitriol. It is the most generally distributed of all metallic minerals, occurring in particles through most rocks, crystalline as well as uncrystalline. Owing to the tendency to alteration just mentioned, it has caused the destruction or disintegration of rocks over the earth's surface to a greater extent than any other agency.

FIG. 9.



Pyrite.

2. **Magnetite, or Magnetic Iron Ore.** — An iron-black oxide of iron, having a *black* powder. It is attractable by the magnet. It often occurs in black octahedrons. It is common in northern New York, in Orange County, New York, in Sussex County, New Jersey, and in many other regions, where it constitutes beds of great thickness, and is worked for making iron. It consists of oxygen and iron in the proportion of 4 atoms of the former to 3 of the latter (Fe_3O_4), and contains 72 parts of iron in 100.

3. **Hematite, or Specular Iron Ore.** — An oxide of iron, of iron-black color when in crystals, but often bright red when massive, the powder being *red.* Red ocher is earthy hematite. It is not strongly attracted by a magnet. Like magnetite, it occurs in great beds in northern New York, in the Marquette region, near Lake Superior, in Michigan, and in many other places. It consists of oxygen and iron in the proportion of 3 atoms of the former to 2 of the latter (Fe_2O_3,) and contains, when pure, 70 parts by weight of iron in 100.

Nearly all rocks of a reddish or red color owe their color to this oxide of iron.

Hematite and magnetite occur, with small exceptions, in beds instead of veins. When the beds are vertical or nearly so, they look like veins.

4. **Limonite.** — A brown, brownish-yellow, or black ore of iron, affording a *brownish-yellow* powder; it is sometimes called *brown hematite. Yellow ocher* is impure or earthy limonite. It differs in composition from hematite only in containing water. When heated, the water is driven off, and it becomes red, and is then hematite in composition. It contains, when pure, about 60 per cent of iron. It is a result of the decomposition of other iron ores, and forms great beds in some regions, as near Salisbury in Connecticut, and in Richmond, Massachusetts. It is often found in bogs, and is then called *bog iron ore.* Limonite is often disseminated through clays, giving them a yellowish or brownish color; and such clays turn red when heated, because they

lose the water which makes limonite differ from hematite. For this reason, bricks are usually red. Clay for making white pottery must contain no iron.

5. **Siderite, or Spathic Iron Ore.** — A gray to brown iron carbonate, without metallic luster, consisting of oxide of iron and carbonic acid. When pure, about 48 parts in 100 are iron. It occurs crystallized, and also in impure massive nodular forms. The iron ore of many coal regions is this massive nodular variety. It is a heavy mineral (the specific gravity 3.5 or above), and by this quality it may be distinguished from other grayish or brownish stones. In heated hydrochloric acid it effervesces, owing to the escape of carbonic acid. This ore, like limonite, is sometimes present sparingly in clays.

6. **Chalcopyrite, or Yellow Copper Ore.** — A brass-colored mineral consisting of sulphur, iron, and copper, about a third of which is copper. It is scratched easily with a knife, and affords a *dark-green* powder, differing thus from pyrite, the mineral it most resembles. It is sometimes mistaken for gold; but, unlike gold, it is brittle. It occurs for the most part in veins with other ores.

7. **Galenite, or Lead Ore.** — A lead-gray ore, brittle and easily pulverized, and affording a *lead-gray* powder, consisting of sulphur and lead, the lead making over eighty-six per cent. It often cleaves into cubic or rectangular forms. It is the common kind of lead ore. It often contains a little silver, and then is worked as a silver ore. It occurs

in cavities in limestones, in northern Illinois, Wisconsin, and Missouri, in Leadville, Colorado, and in Derbyshire, England. It is often found also in veins. At Leadville, and at other places in the Rocky Mountains, the deposits in limestone are directly connected with veins, and are part of the results of vein-making.

8. **Malachite.** — Green copper carbonate, often accompanying other copper ores. *Azurite* is a blue copper carbonate, much less common.

II. KINDS OF ROCKS.

The following are the characters of some of the common kinds of rocks: —

1. **Limestone; Magnesian Limestone.** — These rocks are partly described on pages 23 and 24. They are of dull shades of color, from white through gray, yellow, red, and brown to black, and of all degrees of texture, from the compactness of flint to a coarse granular texture. The test by acids, by heat, and by use of the point of a knife in trial of the hardness, are the means of distinguishing limestones from other rocks. *Chalk* is limestone. Ordinary *marble* is limestone, and sometimes the magnesian kind.

The different kinds of limestone are called *calcareous* rocks, from the Latin *calx*, meaning *lime*.

2. **Sandstone.** — Sandstone is a rock made of sand. The sand may be quartz, like the sand of most seashores; or it

may be powdered granite, or other powdered rock. Sand, when gathered into beds and consolidated, makes sandstone. Sandstones are the most common of rocks. They have various dull colors, from white through gray, yellow, and brown to brownish-red and red.

3. **Conglomerate.** — A conglomerate or pudding stone is a consolidated gravel bed, — gravel being sand mixed with pebbles or small stones. The stones are sometimes large, even a foot in diameter. They are often of quartz, sometimes of other hard rocks, and occasionally of limestone.

4. **Shale.** — Shale is a fine mud or clay consolidated into a rock having a slaty fracture, but less evenly slaty and less firm than true slate. The colors vary, like the colors of mud or clay, from gray and yellowish shades through red and brown to black. Black is a common color, because the plants and animals that live and die in the mud or over it contain carbon, the chief element of coal, and contribute portions of carbonaceous substances to the mud. Such black shales, when burnt, usually become white or nearly so, because the vegetable or animal material is then burnt out. For the same reason black limestones afford white quicklime.

The loose earthy material of the world, in and out of the water, is mostly either sand, gravel, mud, or clay; and thus it has been through all ages. *Sand* is finely pulverized rock. *Mud* is the same, for the most part, but finer; and it may contain rock that is decomposed as well as pulverized. *Clay* is a fine kind of mud; it is mainly either pulverized feldspar along with quartz in fine grains, or else decomposed feldspar with more or less quartz. It comes from the pulverizing of granite, gneiss, and other rocks containing feldspar, or from their decomposition. Clay often contains iron; and when burnt to make brick it becomes red. *Gravel* is mixed sand and pebbles.

The consolidation of sand makes *sandstones;* of pebble beds, *conglomerates;* of fine mud or clay, *shale.*

5. **Argillaceous Sandstone.** — When sands are clayey, the beds make, when consolidated, a clayey, that is, *argillaceous,* sandstone (*argilla,* in Latin, meaning *clay*). Such sandstones usually break into thin slabs, in which case they are said to be *laminated* sandstones; and, if of sufficient hardness, they make good flagging stones for sidewalks. The common flagging stone used in New York and adjoining states is an argillaceous sandstone.

6. **Slate.** — Slate, or *argillyte,* differs from shale in breaking much more evenly, and being much firmer. The slates used for roofing are examples.

7. **Granite.** — Granite is one of the crystalline rocks, its ingredients being, not worn grains like those of a sandstone or conglomerate, but crystalline grains, all having been rendered crystalline together by a process in which heat was concerned (pp. 39, 42). It consists of grains of three minerals, *quartz, feldspar, mica,* mixed promiscuously together. The quartz grains are usually grayish or smoky in color (commonly of a darker tint than the feldspar), and have *no cleav-*

age. The grains of *feldspar* have cleavage, and therefore show smooth, sparkling surfaces when a fragment of granite is exposed to the sun, and their color is usually white or flesh-red. The *mica* is much softer than the feldspar, and with a point of a knife blade its grains may be divided into thin, flexible scales; its colors are white, brownish, or black.

8. **Gneiss.** — Gneiss has the same constituents as granite; but these constituents are arranged more or less in planes, and, owing to the mica, the rock splits into thick layers, and on a cross fracture appears banded. On account of its splitting into layers gneiss is said to be a *schistose* rock (this term being derived from a Greek word meaning *to divide*, and pronounced as if spelt *shistose*). This schistose structure is the only one distinguishing it from granite. It is somewhat like the laminated structure.

9. **Mica Schist.** — Mica schist has the same constituents as granite and gneiss, but the quartz and mica are by far the most abundant, especially the mica; and on account of the large proportion of mica, mica schist divides into thin layers. It glistens in the sunshine, owing to the scales of mica. Sometimes the scales of mica are too small to be distinct, and contain some water in combination, and then it is called *hydromica schist.*

The rocks, granite and gneiss, and gneiss and mica schist, pass into one another through indefinite shadings. There are granites that are slightly gneiss-like, and others of all grades to true gneiss; and there are all grades from gneiss to mica schist, so that it is sometimes difficult to say whether a rock should be called granite or gneiss, and whether another should be called gneiss or mica schist. Again, mica schist shades off into hydromica schist and into argillyte, or clay slate, as the crystalline texture is less and less apparent.

10. **Syenyte.** — Some granite-like rocks contain *hornblende* in place of the mica, with little or no quartz, and such kinds are called *syényte.* The hornblende is grayish-black, greenish-black, or black, and differs from black mica in being brittle, and hence in not affording thin, flexible scales. If quartz is present in abundance, the rock is called *quartz-syenyte.* The so-called granite of the Quincy quarries, near Boston, and the red Scotch granite imported for monuments, are quartz-syenyte.

11. **Syenyte-Gneiss; Hornblende Schist.** — Syenyte-gneiss differs from ordinary gneiss in containing hornblende instead of mica. *Hornblende schist* is a black, slaty rock consisting mainly of hornblende.

12. **Trap, Basalt, Lavas, or Volcanic Rocks.** — *Trap* and *basalt* are igneous rocks; that is, they have cooled from fusion, like the lavas of a volcano. Such rocks have come to the surface in a melted state, through an opened fissure, from some deep-seated region of liquid rock, and have sometimes flowed from the fissure over the adjoining country. The part filling a fissure is called a *dike.* Trap is a dark-colored, heavy rock, more or less crystalline in texture. The most common variety consists of a lime-and-

soda feldspar (called *labradorite*, from Labrador, where it was first found) and augite, along with grains of magnetite. It is the rock of the Palisades along the west side of the Hudson River above New York, of Mount Holyoke near Northampton, and of various hills and ridges in the Connecticut Valley; of many ridges in the vicinity of Lake Superior, and over the western slope of the Rocky Mountains; of the Giant's Causeway on the north coast of Ireland, and Staffa on the western coast of Scotland; and it is common over the globe. Basalt is a similar rock containing scattered grains of chrysolite or olivine.

Some trap contains small nodules consisting of different minerals. These nodules fill cavities that were made by expanding vapors while the rock was still melted. This variety of trap is called *amygdaloid*, because the little nodules sometimes have the shape of almonds (*amygdalum*, in Latin, meaning *almond*.) Trap and basalt frequently occur in columnar forms, as at the Giant's Causeway, many places in the Lake Superior region, near Orange, New Jersey, and elsewhere.

Volcanic rocks, called *lavas*, are those that have been ejected in a melted state from, or about, an open vent called a *crater* (from the Latin for *bowl*). Eruptions around the crater make the fire mountain, or *volcano*.

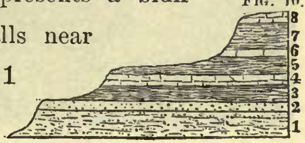
A large part of the common lavas are similar in composition to trap and basalt, although often they are very cellular rocks, and sometimes resemble much the scoria of a furnace.

Other volcanic and igneous rocks are mainly feldspar in composition, and as they therefore contain little or no iron, they are less heavy than trap or basalt. Their specific gravity is mostly 2.5 to 2.8, while that of the trap series is 2.8 to 3.2. A common kind, rough on a surface of fracture, is called *trachyte;* and another, containing isolated crystals of feldspar, is *porphyry.* Rocks made out of volcanic sands are called *tufas.*

III. STRUCTURE OF ROCKS.

1. Stratified Rocks. — Most rocks consist of layers piled one upon another; and the series in some regions is thousands of feet in height. Figure 10 represents a bluff on the Genesee River at the falls near Rochester. In this section Nos. 1 and 2 are sandstone; No. 3, green shale; No. 4, limestone; No. 5, shale; No. 6, limestone; No. 7, shale; No. 8, limestone again.

Fig. 10.

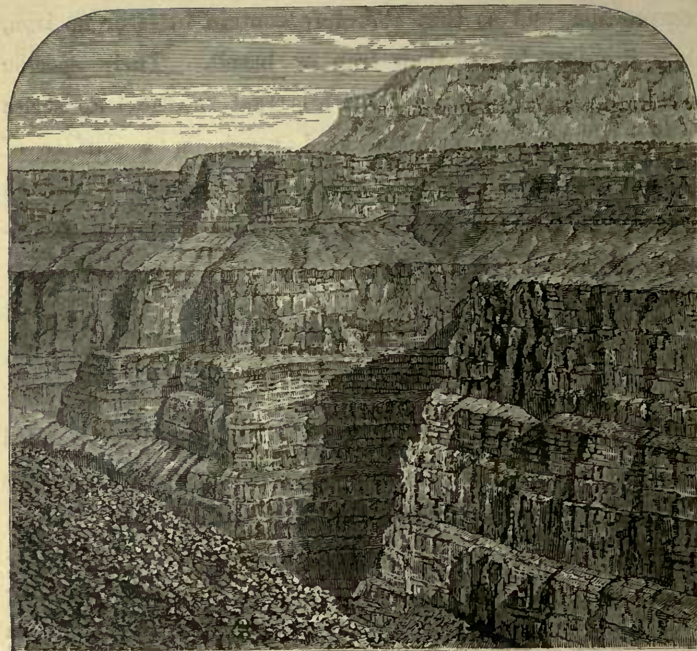


Section on Genesee River.

Another example is here presented (Fig. 11) from the Colorado cañon. The height of the pile of layers in view is over 3110 feet; but the river flows 2755 feet below, and hence the whole height of the wall is 5865 feet. Still another example from the Colorado region is given on page 103.

It is to be noted that (1) the layers were made one after

FIG. 11.



Part of the wall of the Colorado Cañon, from a photograph by Powell's Expedition.

another, beginning with the lowest; that (2) the successive layers correspond to successive intervals of time in geological history.

Rocks consisting thus of beds are called *stratified* rocks, from the Latin *stratum*, meaning *bed*.

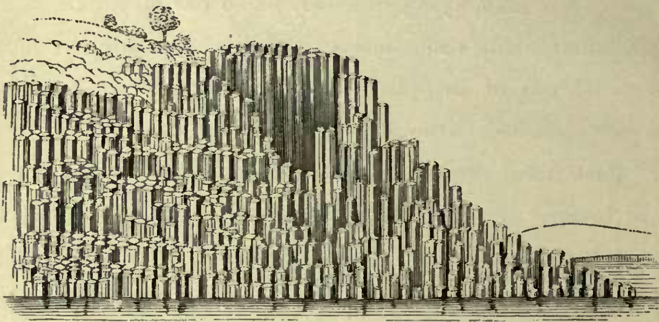
But layer and stratum in geology have not the same meaning. In Fig. 10 the lower sandstone bed, No. 1, consists of *many layers;* together they make a *stratum*. No. 3 is another stratum, — one of shale; No. 4, another, — one of limestone, and also made up of many layers; and so on. Thus there are *eight strata* (*strata* being the plural of *stratum*) visible in the bluff; and each consists of many layers. All the layers *of one kind*, lying together, make *one* stratum.

Sandstone, shale, conglomerate, and limestone are the most common kinds of *stratified* rocks. Gneiss and mica schist also are stratified, although crystalline in texture.

2. **Unstratified Rocks.** — Unstratified rocks are not made up of layers. The granite about the Yosemite, in California, is in lofty mountains and mountain domes, showing no distinct bedding or stratification; and the same is the character of most granite. The trap rocks of the Palisades, on the Hudson, rise boldly from the water and have no division into layers; but, instead, a vertical division into imperfect columns, a common feature of such trap rocks, illustrated on the next page. It is not, however, true that all igneous rocks are *un*stratified; for where lavas have flowed out in successive streams over a region, those streams have made successive beds, and the rocks are truly stratified. But the term *stratified rocks* is usually applied only to the kinds not of igneous origin.

The columnar structure of some trap rocks is well illustrated in the following view of a scene on the shores of Illawarra in New South Wales, Australia. While stratification has come from the successive formation of beds, these columns are a result of the cooling. Cooling causes contraction, and the contraction of the solid rock, as cooling goes on, produces the fractures. These fractures are always at right angles, or nearly so, to the cooling surfaces. Where

Fig. 12.



Basaltic columns, coast of Illawarra, New South Wales.

the rock fills vertical fissures, the columns are horizontal. Even sandstones have been rendered columnar where overlaid by beds of trap, or when they have been subjected otherwise to heat.

PART II.

GEOLOGICAL CAUSES AND EFFECTS.

UNDER the head of Causes, Geology treats of the ways in which (1) rocks, (2) valleys, (3) mountains and continents were made; or, in general, the means through which all changes have been brought about.

I. MAKING OF ROCKS.

THE rocks, briefly described in the preceding pages, have been made by the following methods:

1. **Rocks formed from Fusion.** — Igneous rocks are here included, or those that have cooled from a melted state either beneath the surface of the earth or after ejection at the surface. They are generally crystalline, though sometimes glassy, in texture, each grain in the former case being a separate crystal; yet the small grains are generally so crowded together that they have nothing of the external forms of crystals, and very often are too minute to be easily distinguished. Igneous rocks are of small extent and importance over the globe as compared with those made through the action of water.

2. **Rocks made by Deposition from Waters holding the Material of them in Solution.** — Waters containing lime often deposit it, and so make a kind of limestone. As examples: waters percolating through the limestone roofs of caverns, as they evaporate on the roof, form long pendent cones or cylinders of limestone called *stalactites* (from the Greek for *to distil*); and the same waters, dropping to the floor of the cavern, there evaporate and produce a bed of limestone called *stalagmite.*

There are many springs, and some rivers, in the world, whose waters are calcareous. Such waters petrify the moss, leaves, and nuts of swamps, and sometimes make thick beds of limestone, which are very porous, and irregular in thickness and texture, called *calcareous tufa*, and also *travertine.* On Gardiners River, in the Yellowstone Park, at the summit of the Rocky Mountains, such deposits are forming, and the river is thus made into a series of waterfalls. But such beds of limestone are of even less extent and importance than igneous rocks. None of the great limestones of the world were thus made.

Waters often hold traces of silica in solution, especially if they are hot and alkaline, and they deposit this silica again, making siliceous beds and petrifactions. Some facts on this point are mentioned beyond, among the effects of heat in rock-making. Cold water seldom deposits silica unless where there are the remains of siliceous infusoria, as mentioned on page 54.

3. **Rocks made by the Mechanical Agency of Waters and Winds, exclusive of Limestones.** — Far the larger part of rocks are *fragmental* rocks; that is, they are rocks made out of *fragments* of older rocks. The finest mud or clay consists of fragments of rock material, and hence a shale — a rock made from fine mud or clay — is a fragmental rock as much as a sandstone or a conglomerate.

A large part of the fragments, or the sand, pebbles, and mud, were made by the wearing action of moving waters; and hence such material is called *detritus*, from the Latin, meaning *worn out.* The agency of greatest effect and longest action in past time has been the *ocean;* that of next importance, *rivers;* that next, *winds.* But, preparatory to these agencies, the air, moisture, and the sun's heat have been quietly at work giving aid in the reduction of rocks to fragments or grains; and thus the ocean, rivers, and winds have found much loose material ready for them, instead of being left to make all that was required for their work in rock-making.

The sand, gravel, and mud or clay of which rocks have been made were in general deposited as a sediment from the waters of the ocean or rivers, as will be explained further on; and hence sandstones, conglomerates, and shales are called *sedimentary* rocks.

4. **Rocks made mainly or wholly of Organic Remains, that is, of the Remains of Plants or Animals.** — (1) The great *limestones* of the world are of organic origin; also (2) some siliceous deposits; and (3) the coal-beds and peat-beds of the world.

Many sandstones and shales contain more or less of such remains. Plants, shells, and other distinguishable relics of living species found in rocks are called *fossils*, or *organic remains.* They are sometimes called also *petrifactions*, which means *made into stone;* but not always rightly so, for many fossils consist of essentially the same material that composed the living species. Wood is sometimes changed to stone; and this is then a true petrifaction.

5. **Metamorphic Rocks.** — Fragmental rocks, such as sandstones, shales, and conglomerates, and also limestones, have sometimes been altered (or metamorphosed), over regions of great extent, to *crystalline* rocks, such as gneiss, mica schist, granular limestone, or architectural marble; and these crystalline rocks are hence called *metamorphic* rocks, the word *metamorphic* meaning *altered.* Some granites are metamorphic, while other granites are igneous rocks.

The following order of description is here adopted: —

1. The ways in which plants and animals have contributed to rock-making.
2. The results from the quiet working of air and moisture.
3. The work of winds.
4. The work of rivers.
5. The work of the ocean.
6. The work done by ice.
7. The work of heat.
8. Solidification and metamorphism of rocks.
9. Veins and ore deposits.

1. Ways in which Plants and Animals have contributed to Rock-making.

1. *Making of Limestones.*

The animal relics that have contributed most to limestones are *shells, corals, crinoids,* and *foraminifers.* These are skeletons of animals, that is, stony portions of the body, either made internally in the same manner as the bones of a dog are made, or, like a shell, made externally as a covering for the animal. When the animal dies, the relics pass to the mineral kingdom and are used in rock-making; and, as stated before, nearly all the limestones have thus been made.

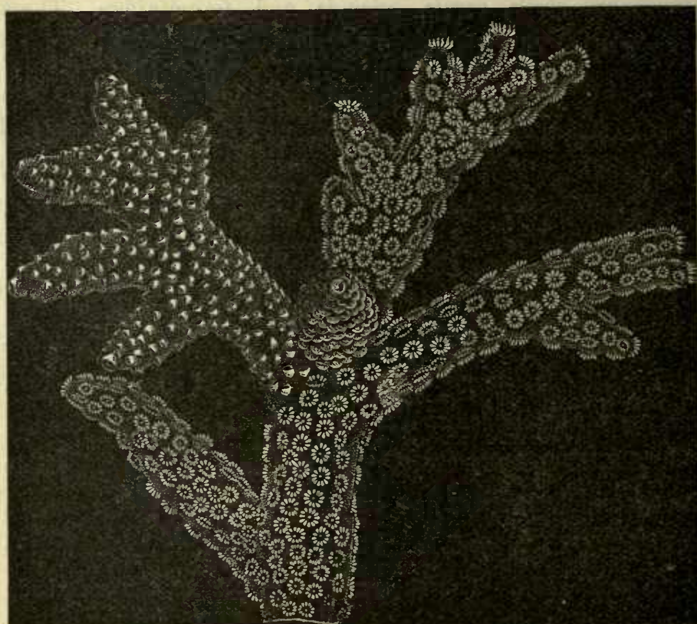
Corals and crinoids are exclusively oceanic species of animals; but, while this is true also of most shells and foraminifers, there are some kinds that flourish in fresh waters, and among shells some, like the snail, live over the land.

1. **Shells.** — Shells are the skeletons of animals related to the oyster, clam, snail, and cuttle-fish, — animals that have a *soft fleshy body,* and hence are called *Mollusks,* from the Latin *mollis, soft.* The shells serve to protect the soft body and give it rigidity.

2. **Corals.** — Coral is, for the most part, the skeleton of polyps, the most flower-like of animals, and it is an *internal* skeleton. One of the branching corals, covered over (one branch excepted) with its numerous little flower-animals, is represented in Fig. 13. Branching corals of this nature are

common in the tropical Pacific and the West Indies, and are called *Madrepores*. Another kind, massive instead of branching, is shown in Fig. 14. The whole surface is a surface of flower animals or polyps; in reference to its star-like cells this kind is called an *Astræa*. The expanded animals (only

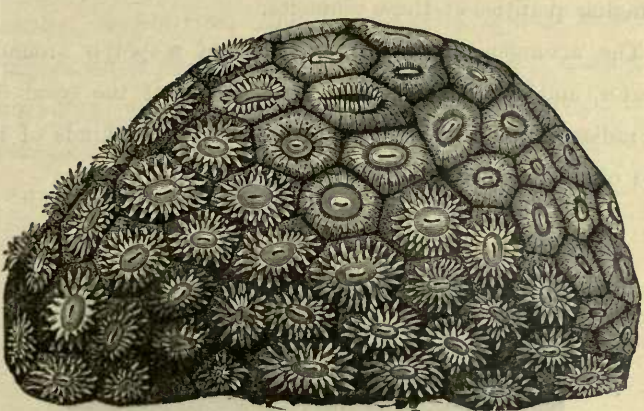
Fig. 13.



Madrepora aspera. D.

part of which in the figure are in this state) are like flowers also in their bright colors. The little petal-like arms (tentacles), in Fig. 13, are tipped with emerald-green, in the living state; some Astræas are purple or crimson, with an

Fig. 14.



Astræa pallida. D.

emerald center, and others have other bright tints. While so much like flowers in appearance, polyps are wholly animal in nature. Each polyp has a mouth at the center above, as shown in Fig. 14; and it eats and digests like other animals. Another kind of coral is represented in Fig. 15, without the animal; it shows the radiating plates in the cup-shaped cavity at the top. Still another, somewhat larger, elliptical in shape instead of cylindrical, and in the living state, is presented in Fig. 16. The mouth is a very long one, and the arms or tentacles which serve to push in the prey it captures are

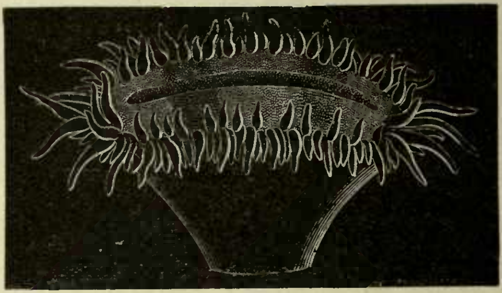
Fig. 15.

Thecocyathus cylindraceus.

also long. It owes much of its power of capturing to the stinging qualities of these tentacles.

The arrangement of the tentacles of a polyp around a center, and also that of the plates inside of the coral cup, is radiate; and hence Polyps, like some other kinds of life, are often called *Radiate* animals.

Fig. 16.

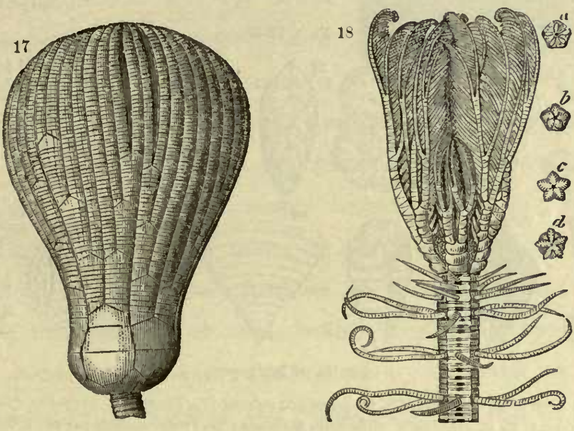


Flabellum pavoninum.

3. **Crinoids.** — Crinoids also are flower-like animals. They were once exceedingly abundant in the seas of the world, but now are rarely found. Two of the kinds are represented in Figs. 17 and 18, the first an ancient species, and the second a modern one from the seas of the West Indies. The arms above are arranged around a center like the petals of a flower, and, like them, they may be opened out wide or closed up so as to look like a bud; and this opening or closing the animal does at will. Below the radiating part, or body, there is a stem, sometimes a foot or more long, which, if the animal is alive, is planted below on

the solid rock, or in the mud of the sea-bottom. Crinoids differ in many respects from polyps. One point is this: the coral which a polyp makes is all one piece, whether massive or branching; while the stony skeleton of the crinoid is in multitudes of pieces. The stem is a pile of little disks often circular and looking like button molds, as in Fig. 17;

Figs. 17, 18.



Crinoids.

Fig. 17, Woodocrinus elegans; 18, Pentacrinus caput-Medusæ, now living in the West Indies; *a*-*d*, calcareous disks or plates of the stem, showing their 5-sided form.

but sometimes 5-sided, as in Figs. 18 *a*, *b*, *c*, *d*, showing some of the forms. The arms also are made up of stony pieces. The cross lines on the arms in the above figures indicate the number of pieces of which each is made. The pieces are held together by animal membrane as long as the animal lives; but when it dies, the pieces usually fall apart, and are scattered by the moving waters.

4. **Rhizopod Shells, or Foraminifers.** — Rhizopods are among the simplest of all animals; they are very minute animals that have no organs of sense, and not even a mouth to eat with.

Some of the shells are represented in Figs. 19 to 32; all are much enlarged excepting those in Figs. 31, 32 *a*, *b*. These animals have the faculty of extending out, at will, feelers

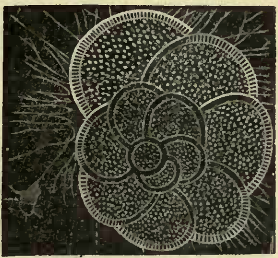
FIGS. 19–32.

Shells of Rhizopods.

Fig. 19, Orbulina universa; 20, Globigerina rubra; 21, Textularia globulosa; 22, Rotalia globulosa; 22 *a*, side view of Rotalia Boucana; 23, Grammostomum phyllodes; 24, *a*, Frondicularia annularis; 25, Triloculina Josephina; 26, Nodosaria vulgaris; 27, Lituola nautiloides; 28, *a*, Flabellina rugosa; 29, Chrysalidina gradata; 30, *a*, Cuneolina pavonia; 31, Nummulites nummularia; 32 *a*, *b*, Fusulina cylindrica.

over the body that are a little root-like, and hence they are called *Rhizopods*, from the Greek for *root-like feet.* An enlarged view of one of the species, with the fiber-like arms extended, is shown in Fig. 33. A particle of food coming in contact with this network of root-like processes is enveloped and digested, the gelatinous substance of the body being nearly homogeneous, and all parts of it possessing the power of digestion. All of the shells in Figs. 19–33 excepting those in Figs. 31, 32 *a*, *b*, are no larger than the finest grains of sand; and yet they contain a number of cells, each of which corresponds to a separate one of the Rhizopod animals.

Fig. 33.



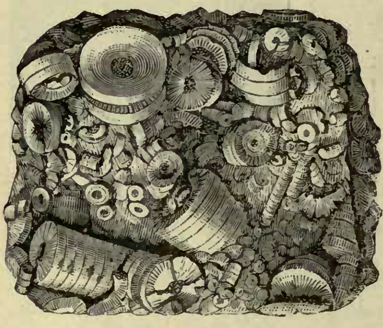
Rotalia veneta.

Fig. 31 is a large foraminifer shaped like a *coin*, and the Latin for coin, *nummus*, suggested for it the name it bears, — a *Nummulite*.

Shells, corals, crinoids, and foraminifers consist almost solely of carbonate of lime, the material of limestone; and hence their consolidation makes limestone. Shells, corals, and crinoids are usually more or less ground up under the action of the waves or currents of the ocean, and thus reduced to fragments or sand, before they are consolidated. Much coral limestone of existing seas — the rock of coral reefs — shows no trace of the corals of which it was made, because all were ground by the aid of the waves and currents to a coral sand or coral mud before consolidation. But in other cases the rock contains fragments of the corals or crinoids, and sometimes entire specimens. Fig. 34 shows the aspect of a crinoidal limestone when the crinoidal remains are not wholly ground up; the disks and cylinders are portions of the stems of the crinoids. The coral reefs of the Pacific are coral-made limestones, and some of them are hundreds of square miles in area and many hundreds of feet in thickness. But besides corals, the shells of the coral-reef seas contribute largely to the limestone material.

Foraminifers are so minute that they need no grinding in order to make a fine-grained rock. They live principally near the surface of the ocean, and their remains are especially abundant over the sea-bottom down to a depth of twelve or fifteen thousand feet, as has been proved by soundings in the Atlantic between Ireland and Newfoundland, and elsewhere. Chalk is made mainly of foraminifers, at depths from a few hundreds of feet to thousands; and it is now being made, and has been through ages past, over the bottom of the ocean.

Fig. 34.



Crinoidal Limestone.

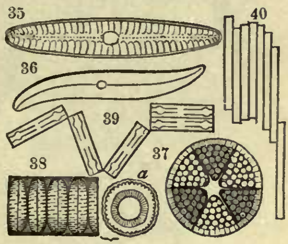
There are also some plants, of the order of Seaweeds, that secrete lime, and which have thereby contributed to rock-making. Among these are included (1) coral-making plants, called *Nullipores,* so named from the fact that, while looking like corals, they have no pores or cells; (2) *Corallines,* which are related to Nullipores, but have delicate jointed stems; (3) *Coccoliths,* microscopic calcareous disks, which are very abundant over some parts of the ocean's bottom and occur also in shallower waters.

2. *Making of Siliceous Rocks or Masses.*

Some of the minutest and simplest of plants and animals make stony skeletons of *silica* instead of carbonate of lime, and hence form out of their stony skeletons beds of silica instead of beds of limestone. Although minute, often requiring a high microscopic power to make them visible, such species have thus been large contributors to rock-making through all geological history. Many of them are remarkable for their beauty of form and texture.

The *plants* here included are called *Diatoms.* Nearly all are too minute to be distinguished without a lens. Some of the forms are shown, highly magnified, in the annexed figures, 35–40. They are strange forms for plants, and still are known to be of this kingdom of life. They have lived in such numbers over the bottoms of shallow ponds, marshes, and seas, that the infinitesimal shells have sometimes made beds scores of yards in thickness. The material of such beds looks like the finest of chalk. Owing to the hardness and extreme fineness of the grains, it was used as a polishing powder long before it was discovered that each particle was the skeleton of a

FIGS. 35–40.

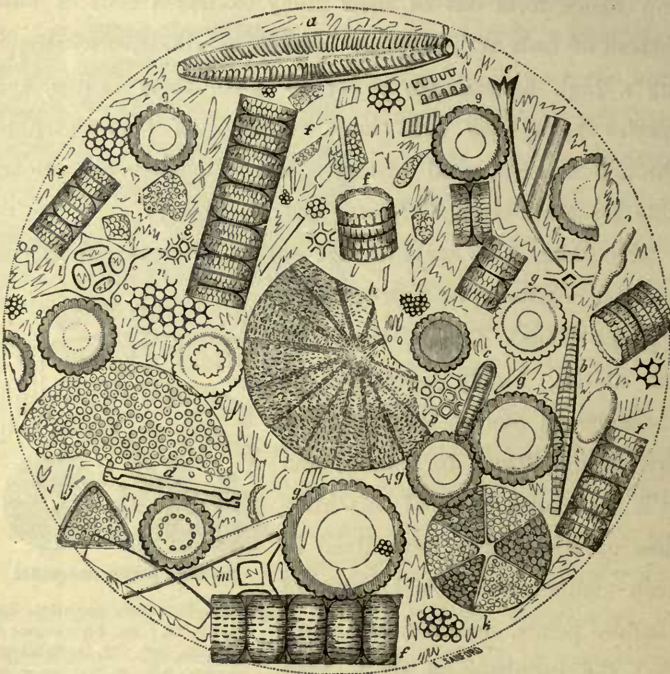


Diatoms highly magnified.

Fig. 35, Pinnularia peregrina, Richmond, Va.; 36, Pleurosigma angulatum, ibid.; 37, Actinoptychus senarius, ibid.; 38, Melosira sulcata, ibid.; *a*, transverse section of the same; 39, Grammatophora marina, from the salt water at Stonington, Conn.; 40, Bacillaria paradoxa, West Point.

microscopic water plant. It is obtained from the bottoms of many marshes, and is sold for polishing; the packages in the shops from beds making the bottom of shallow ponds

FIG. 41.



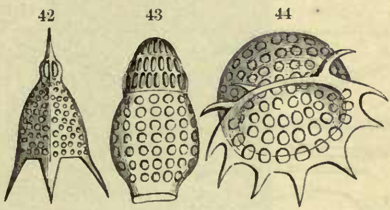
Richmond Infusorial Earth.

a, Pinnularia peregrina; *b*, *c*, Odontidium pinnulatum; *d*, Grammatophora marina; *e*, Spongiolithis appendiculata; *f*, Melosira sulcata; *g*, transverse view, id.; *h*, Actinocyclus Ehrenbergii; *i*, Coscinodiscus apiculatus; *j*, Triceratium obtusum; *k*, Actinoptychus undulatus; *l*, Dictyocha crux; *m*, Dictyocha; *n*, fragment of a segment of Actinoptychus senarius; *o*, Navicula; *p*, fragment of Coscinodiscus gigas.

or marshes are sometimes labeled *Silex*. A bed of great extent in Virginia, near Richmond, is in some places thirty feet thick; and a little of the dust, under the miscroscope of Ehrenberg of Berlin — who first made known the nature of these polishing powders — presented the appearance shown in Fig. 41. All these forms were in the field of his microscope at one time. Nearly every particle is a Diatom or a fragment of one. Some Diatom beds near Monterey, in California, have a thickness exceeding fifty feet.

Among *animals* making siliceous skeletons, the following are examples. (1) A kind illustrated in Figs. 42–44, related to the Rhizopods, but differing in the forms of the shells, and in their consisting of silica.

FIGS. 42–44.



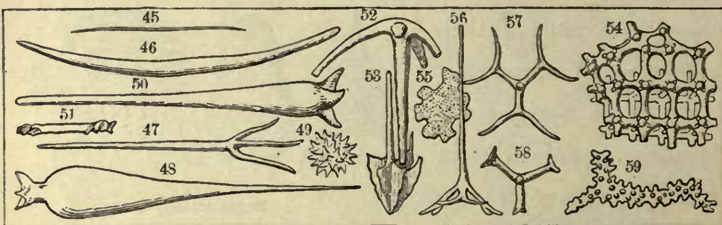
Radiolarians.

(2) Most *Sponges*, for sponges are animal in nature. Ordinary sponges are made of horn-like fibers; but in the living state these fibers are covered thinly with a gelatinous coating which is in reality a layer of animal cells but little higher in grade than Rhizopods. In many of them these horny fibers are bristled with minute spicules of silica of various forms. A few of these forms are shown in Figs. 45–59. Some of the oblong pieces or fragments in Fig. 41, page 52, are spicules of ancient sponges.

Other sponges consist wholly of fibers of transparent silica, excepting a thin coating of animal material. One of these siliceous sponges from the bottom of the East India seas is shown in Fig. 60, half the natural size. The delicacy of the structure might hardly be inferred from the figure; for the sponge looks as if made of spun glass, and as if too fragile to be handled. Such siliceous sponges are common over the bottom of the ocean, and at various depths below the reach of the waves, whose violence they could not withstand.

The *flint* of the world, or *hornstone* as the most of it is called (page 17), is nearly pure silica (or quartz), and, like quartz, it scratches glass easily. It is found imbedded in limestones and other rocks. It has been made mostly out of

FIGS. 45–59.



Siliceous Spicules of Sponges.

spicules of Sponges, Diatoms, and Radiolarians, without any unusual degree of heat. This shows that such deposits, when under water, may be partly dissolved by the cold waters, and then consolidated without any external aid beyond that afforded by the saline ingredients of the waters. By the same means shells and other fossils have often been changed to quartz, or have undergone a true petrification.

The harder parts of Worms, Insects, Spiders, Centipedes, and Crustaceans have contributed to the material of rocks, or occur imbedded in them; so also do the bones and scales

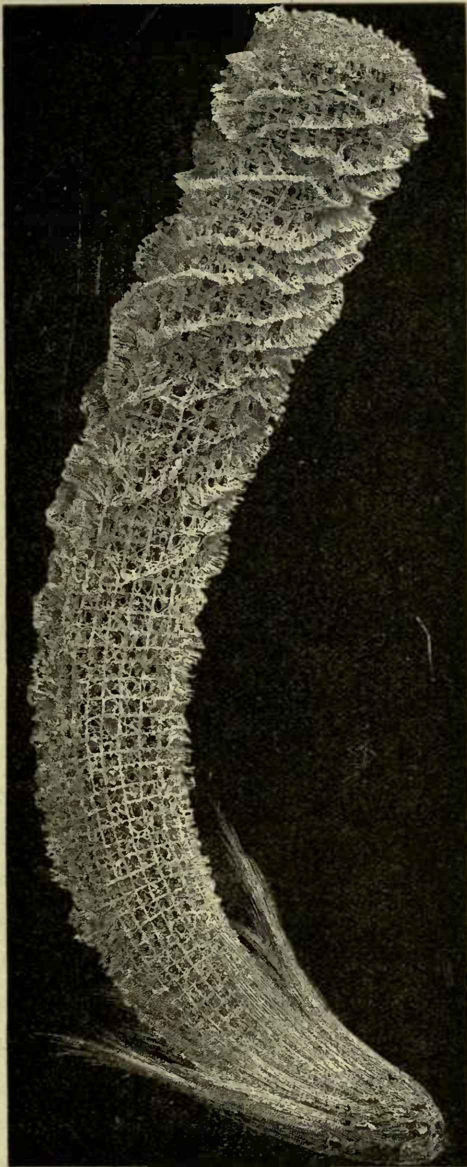


FIG. 60. Euplectella speciosa, or Glass Sponge.

of Fishes and Reptiles; the bones and occasionally the feathers of Birds; the bones and teeth of Quadrupeds of various kinds; and remains of various other forms of life. Besides, the *tracks* of animals are occasionally met with on the surfaces of layers, from those of Worms and Insects to those of Quadrupeds and Man.

The living species of the globe that have contributed most to rocks are those of the waters, because rocks are mainly of aqueous origin; and chiefly marine species, because the greater part of rock-making has been the work of the ocean.

Oceanic life is in greatest profusion along the shallow waters off shore, down to a depth of one hundred and fifty feet; the corals which make coral reefs in our present seas do not live much below this. But there is abundant life at greater depths, and life is not wanting even at a depth of 15,000 feet or more. Crabs with good eyes have been obtained from the sea-bottom at a depth of 5000 feet; lobsters without eyes at a depth of 5000 to 12,000 feet; and a few living Mollusks from a depth exceeding 12,000 feet. Besides these species, there are through all these depths living Corals, Crinoids, and delicate siliceous Sponges related to that figured on page 55. But Rhizopods are the most abundant species (page 48), and with these, there are Radiolarians and the minutest and simplest of plants, Diatoms and Coccoliths. The Diatoms live in the ocean near the surface, but sink to the bottom as they die. The same is true of a large part of the Rhizopods.

3. *Making of Peat-beds.*

Deposits of leaves, stems, and other remains of plants are always found in the water in marshy areas, where spongy mosses of the genus Sphagnum are growing luxuriantly, besides other water-loving plants small and large, with some kinds that can stand the water, but would thrive better were it drier. The moss, which is the chief plant in the increasing deposit, has the faculty of dying below while growing above; and thus its dead stems may be many yards long, while the living part at top is only about six inches long. The small plants and shrubs, and the trees, if such there be, shed their leaves and fruit annually, and these fall into the water. Annual plants die each year, and their stems are buried with the leaves. All the plants, the mosses excepted, sooner or later die, and thus branches and trunks are added at times to the accumulation in progress. Moreover, the bones of Birds and Quadrupeds and remains of Insects and other inferior kinds of life become buried in the deposit.

The materials of plants buried under water undergo a kind of smothered combustion. They become black, then are reduced, below, to a pulpy state, or rarely to an imperfect coal; and the mass thus altered constitutes what is called *peat*.

Dry woody material consists one half of carbon, the main constituent of charcoal, along with two gases, oxygen and hydrogen; and in the change the proportion of the gases to the carbon is diminished about one fifth. The black color, one result of the change, is due to the carbon, as in the case of the black color of soils, many muds, and black clayey and calcareous rocks.

The bed of peat sometimes increases until it is scores of yards in depth. Peat swamps are common over all continents out of the tropics. Even the smaller swamps have usually a peaty bottom. The areas become superficial when the marshes dry up.

The Dismal Swamp in Virginia and North Carolina is a peat swamp from one end to the other; and no one has yet ascertained the depth of the peat. Ireland is noted for its peat swamps; the "mosses," as they are called, of the Shannon, are fifty miles long and two to three miles broad.

The world has had its peat swamps in all ages since the first existence of abundant terrestrial vegetation; and these are the sources of all its coal-beds, each coal-bed having been at first a peat-bed. But the kinds of plants concerned in the making of the peat swamps have varied with the successive ages.

2. Quiet Chemical Work of Air and Moisture.

When rocks are wholly under water, whether it be salt or fresh water, they are generally protected from decay. But if above the water, so that air as well as moisture has free access, nearly all become altered, and many crumble to sand or change to clayey earth.

Blocks of some kinds of sandstone that would answer well for under-water structures, when left exposed to the air for a few years fall to pieces, or peel off in great concentric layers. Crystalline limestone (white and clouded marble) in many regions covers the surface with marble dust from its decay. Gneiss and mica schist are among the durable rocks; and yet much of the gneiss and mica schist of the world undergoes slow alteration, so that in some regions these rocks are rotted down or have become soft earth or a gravel to a depth of fifty or a hundred feet, and even two or three hundred feet in tropical countries. This is the amount of decomposition produced in those places through a very long period of time, perhaps the whole time from the epoch of their elevation above the ocean. But it is no measure of the amount that would have taken place if the decayed portion had been removed as it was formed, as has often happened; for, in that case, alteration would have proceeded with much greater rapidity because of the freer access of air and moisture.

The granite hills are often thought of as an example of the everlasting, as far as anything is so on the earth. But, while there is granite that is an enduring building stone, a large part of the granite of the world becomes so changed on long exposure that the plains and slopes around are thence deeply covered with the crumbled rock, and great masses may be shivered to fragments by a stroke of a sledge. Many granitic elevations over the earth's surface have disappeared beneath their own débris. Much trap-rock is as firm as the best granite. But other kinds are rotted down to a depth of many feet or yards, and sometimes only here and there a ledge shows itself above the ground as the remains of ranges of hills.

Even the most solid trap, where exposed to the elements, has a decomposed outer layer, or is *weathered*, as the change is called. This crust is often but a line or two deep and has everywhere the same depth over blocks of like kind. But the uniformity in depth is owing to the fact that, as the elements eat inward, there is as gradual a loss of the altered grains over the outer surface.

Thus invisible agencies are producing the slow destruction of the exposed parts of nearly all the rocks of the globe, even to the tops of the lofty mountains. The firmer kinds of slates (argillyte), some hard conglomerates and gneisses, and the compact limestones are among the rocks that defy the elements most successfully.

In this way rocks have been prepared for the rougher geological work carried on by moving water and ice; and through the same means the earth or soil of the world has to a large extent been made.

This quiet work of air and moisture is *chemical* work; and it is mostly performed through the chemical action of two ingredients present in them, — *carbonic acid* and *oxygen*. Other agencies aid in this slow destruction, as explained on pages beyond.

3. The Work of Winds.

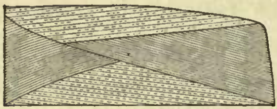
The wind, or moving air, works geologically by transportation, by the deposition of the material it transports, and by abrading and rending the rocks and other objects in its way.

1. **Transportation and Deposition.** — The winds carry sands from one place to another; and wherever the earth's surface is one of dry sand, and the winds blow strongest and longest in one direction, great accumulations of sand are made. Even when the windows of a house in a city are ordinarily kept closed, the dust will get in.

Seashores are often regions of sand, owing to the work of the waves. The heavy winds take up the loose, dry sands and carry them beyond the beach, to make ranges of sand hills, often 20 to 30 feet or more high. Thence the hills frequently travel inland, through the same means, sometimes burying forests, as on the west coast of Michigan, sometimes overwhelming villages, as in England and France, leaving at times only the top of a church spire to mark the site. The west winds have driven the sands of the Desert of Sahara over parts of Egypt, and ancient cities have thus been buried.

The *stratification* of a hill of drifted sands is so peculiar that it is easy to tell when sand rocks have been formed through the agency of the winds. Fig. 61 represents a part of a section observed in the Pictured Rocks on the south shores of Lake Superior. The layers dip in many directions. Such a structure is owing to the accidents to which the sand hills are exposed. A heavy storm — perhaps aided by heavy waves at high tide — often carries away part of a hill. Then the winds build it up anew, putting the successive drifts — which make the successive layers — over the new surface, differing much from the first in its slopes. The hill suffers from another storm, and is again built up during the period of quieter weather that follows. This may take place many times. The result is the kind of irregularity of stratification illustrated in Fig. 61.

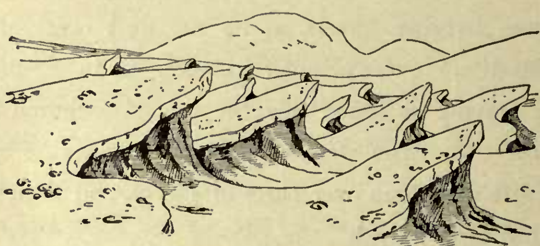
Fig. 61.



Part of a Section of a Drift Sand Hill, showing the Stratification.

2. **Abrasion.** — Sands carried by winds over rocks often wear the surfaces deeply, as well exemplified in the semi-desert regions of southern California, Nevada, and other dry parts of the west, in the Grand Traverse region near Lake Michigan, and elsewhere. This agency in dry countries has scoured

Fig. 62.



Wind-worn Rocks of the Egyptian Desert.

out gorges, shaped and undermined bluffs, and thus given to the landscape its prominent features. Fig. 62 illustrates the work of the winds in the Egyptian desert; the upturned ledges have had their softer layers worn away, leaving a compact limestone layer as the summit of each. Even the harder rock yields; for the markings over the surface indicate the positions of fossils that are left projecting because siliceous.

The abrading work, it is to be noted, is performed for the most part by the sand and gravel which the air transports. Man has taken the hint, and now uses sand driven by steam to etch on glass and to carve granite and other rocks.

3. **Rending.** — The rending power of moving air is shown at times in the tearing of houses to pieces or taking off of their roofs, in the overthrowing of walls and uprooting of trees. These effects depend, not on any transported sand in the air, but on the movement of the air in mass against the obstructing agent.

4. The Work of Fresh Waters.

Running water is at work universally over a continent wherever the clouds yield rain and there is a slope to produce movement; and it acts with greatest energy where the slope is greatest, or about high hills and mountains. It works at abrasion, transportation, and deposition, and with vastly greater efficiency than moving air.

The waters of the rains, mist, and dew about the mountain tops descend in drops and rills, and then gather into plunging streamlets and torrents; the many torrents combine below into larger streams; and these, from over a wide region, unite to make the great rivers. The Mississippi has its arms reaching westward and northward to various summits in the Rocky Mountains, and eastward to the Appalachians; and its greatness is owing to the vast breadth of the area it drains. Not only mountains, but all the small elevations over a land, and even its little slopes, have, when it rains, their rills combining into torrents, and these into larger streams, which flow off to join some river.

The waters of the clouds no sooner drop to the ground than they begin to tear off and carry away grains of earth from the rocks or slopes. The work over the larger part of a country may be almost wholly suspended in the dry season; but when the rains set in, the surface is alive with its workers, small and great. Torrents become increased immensely in depth and force, and earth and often rocks are torn up and borne along in vast quantities.

The little rills groove lightly the sand or gravel over which they flow. The streamlets, made by the uniting rills, cut deeper and wider channels. The torrents produced from the combined streams and streamlets gouge out and wear away even the harder rocks, and, as their volume increases, make great valleys. The subject of the making of valleys is illustrated on page 103.

Where, along a valley, harder and softer layers of rock alternate, one lying above the other, the harder rocks wear slowly, while the softer yield easily; and so a valley is made to have abrupt descents along its channel, and the stream goes in leaps or *waterfalls*, as it flows on its way. The harder rock at Niagara, making the top at the falls, is limestone, and the softer rock below is shale; and the wearing away of the shale has preserved the verticality of the precipice, as the erosion of the gorge has proceeded, and the falls have moved up stream.

The more rapid the flow of the water, the coarser the detritus it can transport; and as a stream slackens its rate the coarser material falls to the bottom, leaving only the finer to be carried on. First the large stones, and then the smaller, will drop as the torrent becomes less and less violent; but the earth and gravel may be borne on to the rivers; and these, in their times of flood, may carry a large part of the burden of earth to the ocean.

Under such a rough-and-tumble movement stones are worn to earth and gravel, and in this pulverized state they may continue the journey seaward. A single heavy rain storm has sometimes so filled the narrow gorges of a mountain that vast deluges of water, rocks, gravel, and trees have swept down, carrying away houses and spreading desolation over the plains below.

Through the wearing effect of rivers and their tributaries, reaching to every part of a continent, the mountains, ever since their first emergence, have been on the move to the ocean, and we cannot judge of their former height from what now exists.

The process of erosion is often called *degradation*, because mountains and hills are made low by it; *denudation*, because it removes their exterior; *erosion*, because it excavates river channels and valleys.

The material transported by rivers is called *sediment*, or that which settles in the water; and when it is fine mud, *silt*. It is also called *detritus*, from the Latin for *worn out*, because it is worn-out rock.

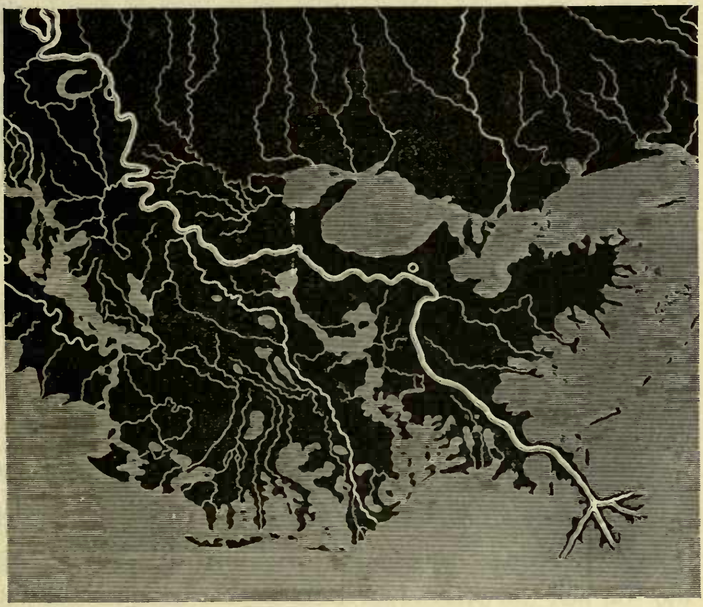
The average amount of sediment annually carried to the borders of the Gulf of Mexico by the Mississippi River has been stated to be 812,500,000,000 pounds, or enough to make a pyramid a square mile at base over 700 feet in height. This material is deposited about the mouth of the river, and is gradually extending it farther and farther into the Gulf.

The fine sediment of rivers settles much more rapidly in salt water than in fresh, and this is one reason why this material is prevented from being carried off to the deep ocean.

The great area about the mouth of a large river over which these deposits are distributed is usually intersected by channels, and constitutes what is called a *delta*, — so named from the name of the Greek letter D, which has a triangular form (Δ). Fig. 63 represents the delta of the Mississippi.

The channel of the river extends far into the Gulf of Mexico, and terminates in several mouths. The delta stretches northward nearly to the mouth of Red River.

Fig. 63.



Delta of the Mississippi.

The waves and currents of the gulf act with the currents of the river in the deposition of the sediment.

The Mississippi is an example of what all rivers are doing, each according to its ability. Some carry their detritus to lakes to extend their shores, and aid in filling them. But much of the detritus is left on the various river flats, and this part is called *alluvium*. Again, a large part reaches the ocean, and is distributed along the borders, making sand-flats, mud-flats, and ultimately good dry land, to widen the serviceable area of the continent.

The banks and bottom of a river are generally made of coarser or finer material, according to its rate of flow in the different parts. Where it is very slow the bottom and banks are sure to be of mud, for the very slow movement of the waters gives a chance for the finest detritus to settle; but if rapid it will consist of pebbles, if the region contains them. The bank struck by the current is, in general, more pebbly than the opposite.

Rivers grow Old. — A river, by its work of erosion at bottom, and the transportation down stream of the sediment so made, is ever lowering its bed, and, therefore, gradually diminishing its mean slope. Wherever this slope becomes so slight that the lowering ceases, the river has reached a *level of no work*, or *base-level*. It has grown old. This is the state of many rivers especially in the part toward the sea, and the Mississippi River is an example. In this feeble stage any erosion at bottom that takes place is balanced by the deposition of fine sediment, or silt. Sometimes this deposition exceeds the amount carried off in times of floods; and then the bed of the river keeps rising, from year to year, and the overflows, in flood times, disastrously extend their limits unless prevented by embankments.

Lakes. — The action of the waters of large lakes in rock-making is to a great degree the same as that of the ocean.

5. The Work of the Ocean.

The mechanical work of the ocean is carried forward chiefly through (1) its tidal movements; (2) its waves; and (3) its currents.

1. **Tides.** — With each incoming tide the waters flow up the coast and into all bays and mouths of rivers, rising several feet and sometimes yards above low-tide level; and then, with the ebb, the same waters flow back and once more leave the mud-flats and sand-banks of the bays and coasts exposed to view. This retreat of the tide allows the rivers to discharge freely and carry out their detritus to sea; but soon again the inflow stops the outward movement and reverses it. During the time of slackened flow the waters drop their detritus, part about the mouth of the stream, part along the adjoining coast, and part in the shallow waters of the sea outside.

The *incoming* tide is feeble in movement, swelling gently over the land and up the bays. It becomes rapid only where it passes through narrow channels, in which case the large body of water is forced to make up for the small passage-way by moving at greater speed. But the *outflowing* tide often moves rapidly over the bottom of bays, and especially when a river empties into the bay and adds to the amount of water. Besides, it takes up additional detritus from the bottom, and bears it out to sea. It thus prevents the entrances to bays or harbors from becoming filled up by the deposits of the inwashing tide.

2. **Waves.** — The sea in its quiet state is rarely without some swell, which causes at short intervals a gentle movement on the beach and some rustling of the waters along rocky shores. Generally there are waves and breakers; and when a heavy storm is in progress the waves rise to a great height and plunge violently upon the beach and against all exposed rocks, wave following wave in quick succession through days or it may be weeks together. With each storm the waves renew their violent strokes, and in many seas the action is almost incessant.

The plunge on the beach grinds the stones against one another, gradually rounding them and finally reducing them to sand, and the sand to finer and finer sand. The waters after the plunge retreat down the beach underneath the new incoming wave; and this "undertow" carries off the finer sand made by the grinding, to drop it in the deeper waters off the coast, leaving the coarser sand to constitute the beach.

Thus wave-action grinds to powder and removes the feldspar and other softer minerals of the sand, leaving behind the harder quartz grains; and consequently, the sand and pebbles of beaches consist mostly of quartz. Moreover, where beaches of sand line a coast there are offshore deposits of mud made out of the fine material carried seaward by the undertow. In no age of the world have sand-beds been formed without the making of mud-beds in their immediate vicinity.

The cliffs, or exposed ledges of rock, are worn away under the incessant battering and afford new stones and sand for the beach and the shallow waters adjoining. Most rocky shores, especially those of stormy seas, show, by their rugged cliffs, needles, arches, and rocky islets, the effects of the storm-driven waves.

It is to be remembered that the ocean, as stated on page 58, often finds the work of destruction facilitated by the weakening or decomposition the rocks have undergone through the quiet action of air and moisture. Another method of destruction is explained beyond on page 84.

The waves, as they move toward the shores over the shelving bottom, bear the sediment in the waters shoreward, and throw more or less of it on the beach; and thus the beach grows in extent. The sediment is, in general, either what it gets from the battered rocks of the coast, or what the rivers pour into the sea. At the present time the Atlantic receives an immense amount of detritus through the many large streams of eastern North America; and, as a consequence, the shores are extensive sand-flats from New York southward; there are generally long beaches, with shallow basins or sounds inside, and wide low regions more inland.

This Atlantic border has been growing seaward for ages through the means mentioned, with but little aid from the wear of seashore cliffs. But in the earlier geological ages this was not so; for the continent was to a large extent more or less submerged, and the waves made a free sweep over its surface, battering the rocks wherever within their reach over the wide area, and thus making its own sediment; for there were only small streams on the small lands to give any help.

3. **Wind-made Currents.** — The winds, especially the prevailing storm winds, are the chief source of strong currents along sea-borders, as well as of high waves and careering breakers. They drive the waters before them, moving them to considerable depths; and where these currents sweep along a coast, they gather detritus from the bottom and from the beaches, and also from the discharging rivers, and drop it again where obstructing shores or capes are met. This drifting action often makes long sand-spits and sand-bars nearly all the way across the mouth of a bay. New York Bay is thus shut in, the entrances being narrow channels through the sand-bars. These channels are kept open by the outflow of the waters of the Hudson River and some New Jersey rivers, together with those of the outflowing tide.

4. **Contributions to Sea-border Sands and Deposits by the Life of the Waters.** — In the warmer seas of the world *Mollusks* are very abundant. The heavier storm-waves tear them from the muddy bottom in or over which they are living, and throw them on the beach. There they are exposed to the incessant grinding which stones and ordinary sands experience elsewhere, and thus they become reduced to sand.

Every storm adds to the shells of the beach as well as to the shell-sand. Sand-deposits are thus made out of shells; and they keep growing and may become of great extent. They are not deposits of quartz sand, but of calcareous sand. The finer shell-sand is swept out into the shallow waters, and there produces a finer deposit. The hardening of such deposits makes limestone; and the shells that happen to escape the grinding are its fossils. In this way limestones have been made in all geological ages. Shell-rocks are now forming at St. Augustine, Florida, and the limestone there made is used as a building stone.

In other parts of tropical seas there are *corals* growing profusely within reach of the waves, and below to a depth of about 150 feet, with Mollusks and other kinds of sea life. Many of the corals become broken or torn up by the waves and are carried to the beach, and there ground up and spread out in beach deposits and off-shore deposits. The shells of the reef-grounds add much to the coral sands. These beds of sand or mud harden in the water, and then become the coral-reef rock, a true limestone, similar to many of ancient time.

Fig. 64 is a view of a coral island, or *atoll*, of the Pacific. The encircling reef consists wholly of coral-reef rock and overlying coral sands; and the whole height out of water is usually but 12 to 20 feet, or as high as the waves and the winds can throw the sands. The lake or lagoon within is an inclosed piece of the ocean, and often, when a channel for entrance exists, it is an excellent harbor for shipping. Fig. 65 represents one of the ordinary high islands of the ocean with its shores bordered by coral reefs. Such reefs

Fig. 64.

Coral Island, or Atoll.

are usually under water except at low tide. The inner reef *f* is called the *fringing* reef, and *b*, the *barrier*, or outer reef. At *h* there is a channel through the barrier opening to a large harbor. Such reefs and islands exist in various parts of the tropical Pacific, and also in the East Indies and

Fig. 65.

High Island with Barrier (b) and Fringing (f) Reefs.

the West Indies. They border northeast Australia for 1000 miles.

5. **Oceanic Currents.** — The ocean has its system of circulation, or of great currents.

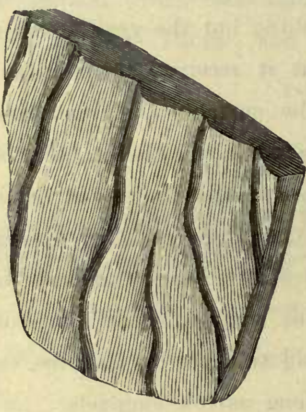
The Gulf Stream is one of these great currents. Its waters flow westward in the tropical Atlantic, bend northward as they pass the West India seas, then flow northeastward, parallel with the North American coast as far as Newfoundland, and then gradually curve eastward, toward Great Britain. Thence a part continues either side of Iceland to the Arctic seas, from which part returns as a cold Labrador current, along the coast of Labrador and farther south; another part continues eastward north of Europe and Asia. This great current moves but 5 miles an hour where swiftest, and at this rate only in part of the straits of Florida. Its average rate, parallel with North America, is $2\frac{1}{2}$ miles an hour; but along the sides of the continent it is hardly felt at all anywhere along this coast, not even in the Florida straits. It hence gets no detritus from the wear of coasts, and is too feeble to carry anything but the very finest silt. The ocean's bottom shows that it receives almost nothing either in this way or from the currents of great rivers. Local currents, made by storm winds along shores, have been far more important transporters and distributers of detritus than these oceanic currents. When, however, the continents were submerged a few hundred feet or less in ancient time, such currents, sweeping over the surface, would have done much work in wearing rocks and transporting detritus, especially in shallow waters and along narrow channels.

6. **Markings made over Sand-flats and Mud-flats.** — Both waves and gentle currents raise ripples over the sands; and the *ripple-marks* made by the ocean in ancient times are often preserved in the rocks (Fig. 66). Wherever they occur they show that the sands of which the rocks were formed were within reach of waves or gentle currents.

The mud of a mud-flat or of a dried-up puddle along a roadside is often found cracked as a consequence of drying; and such *mud-cracks* are frequently preserved in sedimentary rocks (Fig. 67). They are of great interest to the geologist; for they show that the layer in which they occur was not of deep-water origin; but beyond question, was exposed, for a while at least, above the water's surface to the drying air or sun, as mud is now often exposed along a roadside, or over the mud-flats of an estuary. Such cracks become filled with the next deposit of detritus, and this filling has often been

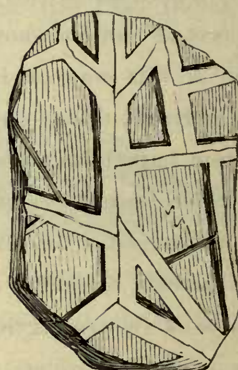
FIGS. 66, 67.

66



Ripple-marks.

67

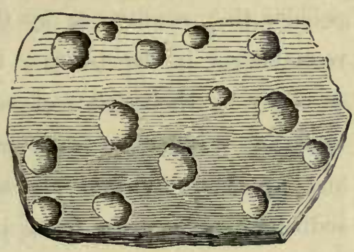


Mud-cracks.

afterward so consolidated as to be harder than the rock outside; and hence on a worn surface the fillings of the cracks often make a network of little ridgelets, such as are shown in Fig. 67.

Again, mud-flats sometimes have the surface covered with rain-drop impressions, after a short shower, in which the drops were large; and many shales (rocks made of mud or clay) retain these markings (Fig. 68).

Fig. 68.



Rain-drop Impressions.

Impressions of the *foot-prints* or trails of animals, also, and even those of insects, are not uncommon. Such delicate impressions are preserved, because soon after they are made they become covered with a layer of fine detritus; and after that nothing can erase them short of the removal of the deposit itself.

7. **Great Extent of Deposits of Aquatic Origin.** — The rocks that have been made by fresh waters and the oceans are of vast extent. They are the sandstones, conglomerates, and shales of the world; and they include the limestones also. The ocean has done far the larger part of the rock-making. In the earlier geological ages it worked almost alone; for the lands were very small, and only large lands can have large rivers and river deposits. Afterward, in the coal era, there was at least one large delta or estuary on the borders of the American continent, — that of the St. Lawrence; and in later times, rivers have given important aid. During the last of the ages, after the continents had reached nearly their present extent, and the mountains their modern height

and numbers, the rivers did the larger part of the distribution of rock material.

Sedimentary rocks show that they were formed through the action of water, often by the rounded or water-worn pebbles they contain, or by the water-worn sand, or from a resemblance in constitution to a consolidated bed of mud or clay; by their relics of aquatic life, and by the indications of wave-action or current-action above pointed out; and by their division into layers, such as exist in known sediments or deposits from waters; and when marine, they indicate it generally by the presence of remains of marine life.

6. The Work of Ice.

1. **Expansion on Freezing.** — When water freezes it expands. If it freezes in a pitcher, the expansion is pretty sure to break the pitcher. If it freezes in the crevice of a rock, it opens the crevice; and by repeating the process, winter after winter, in the colder countries of the globe, it pries off and breaks apart rocks, and often makes a slope of broken blocks, or *talus*, at the foot of a bluff. By opening cracks in this way it gives air and moisture new chances to do their quiet work of destruction.

2. **Transportation by the Ice of Rivers or Lakes.** — When water freezes over a river it often envelops stones along the shore; and then, whenever there is a breaking up, the ice with its load of stones is often floated off down stream;

or if the water of a stream or lake rises in consequence of a flood, the stones may be carried farther up the shore and dropped there, and so make, in time, extensive accumulations of stones, large and small.

In cold countries ice often forms thickly about the stones in the bottom of a stream; and as it is lighter than water it may become thick enough to serve as a float to lift the stone from the bottom, so that both ice and stone journey together with the current, to become lodged somewhere along the shores or dropped to the bottom.

These are commonplace ways in which ice does geological work. Its greater labors are performed when it is in the condition of a glacier.

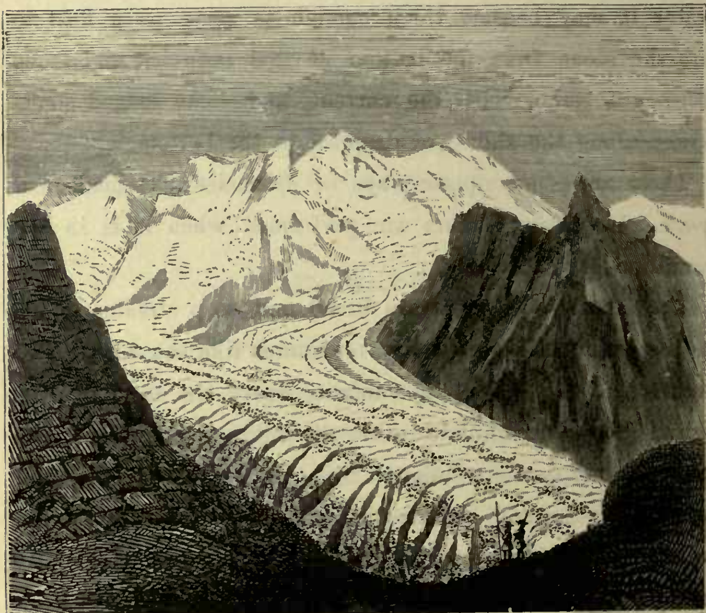
3. **Glaciers.** — Glaciers are broad and deep streams of ice in the great valleys of snowy mountains like the Alps. The snows that fall about the summits above the level of perpetual snow accumulate over the high region until the depth is one or more hundred feet. At bottom it is packed by the pressure and becomes ice. Its weight causes the ice to descend the slopes of the mountains and along the valleys, which it fills from side to side. The width of the ice of the valley may be several miles; its depth in the Alpine valleys is generally from 200 to 500 feet.

The glaciers descend far below the line of perpetual snow to where the fields are green and gardens flourish; and this takes place because there is so thick a mass of ice. In the Alps the glaciers stretch down the valleys 4500 to

5300 feet below the snow-line. At Grindelwald two glaciers terminate within a short distance of the village.

The rate of movement in the Alps in summer is mostly between 10 and 20 inches a day, and half this in winter; 12 inches a day corresponds to a mile in about $14\frac{1}{2}$ years.

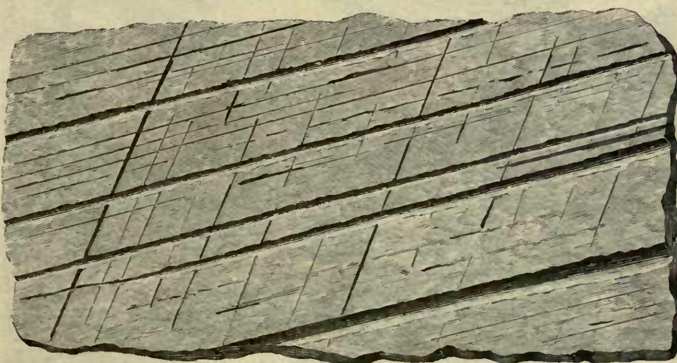
Fig. 69.



Glacier of Zermatt, or the Gorner Glacier.

Fig. 69, from a sketch in Agassiz's great work on glaciers, represents one of these great ice-streams or glaciers descending a valley in the Monta Rosa region of the Alps. A valley often narrows and widens at intervals, or changes its slope from nearly vertical to a gentle incline, or to a horizontal surface. The ice has to accommodate itself to all these variations. On turning an angle it becomes broken, or has great numbers of deep "crevasses" made through it, especially on the side opposite the angle. On commencing a rapid descent, great breaks, or crevasses, cross the glacier from one side to the other. On again reaching a level place, the ice closes up, and the glacier loses nearly all its crevasses. The ice is brittle, and freezes together when

FIG. 70.



Glacial Scratches and Planing.

the separated parts are brought in contact again; so that, as it moves, it goes on breaking and mending itself. Ice is plastic; for it may be made into rods by pressing it through a hole, and will take the impress of a medal; so that in this way also it can accommodate itself to the changing character of the surface over which it moves.

The steep upper slopes of the valley in which a glacier lies often send down stones and earth, or avalanches of ice and rocks. Through such falls a line of earth and rocks is commonly made along either margin of the glacier, which is called a *lateral moraine.* These moraines are carried with the ice to where it melts, and there dropped, making a *terminal moraine.* Other blocks are taken up by the sides and bottom of the glacier.

Fig. 71.

View on Roche-Moutonnée Creek, Colorado.

The rocks of the surface over which a glacier has moved are scratched, planed, or polished, often with great perfection, as illustrated in Fig. 70.

Ledges of rocks also are rounded, making what are called sheep-backs, or, in French, *roches moutonnées.* They are most likely to form where the rock has some portions much harder than others; these hard portions can best resist the wear and they become the sheep-backs. Fig. 71 represents the *roches moutonnées* in a valley of the mountains of Colorado, — a valley in the Rocky Mountains leading up to the Mountain of the Holy Cross, seen in the distant part of the view. It is from the Report of Dr. Hayden for 1873. No glaciers exist there now; but once they were of great extent and depth. The scratching and polishing are done by the stones in the bottom and sides of the glacier; and these stones also, as is natural, are planed off and scratched.

4. **Icebergs.** — In the Arctic regions the glaciers of Greenland, loaded with their moraines, extend down into the sea, and the part in the water sooner or later breaks off and floats away as an *iceberg*. These icebergs are carried south by the Labrador current, and large numbers of them in the course of a season reach the Banks of Newfoundland. There they find the waters warmer, in consequence of the nearness of the Gulf Stream, and they melt and drop their burden of stones and earth into the waters. It has been suggested that the submerged Banks of Newfoundland owe their existence to the melting there and consequent unlading of icebergs.

It thus appears that ice does geologic work (1), in the act of formation, through its expansion; (2) as *glaciers*, by transporting over the land earth and stones and rocks —

some of the rocks as large as ordinary houses — and dropping them when the ice melts; (3) by tearing off rocks from the ledges over which it may move, especially where there are opened seams, or joints; (4) by wearing deeply into the soft rocks over which it may move, and scratching and polishing hard rock; (5) as *floating ice* or *icebergs*, by transporting rocks, stones, and earth over water from one region to another; moreover (6) it often makes temporary dams across valleys, that cause great devastation when they give way; and (7), it makes lakes in valleys and over a glaciated region by the dropping of moraines to act as dams.

7. The Work of Heat.

The effects of heat here considered are the following: —

1. Expansion and contraction from change of temperature.

2. The fusion of rocks, and their ejection through fissures and volcanic vents.

1. *Expansion and Contraction.*

Owing to the alternation each day of sunlight and darkness, the surfaces of exposed rocks experience an alternate heating and cooling, and therefore alternate expansion and contraction. This cause, which is sufficient to break the solder of soldered metallic roofs on houses, to loosen the cemented blocks of a stone wall, and to give a perceptible movement to high stone towers, tends to start off the grains, and sometimes separates an outer layer from bare rocks, especially when the surface is weathered. As this agency is at work over the whole surface of the earth, it is an important addition, in a quiet way, to the chemical work of air and moisture, in the making of earth or gravel for the formation of rock deposits; and it has been so ever since the sun first shone upon bare rocks. A foot or two of soil is a protection against this method of degradation.

Again, heat gaining access to rocks beneath a region expands them and causes an elevation of the surface; and loss of heat produces a reverse effect. Fractures may attend such changes of level, and also light earthquakes.

2. *Making of Rocks through Fusion: Volcanoes.*

1. **Volcanoes.** — Igneous rocks are described on page 33 as having come up in a melted state to the earth's surface through fissures. In many cases they have been ejected at intervals from one and the same opening for long periods of time.

When fissures are filled and closed by one eruption, they make *dikes* of igneous rock, and also one or more *beds*, or *sheets*, if the melted material flows from the fissure over the adjoining region.

But when a vent remains open for many successive eruptions it becomes then the center of a true *volcano* or fire-mountain. The outflows of liquid rock, and ejections of volcanic sand or cinders from the vent on one side or the other, produce a hill or mountain of a form more or less nearly conical. Fig. 72 represents Mount Shasta, one of the volcanic mountains of western North America, having an elevation, according to Whitney, of 14,440 feet. It is not now in action, yet has hot springs near its summit. It

FIG. 72.

Mount Shasta, from the North, from a photograph by Watkins.

also represents well the general form of the great volcanoes of the Cascade range to the north of it in Oregon, and also of those of Mexico, and of the Andes in South America. Of the latter, Cotopaxi is an active volcano 19,613 feet in height, and Arequipa another, 18,877 feet;

while Aconcagua, of Chile, an extinct cone, has a height of 23,000 feet, and is the loftiest peak in the Andes.

Active volcanoes, in time of quiet, send forth only vapors. In periods of eruption, streams of lava (liquid rock) are poured out, either over the edge of the crater or more commonly through breaks in the sides of the mountain. At the same time cinders, or fragments of lava, are often thrown from the crater to a great height above the volcano, or the finer particles called ashes, which drift with the wind and descend in showers. Deposits of wet ashes make a fragmental rock resembling a sandstone or breccia, called *tufa*.

Volcanic cones vary much in angle of slope. When made of dry cinders the angle is often 40° to 42°. If formed through the alternations of lavas and cinders, or of tufas, the slope may be 30° or less, as in Figs. 72 and 73. Fig. 73 gives the slopes of the volcano of Jorullo, in Mexico. Many of the grandest volcanoes of the world, like Etna, and those of Hawaii, in the Sandwich Islands, have an exceedingly gentle slope, the height often only a twentieth of the breadth. Fig. 74 gives the slope of Mount Loa, Hawaii. Its height is 13,675 feet. Such cones are made almost solely of lavas; and they have so gentle a slope because the melted rock of the region flows off freely, it being of the more fusible kind, basalt.

FIG. 73.

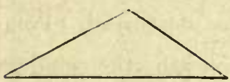
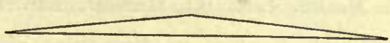


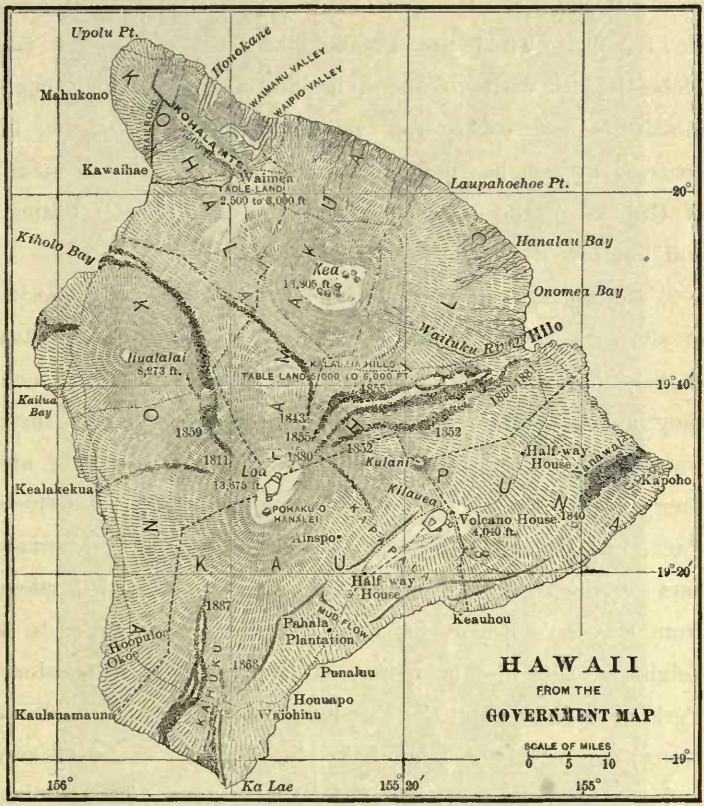
FIG. 74.



The eruptions of volcanoes are owing mainly to the waters that gain access to the fires. The rains of the region produce underground streams and trickling waters that descend and pass into the melted rock, there to be changed to vapor. Sea-water, when volcanoes are near or in the ocean, sometimes presses its way in, or gains access suddenly through fractures. The vapor penetrating the liquid mass expands the whole, causing it to rise in the vent. With the increasing height of the column of melted rock in the mountain, the vapors become more active. The pressure from the high liquid column, and from the vapors, breaks the mountain, and the lavas run out, devastating the country, it may be, for a score of miles or more. When the sea gains sudden access to a volcanic vent, the eruption is accompanied with violent quakings of the mountain. Every few years the country on one side or another of Vesuvius is deluged with the fiery rock, cultivated fields are buried, and not unfrequently villages are destroyed. Pompeii and Herculaneum were buried beneath the cinders of an eruption that took place in the year 79; and since then several streams of lava have flowed down over Herculaneum, adding to the depth at which it is buried.

Mount Loa, on Hawaii, has had eight great eruptions through fissures in the sides of the mountain since 1840. There is a summit crater at a height of 13,765 feet, and another, still larger, called Kilauea, nearly 4000 feet above the sea. The map, Fig. 75, shows the courses of the eruptions. Mount Kea is another volcanic mountain, as high as Loa, and another, Mount Hualalai, is over 8000 feet high.

Fig. 75.



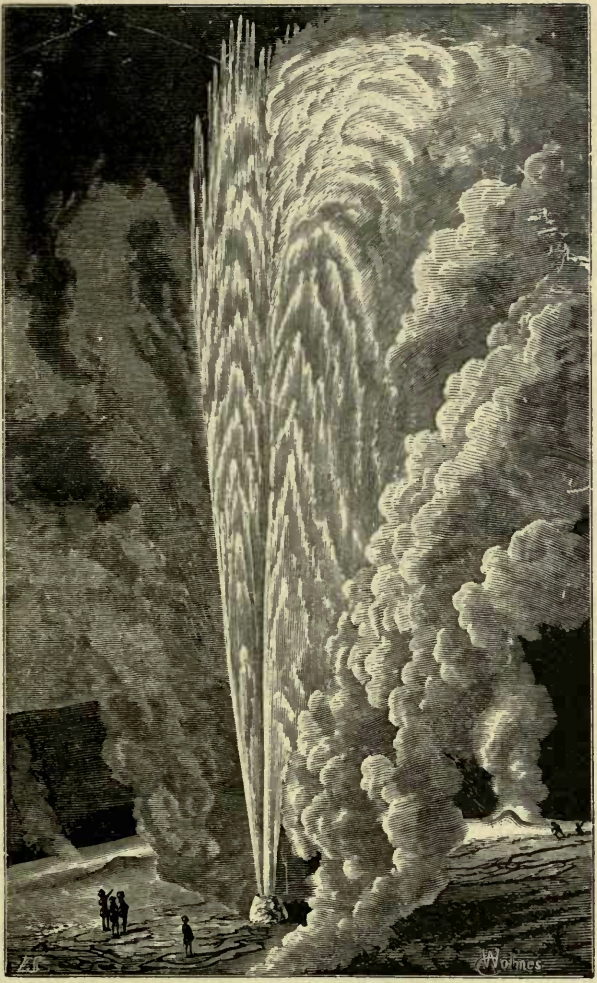
The liquid rock comes up from some deep-seated fire-region.

Volcanic mountains are very numerous along the Andes; in Central America and Mexico; in Oregon and Washington from Mount Shasta to Mount Baker and beyond; in the Alaska archipelago on the north; all along the west side of the Pacific through Japan and the East Indies; southward in the New Hebrides, New Zealand, and in Antarctic regions. Thus the Pacific, the great ocean of the globe, is girt with volcanoes, besides having many, though mostly extinct cones, over its surface. The Atlantic, in contrast with it, has none on its borders, except in the Gulf of Guinea on the coast of Africa, and in the West Indies; and but few over its interior.

2. **Hot Springs; Geysers.** — Hot springs often make deposits of silica on their borders, owing to the silica the heat has enabled the waters to take up from the rocks with which they are in contact. Such springs sometimes throw their waters in jets at longer or shorter intervals, and they are then called *geysers*. One of the geysers of the Yellowstone Park, in the Rocky Mountains (where there are great numbers of them), is represented in action in Fig. 76, taken from Hayden's Report for 1873. It throws the water to a height of 200 feet or more. The geysers of Yellowstone Park are mostly about the Fire-hole River, a fork of Madison River, and near Shoshone Lake, the head of Snake River, and not far from the head of the Yellowstone. The number of hot springs, hot lakes, and geysers in the Park has been stated to be not less than 10,000.

3. **Solfataras.** — Solfataras are feebly active volcanic vents, where vapors issue and sulphur is deposited.

Fig. 76.



Beehive Geyser in Action.

8. Solidification and Metamorphism.

1. **Solidification.** — The two most common methods of solidification of fragmental deposits are (1) by means of lime carbonate (strictly bicarbonate); and (2) by silica.

All waters contain some carbonic acid gas. The rains take it from the atmosphere and carry it down to the soil, lakes, and oceans; and the respiration of animals and the decomposition of organic matter are other sources. When calcareous sands, as those of coral, or shells, or powdered limestone, are wet by carbonated waters, these waters take up some of the lime carbonate in the form of bicarbonate; and this lime carbonate they deposit among the grains, as the water evaporates, and the excess of carbonic acid is exhaled, cementing them together. The process goes on also under water where there is no evaporation, as in the conversion of closely compacted coral sands and shell sands below tide level into coral limestone or shell limestone.

Waters containing a little soda or potash in solution will dissolve the silica of organic relics, such as sponge spicules and Diatoms, even when cold, and more readily when hot. The masses of flint or hornstone found in some beds of chalk and many other kinds of limestone were made out of such relics in the sea through their partial solution and consolidation, and generally without heat above the ordinary temperature.

Hot waters, as explained on page 18, are very likely to hold silica in solution; and if so, such waters, as they cool, will deposit the silica among the grains of quartz sand, or pebbles, and produce the firmest of rocks. Oxide of iron, also, is sometimes a cement, even of common gravel beds.

Some of the oldest of sandstones and shales are still soft, or feebly consolidated, because not furnished with any cementing material.

2. **Metamorphism.** — Metamorphism, like metamorphosis, means change of some fundamental kind. In geology it may be change only in texture; but it includes also changes in the nature or composition of the minerals of a rock. It is change produced when rocks are subjected to heat with moisture, for heat cannot be distributed through the rocks without the agency of moisture to become steam and so give it diffusion.

When melted rock ascends along a fissure, it *heats* the walls, and the effects of the heat are in part metamorphic effects. Sometimes it only consolidates the rocks. But, besides this, if a limestone is intersected by the fissure, the heat may crystallize the limestone to a depth of some inches or feet, converting thereby the compact rock into one of crystalline texture looking like coarse loaf sugar. This crystallization is one kind of metamorphism.

It may also make epidote or garnet, or some other mineral, in the wall of the fissure, if the elements of the mineral are present in any of the intersected rocks. This *chemical change* is a second kind of metamorphism.

Other examples occur sometimes about hot springs. The waters of geysers deposit a large amount of silica in the form of opal, making opal basins for themselves to play in, and spreading the opal widely over the region around. They also produce the petrifaction of wood, changing the trunk of a tree into silica.

The above cases are examples of *local* metamorphism; that is, metamorphic change in a rock adjoining a *local source of heat.*

Besides cases of local change, metamorphism has gone forward simultaneously through rock-formations thousands or hundreds of thousands of square miles in area, and a score or more thousands of feet thick; the whole having been heated up to a high temperature at one time through some subterranean method. In this grand way, changes (1) in crystallization and (2) in chemical composition have been produced on a vast scale. This is *regional* metamorphism.

Limestone formations have been rendered crystalline through the whole of a heated region. A sandstone, made of granitic sand, has received a new crystalline finish to its grains, and has become granite again, or if retaining its stratification, it has become the related rock, gneiss.

Further, the minerals occurring as impurities in various rocks subjected to the heating have undergone more or less change in composition, and have been converted into crystals. A limestone containing impurities of clay, sand, iron oxide, and other materials has come from the great laboratory of nature full of crystals of different kinds and colors; and so it has been with other rocks. For vapor or steam at a high temperature has great decomposing and recomposing power. Laboratory experiments have made by its means crystals of various minerals. Moreover, many of the world's finest gems — its emeralds, sapphires, rubies — are in part of metamorphic origin.

As the heat concerned may be more or less great, and the rocks subjected to the process have been of all kinds, from better shales to sandstones and conglomerates of various composition, and also to limestones, the diversity of results is very large. Some of the kinds of metamorphic rocks are mica schist, hydromica schist, hornblende schist, chlorite schist, as well as gneiss, and part of the granite of the world. The heat of metamorphism was generally below that required for the fusion of the rocks; for their stratification is generally retained. For example, the layers of mica schist and gneiss usually correspond with the bedding of the sandstone or shale out of which they were made. But, in some cases, the heat was sufficient to soften the rock, and then the planes of stratification were obliterated, making granite instead of gneiss, — granite differing from gneiss only in the absence of anything like stratification.

In cases of regional metamorphism the heat has been derived from profound movements that were in progress in the rocks. The great region was in the process of mountain-making; the upturning and flexing of rocks many thousands of feet thick were going forward in order to make a range of mountains out of them. The friction produced by the vast movements was the chief source of the heat. Some heat, however, was the heat of the earth's interior, for it has been found that in descending below the earth's surface, after passing the level which has constantly the mean temperature of the place, the temperature increases about 1° F. for every 50 or 60 feet of depth.

As the heated region has often been hundreds of miles long and thousands of square miles in area, and the temperature for the most part over 1000° F., it is not surprising that crystallization and other changes of great rock formations should have been a result. The larger part of the rocks of New England and of much of the Atlantic border to the south, of Canada to the north, of the northern part of New York, Michigan, Wisconsin, and Minnesota, of large areas in the summit region of the Rocky Mountains, and over the Pacific slope, are metamorphic rocks.

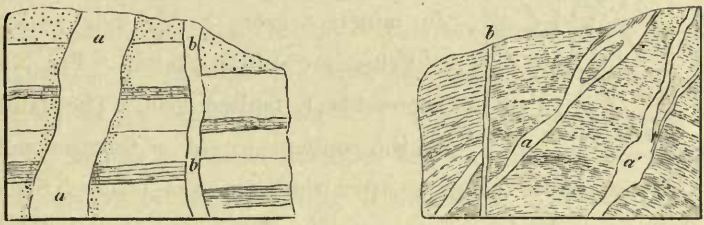
9. Veins and Ore Deposits.

1. **General Characters.** — Veins fill fissures in the earth's rocks. They may cut across the rocks vertically or nearly so, as in Fig. 77 (*aa*, *bb*); or be much inclined, as in Fig. 78. The fissures may be regular, with nearly parallel walls for long distances; but they commonly vary greatly

in width along their course. The width may be that of paper, or of hundreds of feet.

Besides veins *intersecting* the strata, there are others of large size as well as small, that are the fillings of *openings between the layers of a laminated or schistose rock*, as

77 FIGS. 77, 78. 78

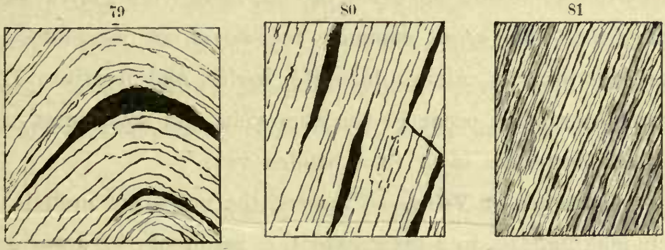


Intersecting Veins, *a*, *a'*, *b*.

illustrated in Figs. 79 to 81. In Fig. 81 the openings are but a small fraction of an inch in thickness, and occur between successive layers.

FIGS. 79–81.

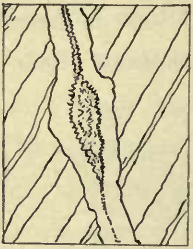
79 80 81



Interlaminating Veins.

The above figures represent simple veins. Many veins are made up of two or more layers parallel to the walls. Such veins are called *banded* veins, because they appear banded in a transverse section. In Fig. 82 there are two such layers, one attached to each wall. Between the layers there is often a layer of ore; and in other cases, wider spaces occur at intervals containing ore, as represented in Fig. 82. When a vein contains ore, it is called by miners a *lode*.

Fig. 82.



Banded Quartz Vein.

Veins are often *faulted*. Fig. 78 represents a faulted vein. The fault is the consequence of a fracture and a lateral shove along it after the vein was made. Such shoves or displacements may be for a few feet, or for hundreds or thousands of yards, making it very difficult to find the continuation of the vein.

2. **Material of Veins.** — Veins often consist wholly of quartz; others are of coarse granite, or some related rock. Some are made of ore alone; but often the ore is associated with other materials. The most common *vein-stones*, or associates of ores, are quartz, calcite, dolomite, barite, and fluorite. Different ores often occur in the same vein, and sometimes each makes a separate layer in a banded vein.

3. **Formation of Veins.** — Fissures, the necessary prelude to vein-making, are, to a great extent, a result of the upturning and flexing or wrenching movements incidental to mountain-making. Hence veins are most numerous in mountain regions or regions of upturned rocks; but many occur in the outskirts of such regions.

The making of ordinary veins has required heat. The material has not come up into the fissure in a melted state, as in the making of dikes, but has entered gradually by the sides, or from below, in solution in hot water. The vein-material has been deposited first against the walls; and afterward the central part was filled, as illustrated in Fig. 82; and if consisting of more than two bands, each band, after the deposition of the outer one, has been added successively in the unfilled center.

4. **Sources of Heat involved in Vein-formation.** — There are two classes of veins differing in the source of heat.

1. *Veins in making which the heat concerned was produced, to a large extent, by the friction attending mountain-making.* — The heat, in this case, was the same that produced the metamorphism of the rocks, and this latter work may have been still in progress. Such veins intersect metamorphic rocks. Quartz veins are most abundant in the rocks of feeble metamorphism, as chlorite schist and hydromica schist, because silica solutions may be made at a low temperature; and granite veins occur chiefly in mica schist and gneiss.

Gold is obtained from quartz veins, where it exists mostly in minute scales, often with lead ore and pyrite; it was taken into the vein at the same time with the quartz from the outside rocks of the region.

2. *Veins in making which the heat was supplied by igneous eruptions.* — Great igneous eruptions occurred in early geolog-

ical time, in the region of Lake Superior, and especially along the south side of the lake at Keweenaw Point; and owing to the heat of the melted rock, copper was brought up by the sides of it, as it ascended, and partly within it; and thus the rich mines of native copper in that region were made. It is probable that the copper was derived from veins of copper ore that existed somewhere deep below in the rocks intersected by the fissures.

In many silver-mining regions of the Rocky Mountains, where the ore is derived in like manner from the deeper parts of the fissure walls, the fissure in its upper part intersects limestone strata; and as limestone is easily eroded by mineral or acid vapors, great caverns were made in the limestone by such vapors, and at the same time the ores were deposited in these cavities or caverns. The ores are often distributed also along the walls of a fissure, but in general the harder or more enduring rocks of the walls get none of it.

In Missouri, northern Illinois, and southern Wisconsin, there are great deposits of lead ore or galenite in cavities of different limestone formations, much resembling those of the Rocky Mountain mines just described. But as no evidence has yet been obtained to show that the deposits are connected below with igneous rocks, the ore is supposed to have been brought into the cavities from above. The cavities, or the minerals they contain, show that they were enlarged by the mineral solution, produced through the oxidation of the ores, as they much resemble those of many silver mines in the Rocky Mountains.

II. MAKING OF VALLEYS.

Valleys are made (1) commonly by *erosion* by the streams of the land; (2) by *upliftings* or *flexures* of rocks making mountains and leaving troughs or low regions between the mountains as valleys; (3) through *fractures* of the earth's crust.

1. Valleys of Erosion.

Slopes of sand or gravel are sometimes deeply gullied by the heavy rains of a single day, or, in geological language, deeply *eroded*, or eaten out, as this word means. This work of the rains often gives a very exact model, on a small scale, of the valleys and ridges of mountain regions. The gully, or little valley, has often (1) a precipice at its head; (2) little waterfalls along the steep part of its course, wherever there was a harder layer of sand; (3) a narrow bottom with steeply sloped sides; but at the foot of the hill, where the surface is nearly horizontal, a broad and flat bottom of sand laid down by the spreading waters. And the ridgelets between the little valleys have often a broken, knife-edge summit in their upper part, and are broader below. The reader should study carefully the first gullied slope of this kind that he may meet with, for it will be a study of valley-making the world over. Only a single night's rain may have sufficed to make the little valleys and ridgelets of the sand slope, because the sand was not firmly consolidated. But if the rocks be ever so hard, they yield in the same way, and with time enough, the same forms, on the scale of the grandest mountain region of the world, have resulted. Many of the river-valleys of North America, and of other continents, illustrate this action of running water. Watkins Glen near Seneca Lake, Trenton and Niagara Falls in central and western New York, the Valley of the upper Mississippi, and the cañon of the Colorado, afford examples. The character of the valleys and ridges will depend much on the hardness, structure, and position of the rocks. When the beds are nearly horizontal, precipices and waterfalls are most common.

The Colorado River of western North America runs for 200 miles through a gorge or cañon with vertical walls of rock in many places over 3000 feet high. The sketch in Fig. 83, from a photograph obtained by Powell's expedition, is a view of a portion of this cañon between the Paria and the mouth of Little Colorado, called Marble Cañon. The walls in the distant part of the view have a height of 3500 feet, and consist of limestone, whence its name. In other parts of the Colorado cañon there are various kinds of strata, and in some places the cut has been made deep into the underlying granite, and all is the work of the river. Another scene from the cañon is shown in Fig. 11, on page 36. The waters have a rapid and often plunging flow, owing to the slope, and carry along pebbles and stones, and the stones and sand have been efficient agents in the erosion. But to wear out so wide and deep a channel a long period of time was required. Above the gorge, some miles back from the river, the horizontal rocks are piled up to a still greater height, reaching in some places a level 8500 feet above that of the bed of the stream; and these piles of strata standing in separate ridges, sometimes in the

FIG. 83.

Marble Cañon, on the Colorado.

form of pinnacles, castellated structures, and table-topped mountains, are parts of great rock-formations that once spread across the wide region. They show that erosion has carried away the larger portion of these upper rocks; and that the mountains and pinnacles are merely the remnants left.

The ocean has aided in the degradation of the land where it was partly submerged; but it could not have cut out a gorge or cañon; for the work of the ocean is to wear off headlands, form sand-flats or beaches along coasts, and fill up bays; not to cut channels into a coast and make deep valleys. The ocean has done but little valley-making, and only that of the broadest kind, when its wide currents swept over a submerged continent. The gorging of mountains and plains it has left to the running waters of the land, aided in some cases by glacier-ice (page 79).

2. Valleys made by the Upheaval of Mountains.

The wide Mississippi Valley is a depression between the Rocky Mountains on the west and the Appalachians on the east. The making of these mountains was the making of the valley. The Connecticut and Hudson Rivers occupy depressions that were probably made by uplifts either side of them. The Adirondacks are among the oldest of mountains. Long after these the Taconic Mountains, along the western border of New England, were made; and when raised, the valley in which Lake Champlain lies was a low region between them. Again, the valley of the Sacramento originated in the making of the Sierra Nevada on one side, and, later, the Coast ranges on the other. All the continents afford similar examples.

3. Valleys made by Fractures of the Earth's Crust.

(1) A great fissure in a volcanic mountain opened for the ejection of lavas has sometimes been left, after the eruption

ceased, as a deep valley. (2) Great regions have subsided in consequence of subterranean movements, leaving valley-like depressions. (3) Profound fractures have taken place in connection with mountain-making, leaving sometimes open rents, as narrow valleys or gorges.

But, notwithstanding the frequency of fractures, there are few valleys over the earth that can be pointed to as made in this way. Fractures have sometimes determined the courses of streams; but the stream, thus guided in its original course, has afterward itself carried forward its work of erosion, and made the great valley in which it flows.

III. MAKING OF MOUNTAINS, AND THE ATTENDANT EFFECTS.

There are three prominent methods of producing mountain elevations.

1. Mountains made by Igneous Ejections.

Mountains have been made by igneous ejections, especially by those of volcanic vents, as explained on page 85. Thousands of square miles over the western slope of the Rocky Mountains have been covered by igneous rocks, and in Oregon they have a thickness of more than 4000 feet; and, besides, they form cones there, whose summits are 10,000 to 14,440 feet above the sea. The loftiest peak of the Andes, 23,000 feet high, as already stated, and numerous others in that chain, were made by volcanic action. Mount Etna, in Sicily, is nearly 11,000 feet high; two volcanic mountains of Hawaii are nearly 14,000 feet high; Orizaba, in Mexico, 18,200 feet.

This is the least important of the methods by which mountains have been formed.

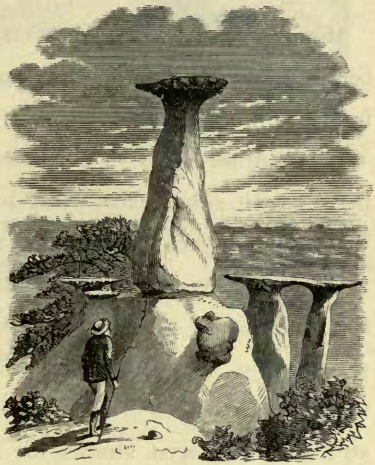
2. Mountains and Hills produced by the Erosion of Elevated Lands.

In all mountain regions the lofty summits and ridges have been shaped out mainly, as already explained, by running water, and such heights are therefore examples of the results of erosion on elevated lands. But the mountain-making is more completely the work of erosion when a region of horizontal rocks, which was a lofty plateau when first raised, has undergone long erosion. Owing to the height, perhaps several thousand feet, the torrents which the rains make and feed have a steep descent, and therefore great eroding power; and ultimately such a plateau has often been reduced to a region of profound valleys and precipitous ridges. The elevations described on page 103 as the remnants of a great rock-formation, are examples of mountain sculpture of this kind. These remains are battlemented heights, temples of mountainous dimensions, towers, and columns. The Catskills are a group of high summits 3000 to 4000 feet above the sea level, carved by running water out of an elevated region of nearly horizontal rocks. Such examples are common over the world. For, in the changes of level which the earth's crust has undergone, areas have often been lifted without much disturbance of the beds.

The elevations have often a broad cap of harder rock at top, and if of much breadth they are called *mesas*, or table-mountains, from the Spanish *mesa*, a *table*. Many *mesas* over the Pacific slope have at top thick sheets of some igneous rock, which has served to protect the rock below from wear.

Examples of monumental forms on a small scale occur in Colorado, and have given the name of Monument Park to the region. Fig. 84 is a sketch of one of its scenes, from Hayden's Report for 1873. Such effects of erosion may have been produced mainly by rains and running water; but they are in part due to the winds; to the quiet work, chemical in nature, of air and moisture; to the alternate heating and cooling of the surface in consequence of the daily changes of temperature; and in frosty regions, or where the winters are cold, to the freezing of moisture over the surface.

FIG. 84.



Scene in Monument Park, Colorado.

Over undisturbed regions of Tertiary and Quaternary formations of moderate elevation, erosion has often reduced the once level surface to a collection of hills. In some parts of the eastern slope and summit of the Rocky Mountain region the Tertiary is worn into a labyrinth of valleys and variously shaped ridges, needles, and table-like elevations.

This mountain-making by erosion is an external sculpturing of the earth's surface, and not true mountain-making.

3. Mountains made by Upturnings and Flexures of Rocks, and Bendings of the Earth's Crust.

Mountain ranges have been made, for the most part, through bendings of the earth's crust, and the upturning, flexing, and faulting of the rocks.

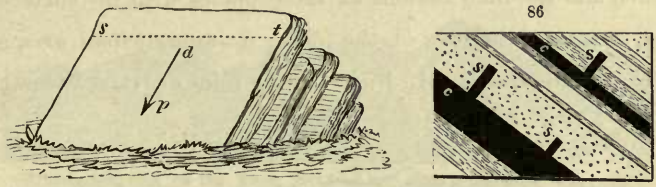
1. **Upturned Rocks.** — The layers of stratified rocks were originally, with small exceptions, horizontal, this being the position which layers of sediment usually have when forming. Now, very commonly, they are more or less upturned. Sometimes the angle of inclination is small; but in most mountain regions the beds are steeply inclined, and often are vertical or nearly so. In the study of the inclined position of strata the geologist studies the origin of mountains.

The inclination of the beds below a horizontal plane is called the *dip;* and the horizontal direction at right angles to the *dip* is the *strike.* When the roof of a house slopes in opposite directions from a horizontal ridge-pole, the angle of slope or the pitch of the roof corresponds to the *dip;* and the direction of the ridge-pole, to the *strike.*

Some of the positions of upturned rocks are shown in the following figures. Fig. 85 represents a ledge of rocks projecting above the ground; *dp* is the direction of the *dip*, and *st* that of the strike. Fig. 86 represents a portion of the coal-formation with stumps of trees rising out of the coal-beds,

Figs. 85, 86.

85 86



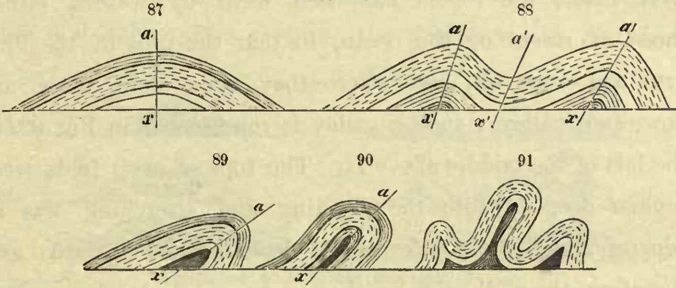
Upturned Strata.

which have lost their vertical position because of the upturning of the strata.

2. **Flexures.**— Figs. 87–91 represent flexures or folds of the strata, such as are of common occurrence. The folds in a

Figs. 87-91.

87 88



Flexed or Folded Strata.

mountain region are sometimes many miles in span; and often one arch rises beyond another. The Appalachians and Jura Mountains are full of examples.

The upward bend (at *ax* in Figs. 87–90) is called an *anticline*, from the Greek signifying *inclined in opposite directions;* and the downward bend (at *a'x'*) a *syncline*, meaning *inclined together.* *ax*, *a'x'* are the positions of the *axial planes* of the folds, and the intersections of these planes with the surface of the strata are the *axes* of the folds; *ax* an *anticlinal axis*, and *a'x'* a *synclinal axis.* In Fig. 91 three folds are raised together.

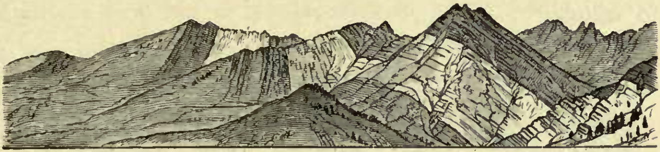
FIG. 92.

Section from the Great North, to the Little North, Mountain, through Bore Springs, Virginia. *tt*, positions of thermal springs.

Fig. 92 represents an actual section six miles long, from a part of the Appalachians, illustrating well the flexures. But it illustrates another fact: that, since the flexures were made, the region has been worn by waters, either those of rivers or the ocean, so that the tops of the flexures are worn off, and where they once were there are now often valleys; such a valley is represented in Fig. 92, to the left of the middle above II. The tops of such folds were broken deeply while the bending and stretching was in progress, and the breaks would have opened upward; and therefore these should be the parts most deeply eroded. The thin black layer over IV, on the left, was once continuous with IV, near the middle of the section; and so with the rest. To the right the beds are vertical.

Another view of upturned and eroded rocks as they occur at a place in western Colorado is given in Fig. 93. The strata in the foreground have the dip and order of superposition the reverse of those more distant, showing that a twist is connected with the upturning. Other examples of folding

FIG. 93.

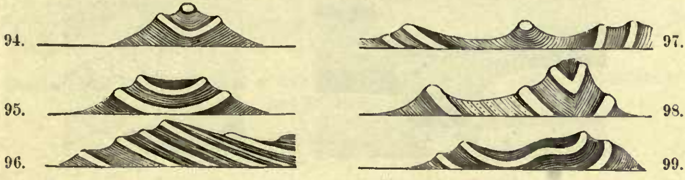


Upturned Strata of the West Slope of the Elk Mountains, Colorado.
The light-shaded stratum, Triassico-Jurassic; that to the right of it, Carboniferous; that to the left, Cretaceous.

and of subsequent degradation, from the Alleghanies, are illustrated in Figs. 94–99. In each case the harder stratum in the series determines in a large degree the final form of the hill and the landscape effect of the erosion.

Fig. 100 represents a still more remarkable case of flexures and subsequent erosion; the folded region has been

FIGS. 94—99.



Degradation of a Folded Mountain Region.

worn away to a nearly level surface, so that the existence of flexures is to be ascertained only in vertical sections of the rocks. Regions of such folded rocks are generally very difficult to study, because of the extensive erosion.

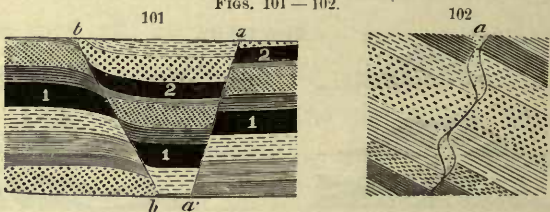
Ledges and ridges in which the strata slope only in one direction are often one side or part of a great fold. But in many cases, by shoving along faults and over the rocks beyond there is only a slope in one direction made, and this is called a *monocline,* from the Greek for *one* and *incline.*

FIG. 100.

General View of Folds in the Archæan Rocks of Canada.

3. **Fractures and Faults.** — Besides flexures, great and small *fractures* have been made in large numbers during epochs of upturning or mountain-making. Fig. 101 represents strata thus broken; and, moreover, the beds are *faulted* or displaced along the fractures. The beds numbered 1, 1, 1 were once a single continuous layer;

FIGS. 101 — 102.



Fractures and Faults.

and so with the others; but at the time of fracture there was a dropping of the middle portion, so that along each fracture there is now a *fault*, or displacement. Another case is illustrated in Fig. 102; here as the fracture was irregular in its course, the displacement has brought projecting parts of the two sides together. Veins have often been rendered irregular in width, or entirely interrupted, in this way. Fig. 82 on page 98 is another example of such irregularities. The figures represent faults or displacements of only a few feet or yards; but in many faults, produced in the making of a range of mountains, the rocks of one side of a fracture have been pushed up, or have dropped down, thousands of feet.

When fractures are very numerous in the rocks of a region, and in parallel planes of great extent and regularity, and have the walls in contact or nearly so, they are called *joints*.

4. **Unconformable Strata.** — Rocks are often laid down horizontally *over upturned* rocks; the layers of the two do not then *conform* to one another. In Fig. 103, rocks 1 and 2 are

FIG. 103.

Section from the South Side of the St. Lawrence, Canada, between Cascade Point and St. Louis Rapids.

1, Gneiss; 2, Potsdam sandstone.

unconformable with each other, while 2 and those overlying 2 are conformable. There is a *fault* across the whole to the left of the middle; and two others farther to the left, which are confined to the lower beds, 1, and which, therefore, were made before the next stratum above, 2, was deposited.

5. **Earthquakes.** — The upturning, flexing, and fracturing of rocks could not have taken place on so grand a scale without sudden shakings or jars of the rocky strata; and every such jar was an *earthquake.* A scratch of a pin on the end of a log may be heard by placing the ear at the other end, because the vibration made by the scratch travels along the log, and with great rapidity. A jar in the earth's crust or its rocks travels in the same way. It has often, in modern times, been felt through a large part of a hemisphere. Subterranean thunder has been a consequence of it; and profound fractures of the earth's surface, resulting sometimes in the destruction of cities and human lives. Earthquakes occur whenever there is any yielding or slipping along a fracture of the rocks beneath the earth's surface; and they are most likely to occur along the mountain border of a continent where have been the greatest upturnings and fracturings. They are especially common where there are volcanoes along such borders.

6. **Metamorphism.** — The upturning, fracturing, and flexing attending mountain-making accounts for the heat required for *metamorphism,* and for the very wide extent of most areas of metamorphic change; for, as has been stated, the great regions of metamorphism are regions of upturned rocks.

7. **Making of Material for Mountain Ranges.** — The rock formations out of which great mountain ranges, like the Appalachian range, have been made include those that

were deposited over the region during many preceding periods. In the case of the Appalachians, the region extended from near Albany, New York, to Alabama and Mississippi, or about 900 miles, and it was over a hundred miles across where widest. And the rocks that were upturned are those of all the eras from the close of the Archæan to the close of the Coal or Carbonic era. As most of these rocks bear evidence by means of ripple-marks, and mud-cracks, and in other ways, of shallow-water origin, it is necessarily inferred that the whole great region was undergoing a slow subsidence, during the progress of the rock-making, the depth of which where greatest was equal to the maximum thickness of the rocks. This great syncline in the earth's crust, taking all Paleozoic time to make, and 40,000 feet deep in some parts, was the prelude to the making of the Appalachian range. A similar syncline has preceded the birth of most other mountain ranges.

8. **Cause of Upliftings, Fractures, and Flexures, and of Mountain-Making.** — If a quire of paper, lying on a table, be pressed together at the front and back edges, it will rise into a fold; and, in case the paper is of a soft and inelastic kind, into a series of folds. Pushing from below will make it bulge upward, but only *lateral* pressure will make a succession of folds. The facts with regard to flexures in the rocks of mountain regions prove that the force which has made the great series of folds, uplifts, and fractures has acted *laterally;* that is, it was *lateral pressure within the earth's crust.*

Mountain ranges occur on all the continents, showing that the cause of uplift and flexure has been a universal one; and, in accordance, lateral pressure within the earth's crust is a force necessarily universal in its action. Mountain ranges are hundreds and even thousands of miles in length; and a cause thus universal is sufficient to have made all, whatever their length or height.

This lateral pressure is attributed to the admitted fact that the earth has cooled from a state of fusion; and that the crust formed thickened below from the continued cooling. In cooling from fusion a rock contracts, losing on an average a twelfth of its bulk; and hence continued cooling means continued contraction, and an effort to draw the surface rock downward. The crust, under such circumstances, would be necessarily put into a state of pressure of every part against every adjoining part, like the pressure between the stones of an arch; and if any part gave way, or the crust were flexible at all, there would be uplifts, flexures, breaks, and faults.

The flexures in the earth's strata are, then, the effects of this lateral pressure, and the great mountain chains are evidence as to its extent and power.

The mountain chains are situated, for the most part, on the borders of the oceans. Thus on the Atlantic border there is the Appalachian chain, while on the Pacific border stand the lofty Rocky Mountains. Again, in South America there are the Brazilian Mountains on the east, and the far greater chain of the Andes on the west. Other continents illustrate the same truth, — that the continents have high borders and a low interior, and also that the highest border faces the larger ocean.

Moreover, the volcanoes of the continents are, with few exceptions, near the ocean, and far the greater part of them are on the borders of the Pacific or larger ocean (page 90).

These facts prove that the breaks and uplifts that were made by lateral pressure in the earth's crust were mostly confined to the borders of the oceans, and that they were most extensive on the sides of the largest ocean.

A reason for this position of the great mountain chains near the oceans is found in the fact that the crust of the earth that lies beneath the ocean's bed is lower in level than that of the land, and the basin-like depression has rather abrupt sides toward the continents. Owing to this, the action of the lateral pressure from the direction of the ocean was *obliquely upward* against the land, and therefore just what was required to push *up* the borders of the continents into mountains, or to produce flexure after flexure in the yielding rocks, or to break them and give outflow to floods of lava.

The subsidence during all Paleozoic time, producing the syncline or trough full of strata out of which the Appalachian range was made, has been attributed to the *weight of the accumulating strata* and not to lateral pressure. This supposed cause of subsidence is a true cause; but whether it was the chief cause or not is still undecided.

9. **Mountain Chains.** — Mountain chains are the result of more than one mountain-making process. A single example will suffice to illustrate this truth. The whole area of elevated land from Labrador to Alabama is called the *Appalachian chain*. But the Adirondacks, the Highlands of New Jersey, and portions of the Blue Ridge of Pennsylvania and Virginia were made at the close of Archæan time, long before the rest. The Taconic Mountains *east* of the Adirondacks were next raised, being of Middle Paleozoic origin; then, after other long eras had passed, at the close of Paleozoic time, or the Carbonic era, the Appalachian *range* from New York to Alabama, *west* of the line of the Blue Ridge and Highlands, was completed. Thus the Appalachian *chain* was a result of a succession of mountain-making efforts, one producing one part, and the rest others. The process did not go on twice along just the same line of country, but to one side of the preceding, either east or west. Since the completion, the country has been raised as a whole by a gentle bending upward of the earth's crust, the lateral pressure in this case, after the mountains were made, and their rocks folded and consolidated, producing a gentle flexure of the crust and not any folding of strata.

In Mesozoic time, after the making of the Appalachian range, there was, to the eastward, mountain-making of a different kind. Along the regions of the Bay of Fundy, the Connecticut Valley south of New Hampshire, and a long range of country from the Palisades on the Hudson through New Jersey and Pennsylvania to and through North Carolina (each region parallel to the part of the Appalachian chain west of it), where several thousand feet of Triassic sandstone had been deposited, there occurred, finally, together with a small upturning of the strata, a great fracturing of the earth's crust, the fractures deep enough to let out melted rock; and this rock, cooled, constitutes the Palisades on the Hudson, Mount Holyoke in Massachusetts, East and West Rock near New Haven in Connecticut, and various other trap ridges in the Connecticut Valley, Nova Scotia, and the more southern sandstone regions. Here the lateral pressure produced little upturning, but much fracturing, with extensive igneous ejections; and this exemplifies a second method of action in mountain-making, a method which was most common in the later part of geological time. After this epoch of disturbance there was no other general upturning along this Atlantic border. Mountain-making was there for the most part ended. But on the Pacific side, the Rocky Mountains were not finished before the close of the Cretaceous period, when the long Laramide mountain system, reaching from near the Arctic Sea to Central America, was made. Moreover, the area of the Rocky Mountains was not lifted to its present height before the close of the Tertiary.

In like manner, the last mountain-making in the chain of the Alps and Himalayas was delayed until the close of the Middle Tertiary; and after that time the Alps received 10,000 feet of their height and the Himalayas 20,000 feet. Moreover, to this later part of geological time, the Cretaceous and Tertiary, belong the greatest of all volcanoes and igneous eruptions over the world.

10. **Making of Continents and the Oceanic Depression.** — Contraction from cooling also gives a reason for the existence of the great depressions occupied by the oceans; for, on this view, they are the parts of the earth's crust that have sunk most with the progressing contraction, — the parts, therefore, which were last stiffened, when the crust was in process of formation; while the continents were the portion that contracted least, or which first became solid.

11. **Conclusion.** — There is thus, in the single fact that the earth is, and ever has been, a cooling globe, and therefore universally a contracting globe, an explanation (1) of the gentle oscillations of level in the earth's surface that have been quietly going on through all past time; (2) of the upturnings, flexures, fractures, faults, and upliftings of strata, and the bendings of the earth's crust, which have resulted in the making of the great mountain chains of the globe; (3) of the opening of fractures down to the deep-seated regions of fire giving exit to floods of liquid rock and producing volcanoes; (4) of the alteration of rocks, or their metamorphism, changing the rude sand-beds and mud-beds into crystalline rocks, and filling fissures with veins of ores and gems; (5) of earthquakes, the great earthquakes

and the larger part of the smaller ones; and, finally, (6) an explanation of the origin of continents.

It may be thought that by thus referring to secondary causes the making and crystallizing of rocks, the placing and raising of mountain chains, and even the defining of continents, we leave little for the Deity to do. On the contrary, we leave all to him. There is no secondary cause in action which is not by his appointment and for his purpose, no power in the material universe but his will. Man's body is, for each of us, a growth; but God's will and wisdom are manifested in all its development. The world has by gradual steps reached its present perfected state, suited in every respect to man's needs and happiness, — as much so as his body; and it shows throughout the same Divine purpose, guiding all things toward the one chief end, — man's material and spiritual good.

PART III.

HISTORICAL GEOLOGY.

SUBJECTS AND SUBDIVISIONS.

Historical Geology treats of:—

1. The succession in the formation of the rocks of the earth, and in the conditions under which they were made.

2. The progress in the continents, from their small beginnings to their present magnitude.

3. The changes of level ever going on, and the raising of mountain ranges at long intervals, the highest and longest in the later part of geological time, just before the era of Man.

4. The multiplication of rivers as the dry land extended, and thereby the excavation of valleys, the shaping of lofty ridges giving grandeur to the mountains, and the spreading of the lower lands with soil and fertility.

5. The changes in climate, from the universal warmth of the Archæan world to the existing variety of heat and cold.

6. The succession in the species under the two king-

doms of life, Plants and Animals, from the simpler forms of early time to Man.

The rocks are sometimes spoken of as the *leaves* of the geological record. But these rocks are in various lands, here some and there others; and how can they be brought into order so as to make a continuous history worthy of confidence? The case would have been hopeless were it not for one branch of this history, — that relating to the *progress of life*. There has been, as above intimated, a succession in the species of plants and animals that have lived upon the globe. The earliest kinds were followed by others, and these by still others, and so on, through age after age, before the final appearance of Man. The plants and animals that lived in the successive periods left their relics — that is, stems or leaves, shells, corals, bones, and the like — in the mud or sand of the sea-bottom, seashore flats, and beaches, and in other deposits of the era; and these sand-beds and mud-beds are now the rocks of those periods. Hence in the rocks of one era we find different relics, or fossils, from those of the preceding or following era. Geologists have ascertained the kinds that belong to the successive rocks, or eras of the world; so that, if they come upon an unknown rock with fossils, in a country not before studied, it is only necessary to compare the fossils found with the lists already made out.

For a long part of early time after life was abundant there were no fishes in the world. The discovery of a fossil fish in a bed of rock is evidence that the bed does not belong to the formations of that earliest time, but to one of some later period. After the first appearance of fishes the kinds changed with the progress of time; so that if, in the case of our discovery, we can ascertain the subdivision of the class to which our fossil fish belonged, we can then decide approximately the age of the rock which afforded it. No herring, cod, and salmon are known to have existed until near the last of the geological ages; and if the species turned out to be related to these, we should conclude that the rock was among the later in geological history; and a determination of the species might lead to the precise epoch to which it pertained. Bones of beasts of prey, cattle, and horses are found only in rocks of the last two geological eras.

Thus, owing to the succession of life on the globe, the geologist is enabled to arrange the fossiliferous rocks in the order of their formation, — that is, the order of time.

If a stratum in one locality contains no fossils, or if its fossils have been obliterated by heat producing metamorphism, the stratum is traced by the geologist to another locality, with the hope of there discovering fossils, or at least of finding them in an underlying or overlying stratum. In this and other ways doubts are gradually removed, and the true succession in any region is made out.

The history has thereby been divided into four grand sections: —

I. ARCHÆAN TIME; that is, *beginning* time; the word *Archæan* is from the Greek for *beginning.*

II. PALEOZOIC TIME, or the era of the *ancient* forms of life; *Paleozoic* being from the Greek for *ancient* and *life.*

III. MESOZOIC TIME, or the era of *mediæval* forms of life; *Mesozoic*, from the Greek, signifying *middle* and *life.*

IV. CENOZOIC TIME, or the era of the *more recent* forms of life; *Cenozoic* signifying *recent* and *life.*

Paleozoic time, which was probably threefold longer than all later time, has been divided into five eras: (1) the CAMBRIAN; (2) the LOWER SILURIAN; (3) the UPPER SILURIAN; (4) the DEVONIAN; and (5) the CARBONIC ERA. The Cambrian and the Lower Silurian eras correspond to the REIGN OF TRILOBITES, the Upper Silurian and Devonian to the REIGN OF FISHES, and the Carbonic era to the REIGN OF AMPHIBIANS.

Mesozoic time corresponds to the REIGN OF REPTILES.

Cenozoic time is divided into two eras, called (1) the TERTIARY, or ERA OF MAMMALS; and (2) the QUATERNARY, or ERA OF MAN.

The above-mentioned names of the grander divisions of geological time give a general idea of the progress in life. For its better appreciation a brief account is here given of the principal groups in the classification of animals.

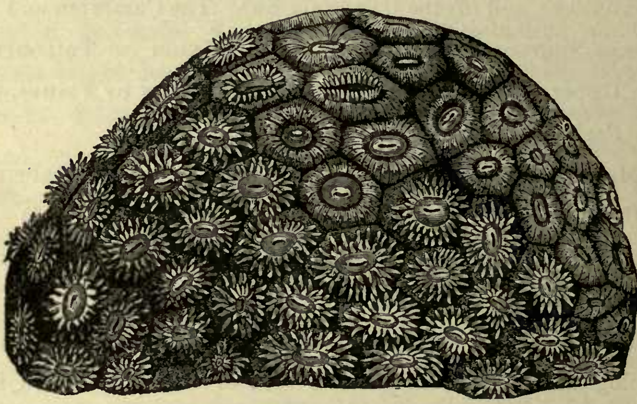
Classification of the Animal Kingdom.

The kingdom of Animals has five primary divisions — Protozoans, Radiates, Non-articulates, Articulates, and Vertebrates.

1. **Protozoans.** — These are mostly microscopic species, with no differentiation into tissues and organs. Most of them have not even a mouth. In the typical Protozoans, the body consists only of a single cell. The Rhizopods (p. 48) and Radiolarians (p. 53) are here included. The word *Protozoan*, from the Greek, means *first* or *simplest animal*. Sponges are of a little higher grade. They are large, consisting of numerous cells, but the cells show little differentiation.

2. **Radiates.** — Animals having a *radiated* structure; that

FIG. 104.



Astræa pallida D.

is, having the parts arranged radiately around a center. In most of the species, the mouth is situated at or near the center, as in polyps, the animals of Corals, which look very much like flowers on account of the radiate arrangement. Each one of the expanded polyps in a living Coral (Fig.

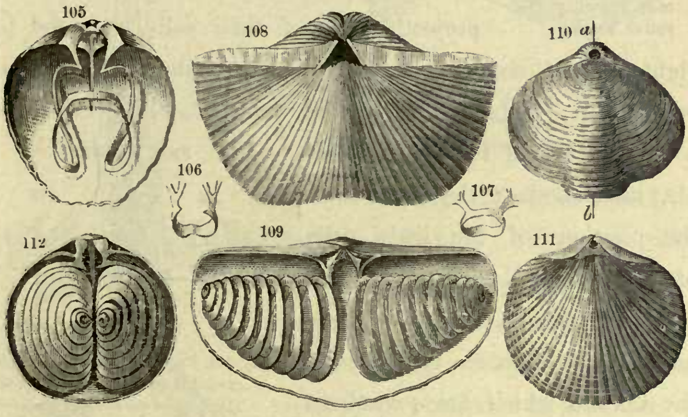
104) shows well the *radiate* character. For other figures see pages 44, 45, and 46.

The Crinoids, represented on page 47, are other examples of Radiate animals.

3. **Non-Articulates.** — 1. *Molluscoids.* — Molluscoids are divided into *Brachiopods* and *Bryozoans.*

A *Brachiopod* has a pair of shells, or in other words, a shell consisting of two valves like a Clam, Scallop, or Oyster. But, as Figs. 105 to 112 show, the shells are sym-

FIGS. 105-112.



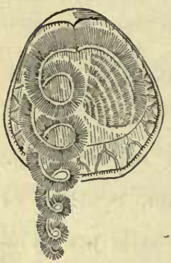
Brachiopods.

Fig. 105, Waldheimia flavescens; 106, loop of Terebratula vitrea; 107, Terebratulina caput-serpentis; 108, Spirifer striatus; 109, same, showing interior of dorsal valve; 110, Athyris concentrica; 111, Atrypa reticularis; 112, same, showing interior of dorsal valve.

metrical in form, so that a vertical line through the middle (Fig. 110) divides them into equal halves. Moreover, the valves are, respectively, dorsal and ventral, not, as in the Clam, right and left.

Inside of the shell there is often a loop-shaped or spiral arrangement for the support of a pair of spiral arms. In Fig. 113 one of these arms is rolled up spirally, and the other is extended out of the shell. The mouth is opposite the middle of the lower margin, whereas in a Clam it is at one end.

FIG. 113.



Rhynchonella psittacea, showing the spiral arms.

Bryozoans are minute species, but they form compound groups, many of which resemble Corals in form and stony texture. The animals look like polyps *externally*, as shown in Fig. 114, which represents them projecting out of their cells, enlarged to eight times their natural size. Fig. 114 *a* shows the animal wholly out of its cell and more enlarged. Fig. 115 is a a view of one of the delicate Corals, natural size; the dots show the positions of the little cells of the animal. The species are called *Bryozoans*, meaning *moss-animals*, the name alluding to the Corals, which are sometimes moss-like in delicacy and form. They also make crusts over shells and stones. Although so small, these Bryozoan Corals are a prominent constituent of some ancient limestones.

FIGS. 114, 115.

Bryozoans.

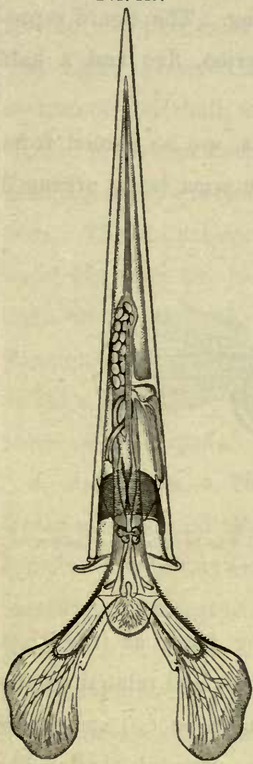
Fig. 114, Escnara, showing animals extended out of their cells (× 8); 114 *a*, one of the animals removed from its cell more enlarged; 115, Ptilodictya fenestrata, natural size; 115 *a*, portion of surface of same enlarged.

2. *Mollusks.* — These are animals like the Oyster, Clam, Snail, and Cuttlefish; having a soft, fleshy, bag-like body, with sometimes an external shell for its protection, or an inter-

nal bone or shell to give a degree of firmness to the fleshy body. The following are the principal groups: —

Lamellibranchs have bivalve shells as in the Clam, Mussel,

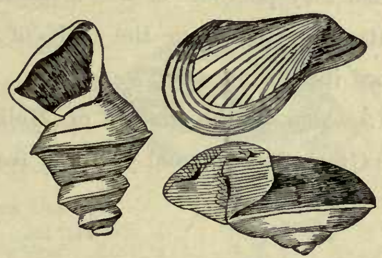
FIG. 119.



Modern Pteropod.
Styliola (× 5½).

FIGS. 116–118.

117 116



118

Mollusks.

Fig. 116, LAMELLIBRANCH: Avicula Trentonensis; Figs. 117, 118, GASTROPODS: 117, Murchisonia bicincta; 118, Pleurotomaria lenticularis.

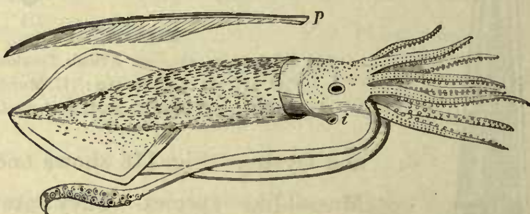
and Oyster. Fig. 116 shows one of the Mussel-like species. They are called Lamellibranchs because the gills (or branchiæ), which lie against the body on either side, are thin, lamellar organs.

Gastropods include Snails and all other species having a spiral shell and a single continuous chamber within, and also some species with shells of other forms, and some without shells. Figs. 117, 118 are examples. The name is from the Greek for *venter*, or the *under side of the body*, and *foot*, because the animals crawl on the ventral surface.

Pteropods, now represented only by a few small species, having thin translucent shells (or none), have often slender conical forms, and this was the common form in ancient time. As Fig. 119 shows, they are furnished with short paddles, which they put out for use in swimming. The figure represents a species from the Gulf of Mexico, five and a half times its natural size.

Cephalopods, the highest of Mollusks, are so named from the Greek for *head* and *foot*, the feet or arms being arranged

FIG. 120.



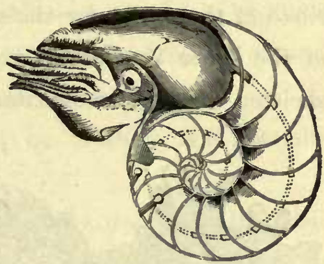
Modern Cephalopod.

The Calamary or Squid, Loligo vulgaris (length of body, 6 to 12 inches); *i*, the funnel through which the water and ink are thrown out; *p*, the "pen."

around the mouth. The eyes are very large as in Fishes. In one division of them, that of the Squids and related species (Fig. 120), the animal has an internal bone (*p*) sometimes called from its form the *pen*, and no external shell. The body is inclosed in a bag or outer tunic, which is open a little distance back of the eyes, and the animal propels itself backward through the water by taking in and ejecting water from the bag. It has an ink-bag inside, to enable it to becloud the water when pursued. The funnel, through which the water and ink are thrown out, is shown at *i*, Fig. 120.

The *Nautilus* (Fig. 121) is an example of a Cephalopod having a coiled external shell. The figure presents a vertical section of the shell, and shows that it is divided by transverse partitions into a series of chambers. The animal occupies the outer chamber, but has organic connection with the interior through a membranous tube called a *siphuncle.* In these chambers, the shells differ from those of Gastropods.

Fig. 121.



Modern Cephalopod.
Nautilus (× $\frac{1}{6}$).

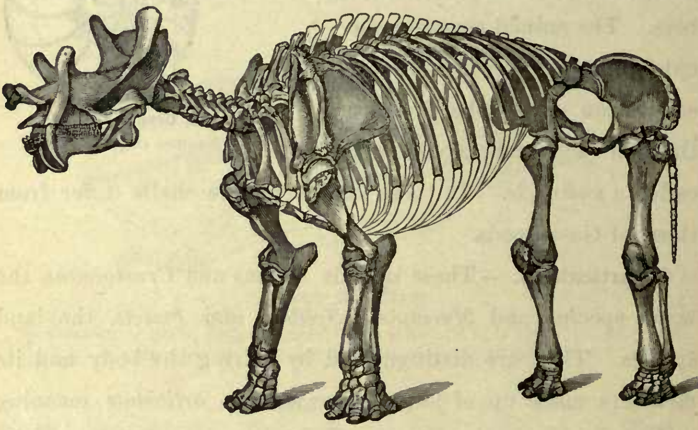
4. **Articulates.** — These include *Worms* and *Crustaceans*, the water species, and *Myriapods, Spiders*, and *Insects*, the land species. They are distinguished by having the body and its members made up of joints or segments, *articulate* meaning *jointed.*

Crustaceans include Crabs, Lobsters, Shrimps, and other species; and are so named because they have a crust-like exterior which is sometimes called the shell.

5. **Vertebrates.** — The higher and more typical Vertebrates have internally, along the back, a series of bones making together the *vertebral column.* In Fig. 122, representing one of the gigantic Mammals of ancient time, the vertebral column

is seen extending from the head into the tail. Each separate bone of the column is called (from the Latin) a *vertebra.* The great nerve of the body, called the spinal cord, lies concealed in a tubular bone-sheathed cavity along the dorsal side of the column; and on the ventral side of the column there are the ribs and the cavity for the stomach and other viscera. Some of the lower Vertebrates exhibit the characteristic vertebral skeleton only in a rudimentary state of development.

Fig. 122.



Vertebrate.
Tinoceras ingens.

The principal subdivisions of Vertebrates are Fishes, Amphibians, Reptiles, Birds, and Mammals.

1. *Fishes.* — The species breathe by gills. They have generally two pairs of fins on the under surface, the pectoral and the ventral, corresponding to the two pairs of limbs of higher Vertebrates.

2. *Amphibians*, or *Frogs and Salamanders.* — Amphibians have gills in the young or tadpole state, and lose the same on becoming adult. In the change from the tadpole, or fish-like stage, to that of the Frog, there is a loss also of the tail; but the Salamander retains the tail through life and thus has the form of a Lizard. All other Vertebrates breathe only by lungs.

3. *Reptiles.* — Reptiles have the body either naked or covered by scales or bony plates, and are oviparous.

4. *Birds.* — Birds are covered by feathers and are also oviparous.

5. *Mammals.* — Mammals *suckle their young*, as the word from the Latin implies. They are the highest of Vertebrates, and include Man as well as the Dog, Cat, Horse, Seal, and Whale.

All animals that are not Vertebrates are called *Invertebrates.*

In the Cambrian era and part of the Lower Silurian, the animals were all Invertebrates.

In the table on page 125 the expressions *Reign of Trilobites*, *Reign of Fishes*, *Reign of Reptiles*, *Reign of Mammals*, etc., are not to be understood as implying that the several groups of animals mentioned were confined to the era named in connection with them, but only that they were the most characteristic species of the era.

Fishes began before the Lower Silurian era was completed, and continued on through geological time; but until the close of the Devonian they were the highest of living species.

Under the Reign of Reptiles, the class of Reptiles, which began in the preceding era, had larger, more numerous, and higher species than before or afterward; the era was eminently that of the Reign of Reptiles, the type having reached its maximum then; that is, having *culminated.*

Mammals of a low order called Marsupials existed in the Mesozoic, or during the Reign of Reptiles; but during the Cenozoic, or the Reign of Mammals, Reptiles were comparatively few, and ordinary Mammals were the highest and the dominant race. Again, the era of Coal-plants was not the only era in which coal-plants lived and coal was made; but it was the era which was most remarkable for the making of coal-beds, and especially for coal-making plants of the tribe of *Acrogens,* the highest of Cryptogams, such as Ferns, Ground Pines or Lycopods, and Horsetails or Equiseta, which then grew to the size of tall shrubbery and forest trees. In later ages also coal-beds were made, but of less extent, and mainly out of other kinds of plants. The Carbonic era is often called the *Era of Acrogens,* and also the *Era of Amphibians.*

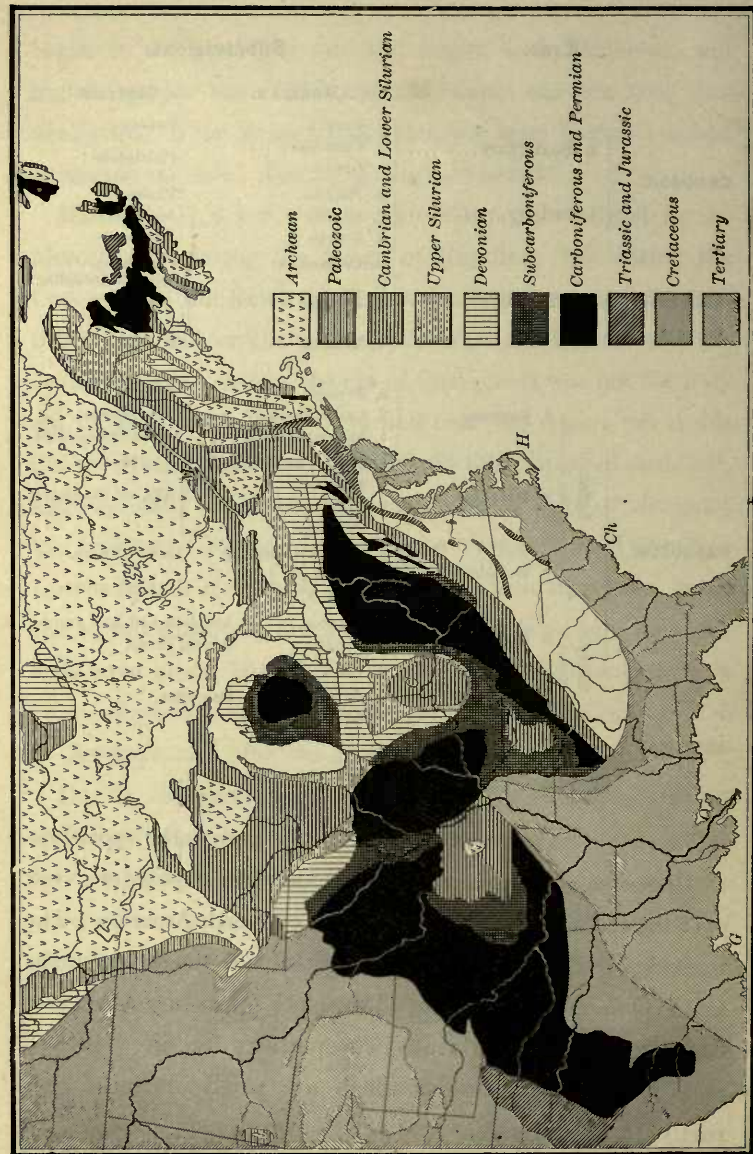
During the progress of an era, changes of level, or catastrophes of some other kind, have at intervals produced extensive disappearances of species over a Continental sea, and also abrupt changes in the kinds of rock-deposits in progress, if not also upturnings of strata. Such events are made the bases of subdivision of eras into *periods* and *epochs.*

The following table gives a general view of the successive eras, with some of the subdivisions that have been adopted; the first in time or earliest being at the bottom.

Eras.			Subdivisions. American.	Subdivisions. British.
CENOZOIC..		2. Quaternary	3. Recent.	Recent.
			2. Champlain.	Pleistocene.
			1. Glacial.	
		1. Tertiary	3. Pliocene.	Pliocene.
			2. Miocene.	Miocene.
			1. Eocene.	Eocene.
MESOZOIC		Reptilian	3. Cretaceous.	Cretaceous.
			2. Jurassic.	Jurassic including 2. Oölyte. 1. Lias.
			1. Triassic.	Triassic.
PALEOZOIC.	Later.	3. Carbonic	3. Permian.	Permian.
			2. Carboniferous.	Carboniferous.
			1. Subcarboniferous.	Mountain limestone.
		2. Devonian	4. Portage and Chemung.	Old red sandstone.
			3. Hamilton.	
			2. Corniferous.	
			1. Oriskany.	
		1. U. Silurian	3. Lower Helderberg.	Ludlow group.
			2. Onondaga.	Wenlock group.
			1. Niagara.	
	Early.	2. L. Silurian	2. Trenton.	Llandeilo and Bala groups.
			1. Canadian.	Arenig group.
		1. Cambrian	3. Later.	Cambrian.
			2. Middle.	
			1. Early.	
ARCHÆAN.				

The map on page 136 (Fig. 123) shows the positions of the rocks of the successive ages that are exposed to view over the eastern part of the continent of North America. The markings indicating the age of the rocks of the several areas are explained on the map. The black areas are the great coal areas of the continent. The portions left in white are areas of crystalline rocks which are partly Archæan and partly Lower Silurian.

Fig. 123.



Archæan
Paleozoic
Cambrian and Lower Silurian
Upper Silurian
Devonian
Subcarboniferous
Carboniferous and Permian
Triassic and Jurassic
Cretaceous
Tertiary
H
Ch
G

I. ARCHÆAN TIME.

The first condition of the earth about which geology gives us any hint is that of a liquid globe, or a globe liquid at least at the surface, for mere pressure, it is now believed, would have made the interior solid. Evidence is found in the crystalline character of the oldest rocks; in the fact that many spheres in space, like the sun, are still in such a state; and in the condition of the moon, which is like a globe that has cooled until its surface is all craters and scoria.

Admitting that the earth has cooled from fusion, we are warranted in concluding that, whenever the vapors about the globe began to settle over the solidified but still hot crust, there to make oceans, the rocks exposed to the heated and acid waters would have been eroded by the chemical action of those waters, and by this means they would have been covered after a while with new rock deposits. Moreover, wherever rocks were within reach of the waves, whether emerged or submerged, the waves would have aided in making gravel, sand, and mud, and would have distributed the detritus in beds and strata.

By such means the *original rock* of the cooled crust would have become nearly or entirely concealed by new rock formations. It is questioned whether any part of the original cooled surface is now exposed to view. The rocks made out of that crust, and not those of the original crust itself, are therefore the Archæan rocks of geology.

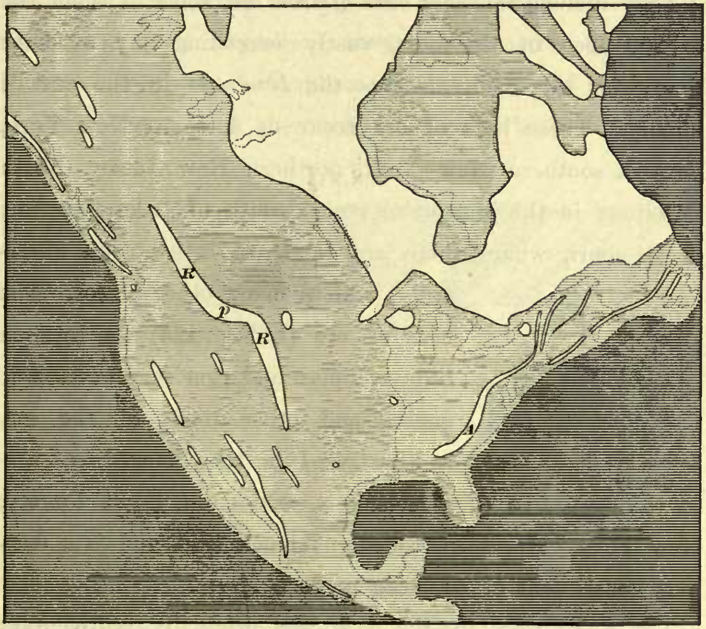
Rocks.

The Archæan rocks of North America cover a large surface over the northern portion of the continent, and also some narrow areas elsewhere along the courses of existing mountains. In the map on page 139 (Fig. 124) the white areas are the regions of exposed Archæan rocks. The largest of them extends from Lake Superior northwest to the Arctic seas and northeast to Labrador. It has rudely the shape of the letter V, and Hudson Bay is included within the arms of the V. A peninsula stretching down from it into northern New York is the region of the Adirondacks. An interrupted series of Archæan areas extends along the Green Mountains, the Highlands of New Jersey, the Blue Ridge of Pennsylvania and Virginia, the Black Mountains of North Carolina, and the region farther southwest. Another such series commences in Newfoundland and extends along Nova Scotia, New Brunswick, and near the coast of Maine. The map gives the positions of other areas to the west, the longest of which is that of the summit of the Rocky Mountains, including the Front or Eastern Range in Colorado, and extending north into British America.

The arms of the great V, or original nucleus of the continent, are approximately parallel respectively to the Atlantic and Pacific coast lines; the other narrower areas follow the courses of the great mountain chains, and are parallel to the same lines. Geology thus affords proof that even in

Archæan time the great outlines of the continent were defined, and that all future progress was carried forward by working on the plan thus early laid down. The rest of the continent was under water (and perhaps also some

FIG. 124.



Archæan Map of North America. White Portions Archæan Rocks.

of the ridges just referred to), but the rocks probably lay at no great depth.

Archæan areas exist also in Scandinavia, Bohemia, Scotland, and some other regions. The facts prove that in Archæan time the ocean and continents were, in the main, already outlined. "The waters" of the world had been "gathered into one place," and "the dry land" had "appeared."

The Archæan rocks comprise gneiss and granite; syenyte, syenitic gneiss, and other hornblendic rocks; chlorite schist, mica schist, quartzyte, limestone, and other kinds.

They include *immense beds of iron ore*, some of them 100 to 200 feet in thickness, vastly exceeding any of later time; for the Archæan was the *Iron age* in the earth's history. These beds of ore occur in northern New York, Canada, southern New York, northern New Jersey, North Carolina; in the Marquette region south of Lake Superior; in Missouri, where there are what are called Iron Mountains; and in many other places. The beds of ore (*i*, Fig. 125) lie between beds of quartzyte, gneiss, hornblendic gneiss, and other rocks of the era, as illustrated in the annexed cut representing a section in Essex County, New York. Hornblende contains much iron, and is a common constituent of Archæan rocks.

FIG. 125.

Beds of Iron Ore (*i*), Essex County, New York.

The rocks were for the most part originally sedimentary deposits; for the gneiss and other schists, and also the quartzyte, are, as explained on page 94, altered or metamorphic sedimentary rocks; they were originally deposits of gravel, sand, and mud made by the ocean. The stratification in the gneiss and other rocks is in general the original stratification of the fragmental beds. The quartzyte differs but little except in hardness from much sandstone. In Wisconsin some of the beds associated with the iron ores are scarcely at all crystalline, the metamorphic change having been slight.

Like other sedimentary deposits, the rocks were laid down in horizontal beds. But they are now upturned at all angles, and often folded, showing thereby that, subsequently to their deposition, they underwent the great disturbances that attend mountain-making. Fig. 126 shows the general condition of the rocks in the Archæan regions of

Fig. 126.

General View of Folds in the Archæan Rocks of Canada.

Canada. The Archæan mountains, including the Adirondacks, the New Jersey Highlands, the mountains of Scandinavia, and others, were made at the close of Archæan time, if not in part earlier. The original height of these mountains may have been many thousands of feet greater than it is now, for all the earth's agencies of destruction have been engaged in the work of leveling them ever since that first of the geological ages.

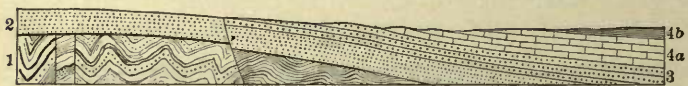
Many Archæan crystalline rocks much resemble the crystalline rocks of later time, and as both are without fossils they may be easily confounded.

The occurrence of beds of iron ore scores of feet thick is one means of distinguishing areas of Archæan age.

Coarse syenitic rocks and labradorite rocks are characteristic of many Archæan regions, although not exclusively Archæan.

Sure evidence of Archæan age is obtained when fossiliferous beds of the *lowest* Paleozoic formations are observed overlying unconformably upturned crystalline rocks, as in Fig. 127. Here the nearly horizontal Cambrian beds No. 2,

Fig. 127.



Section from South Side of the St. Lawrence, Canada, between Cascade Point and St. Louis Rapids.

1, Gneiss; 2, Cambrian sandstone.

with those above, were laid down after the beds below were made, and also after their upturning; and consequently the evidence that the latter belong to anterior time is unquestionable.

Life.

The earlier part of Archæan time was necessarily without life; for until the rocks and seas had cooled down to a temperature below that of boiling water (212° F.) life was not possible.

Plants of the lowest orders can bear a higher temperature than the lowest of animals, and therefore were probably the first living species. Some inferior kinds now live in waters having a temperature of 150° to 180° F., which is above the temperature that any animal life can bear. Much evidence from fossils as to the life is not to be looked for, because the rocks are so generally metamorphic. A supposed fossil Rhizopod has been called Eozoon, from the Greek for *Dawn-life.* But many question whether the specimens are not of mineral origin, and therefore not fossils. A few other dubious traces of fossils have been reported from some of the less metamorphic Archæan rocks. But probable evidence of plants is believed to be afforded by the great amount of *graphite* in some beds. Now (1) graphite is nothing but carbon, the essential principle of mineral coal, and (2) mineral coal was formed from plants; moreover (3) mineral coal has been found in crystalline rocks converted into graphite. Here, then, is probable evidence of the existence of plants. Any plants present were probably Seaweeds, since the Cambrian has afforded relics of no plants but Seaweeds. Along with the true Seaweeds there were probably *Diatoms,* as these minute species are among the simplest of water-plants.

The occurrence of *limestone* strata is also thought to favor the idea of the presence of plants or animals, since the limestones of the world are almost all of organic origin.

Whenever the earliest plant, however minute, was created, a new principle was introduced, that of life, which is able to subordinate physical and chemical forces to its uses, and hold them at service until death occurs. At death, chemical forces resume their ordinary work in the structure, and, by oxidation and other processes, destroy it.

Progress in a system of life becomes from this time the subject of highest interest in the world's history.

II. PALEOZOIC TIME.

The foundations of the continents and their outlines having been established in Archæan time, work now went forward for their completion through further rock-making. The rock-making, as has been explained, was the work of the waves and marine currents, of the rivers and of the winds, and also of quietly acting chemical and physical agencies, in decomposing and disintegrating the rocks above the water's level, thus facilitating the work of the waves, rivers, and winds. In addition, living species were early in the seas, and contributed, as they died, shells and other calcareous relics for the formation of limestones.

During Paleozoic time the greater part of the rocks of the eastern half of North America were completed; and by the close of Mesozoic time, nearly all the rest had been made, and the great Interior seas of the continent had become dry land. Afterward, rock-making was carried on by the sea along the continental borders, and also over the Interior by freshwater agencies; and this work is still going on.

The following are the subdivisions of Paleozoic time, beginning with the lowest: —

1. Early Paleozoic.
   1. Cambrian era. } Reign of Trilobites.
   2. Lower Silurian era. }
2. Later Paleozoic.
   1. Upper Silurian era. } Reign of Fishes.
   2. Devonian era. }
   3. Carbonic era. Reign of Amphibians, and the era of coal-plants or Acrogens.

1. Early or Lower Paleozoic.

In the map on page 139 the shaded portion of the continent was probably for the most part covered with water at the close of the Archæan era, and was, therefore, the area over which the earliest Paleozoic beds may have been laid down. These beds were mostly, if not wholly, marine; for no fresh-water deposits or fossils have yet been described from them.

1. *Cambrian Era.*

The term Cambrian is derived from the old name of Wales. The Cambrian era is divided into three periods: (1) Early or Lower Cambrian; (2) Middle Cambrian; and (3) Later or Upper Cambrian.

Rocks.

The areas over which Cambrian rocks are now exposed to view border, to a large extent, the Archæan lands. The waves worked about these lands and there made the sand, gravel, and finer detritus out of which the rocks were to a large extent formed,—part of them as beach deposits; part as beds over the bottom in deeper waters wherever detritus was distributed by the currents; and another part as limestones.

Many of the sandstones, as the Potsdam sandstone, in northern New York, contain worm borings like those made by sea-worms in modern sandy shores (Fig. 149, page 152). Ripple-marks sometimes cover the layers, and footprints or trails of animals are occasionally met with. These burrows and markings are evidence that the rocks were made in shallow water or along beaches; that the work of rock-making was slow and quiet work, just like that along shallow sea-borders of the present day; and also, that in the Cambrian era the tides and currents of the sea were no more powerful than now. None of the beds, so far as has been found, bear positive evidence of deep-sea origin.

The beds occur in northern New York at the east foot of the Adirondack Mountains (which are Archæan) and along the borders of the Canadian Archæan; along the Taconic range in eastern New York and western New England; in the Appalachian region at intervals from New York to Alabama; near the Archæan of Wisconsin and Minnesota; in some parts of the Rocky Mountain region; and as far west as the Sierra Nevada, in California. Far the larger part of the beds made in Cambrian time are now buried beneath the later formations.

Sandstones occur among the deposits of each of the Cambrian periods, and so do limestones. The Potsdam sandstone, at the foot of the Adirondacks, belongs to the Upper or Later division. Limestones of the Early Cambrian outcrop in northern Vermont and in many other regions. The great magnesian limestone of Missouri and some other portions of the Mississippi Valley is in part Cambrian. In some regions that are now mountain regions the thickness of the Cambrian rocks is great, exceeding in some places 20,000 feet.

In Great Britain Cambrian rocks are found in western Scotland and England, and in Wales and Ireland.

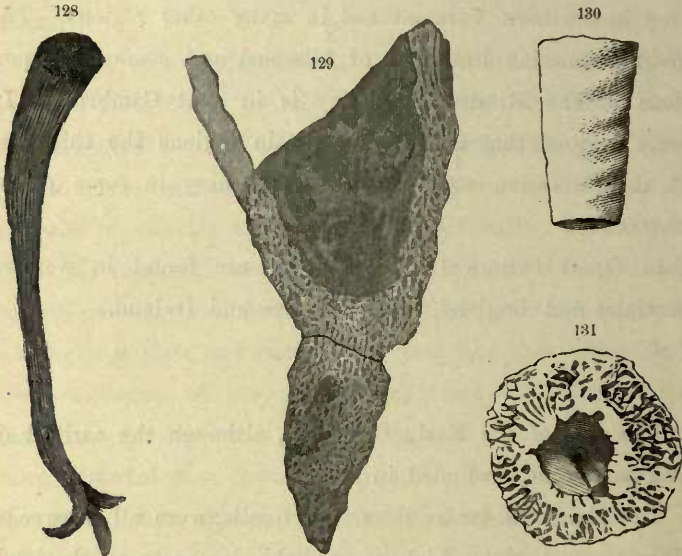
Life.

The seas of the Early Cambrian, although the earliest of Paleozoic time, abounded in life.

The plants, as far as shown by fossils, were all Seaweeds. There were perhaps Lichens over the dry rocks of the land, but no traces of them have yet been found.

The animals of which remains have been found are all marine. The species include *Sponges* (Fig. 128) and *Corals* (Figs. 129–131); and there can be no doubt that the Corals when alive were as beautiful, in their flower-like form (page 43) and color, as those of modern seas. There were also *Crinoids*, the primitive type of Echinoderms, having stems like plants (page 46). Fig. 129, on page 148, representing one of the Corals, shows the interior partly filled with the rock in which the specimen lay buried. Fig. 130 is a side-view of an imperfect specimen of another Coral, and Fig. 131 a cross-section of the same.

FIGS. 128-131.



Sponge; Corals.

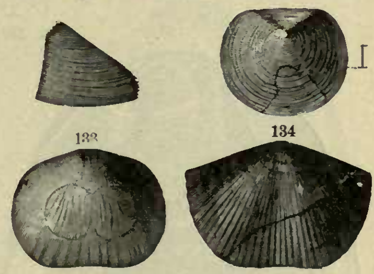
Fig. 128, SPONGE: Leptomitus Zittelli; Figs. 129-131, CORALS: 129, Archæocyathus profundus; 130, 131, Spirocyathus Atlanticus.

Other common species were the *Molluscoids* of the division of *Brachiopods* (Figs. 132 to 134), the most abundant of all Paleozoic fossils.

There were also *Mollusks*, of which three grand divisions were represented, — that of *Lamellibranchs* or "Bivalves"; of *Gastropods* or Univalves (Figs. 136, 137, the former of a kind much like a limpet); and of *Pteropods* (Fig. 138).

The Lamellibranchs and Gastropods were few in species and very small; but the Pteropods were very abundant and of much larger size than any now existing. Moreover, some species had a lid, called an operculum (Fig. 138 *a*), for closing the open end of the shell; and in this respect were superior to modern kinds (Fig. 119).

132 FIGS. 132–134. 132 *a*.

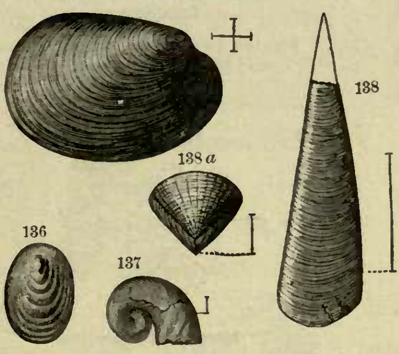


Brachiopods.

Fig. 132, *a*, two views of Acrotreta gemma; 133, Orthis Highlandensis; 134, Orthisina (Billingsella) festinata.

Worms are somewhat doubtfully represented by their tracks and burrows. The *Crustaceans* were represented by Trilobites, the highest life of the Cambrian world. The name alludes to the three longitudinal divisions into which the body is apparently divided. Fig. 139 represents, natural size, a species of the Early Cambrian. In Figs. 140 and 141 the forms of other Crustaceans are shown, the latter one of the Ostracoid or bivalve kind.

135 FIGS. 135-138.



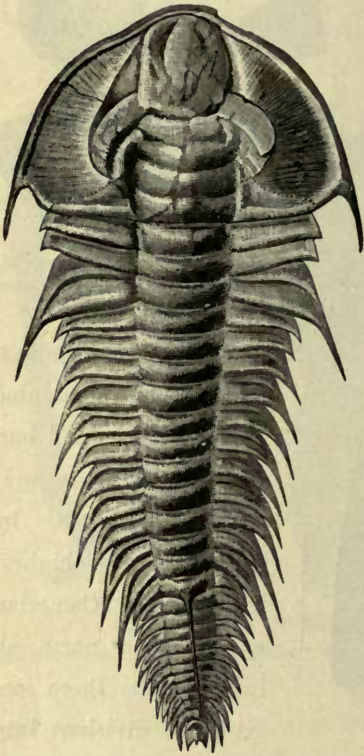
Mollusks.

Fig. 135, LAMELLIBRANCH: Fordilla Troyensis; Figs. 136, 137, GASTROPODS: 136, Stenotheca rugosa; 137, Platyceras primævum; Fig. 138, PTEROPOD: Hyolithes Americanus; 138 *a*, operculum of same.

The two higher subdivisions of Crustaceans are the 10-footed (or Decapods, as Crabs, Shrimps, etc.) and the

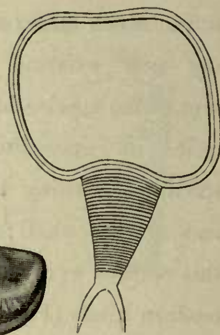
Figs. 139–141.

139.



Trilobite.
Olenellus Vermontanus.

140.



141

Phyllopod and Ostracoid Crustaceans.

Fig. 140, Phyllopod: Protocaris Marshi; Fig. 141, Ostracoid: Aristozoe rotundata.

Figs. 142, 143.

142 143

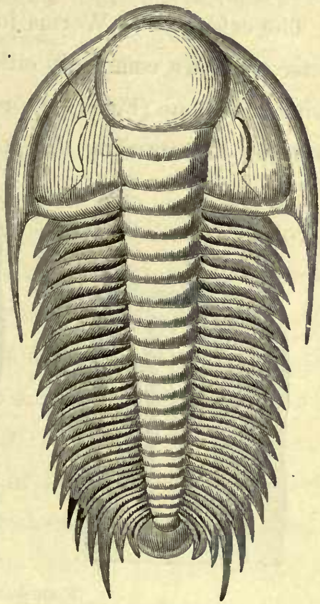
Modern Tetradecapod Crustaceans.

Fig. 142, Serolis (× ½); 143, Porcellio.

14-footed (or Tetradecapods, as the Sow-bugs and Sand-fleas). The Trilobites are most nearly related to the latter, and to that division of the 14-footed species called Isopods, illustrated in Figs. 142, 143.

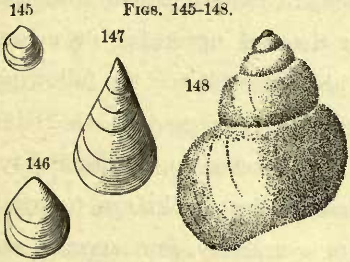
In the Middle and Later Cambrian periods the groups already mentioned were continued, and one new class under Mollusks was added, that of the Cephalopods. But the species found as fossils are nearly all different from those of the Early Cambrian. There were other Trilobites of various genera. One of the larger kinds, from Braintree, near Boston, is represented in Fig. 144; it was ten inches long; another, of the same genus, from New Brunswick, had a length of fifteen inches and a breadth of eleven. Thus these Crustaceans were almost as large as the largest of modern species, while the Mollusks that appeared in the Early Cambrian were all very small species.

Fig. 144.



Trilobite.
Paradoxides Harlani (× ½).

Figs. 145–148.



Brachiopods; Gastropod.
Figs. 145–147, Brachiopods: 145, 146, Lingulella prima (× 1); 147, Lingulepis antiqua; Fig. 148, Gastropod: Holopea Sweeti.

Figs. 145–148 represent a few fossils of the Upper Cambrian. Figs. 145, 146, 147 are shells of Brachiopods called *Lingulella* and *Lingulepis,* from the Latin *lingua, tongue.*

The evidences of Worms in the Cambrian, and also through later time, are commonly either borings which are now filled with sandstone (Fig. 149), or the trails or tracks left on mud-beds by the crawling Worm (Fig. 150).

Figs. 149, 150.

149

150

Worm-borings and Trails.

Disappearance of Species.

The long Cambrian era closed, in eastern North America, without the intervention of a time of upturning or mountain-making to mark the interval between it and the following Lower Silurian era. The transition was gradual, the later beds overlying the earlier without marked unconformability. Still very few of the Cambrian species are known to occur in Lower Silurian beds. Moreover, very few species are known to pass up from the Lower Cambrian to the Middle Cambrian, or from the Middle to the Upper Cambrian.

2. *Lower Silurian Era.*

The Lower Silurian era is divided into two periods: (1) the CANADIAN and (2) the TRENTON.

ROCKS.

The rocks of the Lower Silurian era are to a large extent limestones.

1. **Canadian Period.**— During the earlier of the two periods, the "calciferous sandstone" was formed along the borders of the Archæan lands in northern New York — a rock mostly without fossils. This was followed by the "Chazy limestone," which occurs at Chazy, on the west side of Lake Champlain and in western Vermont, and is in some places abundantly fossiliferous. The St. Peter's sandstone of Iowa has been supposed to be of the age of the Chazy limestone; but this is doubtful.

2. **Trenton Period.**—The Trenton period is represented by the Trenton limestone, a great limestone formation which occurs widely over North America, both along the Appalachian border of the continent and throughout its interior. The Trenton period is the most extensive limestone-making period in the world's history. The limestone indicates that the waters over the Continental area were generally free from sediment, but not that they were deep waters, for modern coral reefs are formed of corals and shells within 100 yards of the surface.

The Trenton limestone was named from Trenton Falls, on West Canada Creek, near Utica, New York, where the gorge is cut through it. The Galena or lead-bearing limestone of Illinois and Wisconsin is Upper Trenton.

Finally, in the later part of the Trenton period, limestone-making was confined almost wholly to the interior region; for the Appalachian area, including New York, was receiving fragmental deposits as shales, sandstones, and conglomerates; and out of the mud-beds the Utica shales and Hudson shales were made at this time. They indicate some shallowing of the waters so that muddy sediments were taken up and widely distributed.

In Great Britain, the Lower Silurian has at base slates and sandstones of the Arenig series. Above them are the Llandeilo flags and the Bala group, corresponding nearly to the Trenton period. The thickness in Wales is stated to be 25,000 feet.

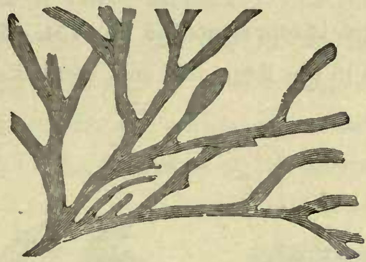
Life.

The seas abounded in life. The plants thus far found in North America are all Seaweeds; but remains supposed to be those of land plants occur in Great Britain, which show that the hills and plains were already green. One of the Seaweeds is represented in Fig. 151; and in Fig. 152, a supposed land plant, near the modern Horsetail or Equisetum in its character. Nodules of coal occur in one of the formations, which are supposed to have come from buried Seaweeds, or else from animal material, or from mineral oil that has been derived from the decomposition of plants or animals.

The animals are chiefly marine *Invertebrates*, as in the Cambrian. But before the close of the Trenton period there were

FIGS. 151, 152.

151



152

Seaweed; Land-plant (supposed).

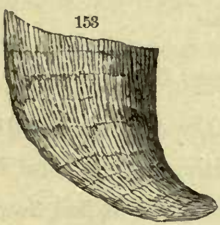
Fig. 151, SEAWEED. Buthotrephis gracilis; Fig. 152, LAND PLANT (supposed): Protannularia Harknessi.

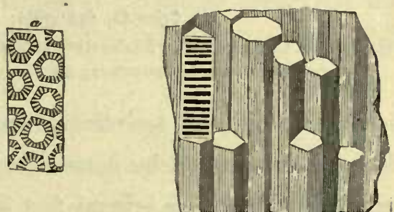
also Fishes, marine *Vertebrates*, and the earliest known of *Insects.*

Among *Protozoans* there were Rhizopods and Sponges.

FIGS. 153, 154.

153





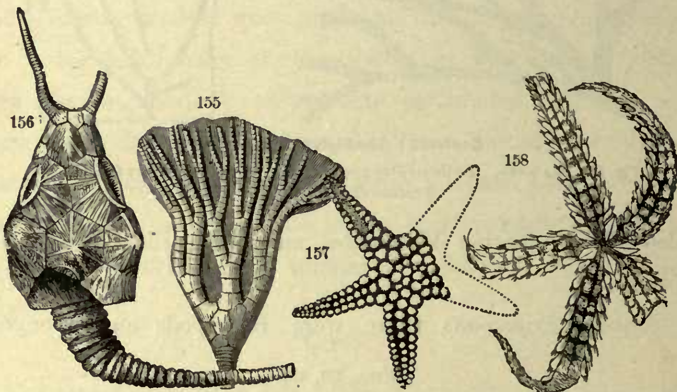
Polyp Corals.

Fig. 153, Streptelasma corniculum; 154, Columnaria alveolata; 154 *a*, top view of same.

The *Radiates* included Corals, Crinoids, and Starfishes. Fig. 153 is a side-view of one of the conical Corals of the Trenton limestone; the top has a cup-like cavity radiated with calcareous plates, somewhat like Fig. 15, page 45; and the living polyp must have much resembled that of Fig. 16, except that it was circular.

Another Coral, honeycomb-like in its columnar structure, and hence named Columnaria, is represented in Fig. 154. The cells are radiated, as shown in the figure, but in a vertical sec-

FIGS. 155–158.



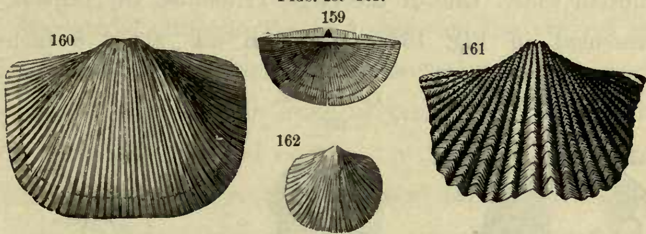
Crinoids; Ophiuroid; Asterioid.

Figs. 155, 156, CRINOIDS: 155, Pleurocystites filitextus; 156, Taxocrinus elegans; Fig. 157, ASTERIOID: Palæaster matutinus; Fig. 158, OPHIUROID: Tæniaster spinosus.

tion (as seen in such a section of one of the cells in Fig. 154) the cells are crossed by horizontal partitions. The coral has been found in masses several feet in diameter. It had flower-like animals similar to those of Fig. 14, but smaller.

Figs. 155–158 represent some of the Crinoids and Star-fishes. Fig. 156 is a Crinoid from the Trenton limestone, though not a perfect one, as the arms are broken off at the tips, and the stem below (by which it was attached to the rock of the sea-bottom, and which may have been several inches long) is mostly wanting. Fig. 155 shows the form of another kind of Crinoid, one of very irregular shape, called a Cystid, from the Greek for *bladder*. Its stem, when it was living, was run down into the mud of the sea-bottom, instead of being attached to a rock. The arrangement of plates on the body is irregular, and it has only two arms. Figs. 157, 158 are two of the Starfishes of the ancient seas.

FIGS. 159–162.



Brachiopods.

Fig. 159, Leptæna sericea; 160, Orthis occidentalis; 161, O. biforata; 162, O. testudinaria.

Brachiopods were very numerous. Some of them from the Trenton limestone are represented in Figs. 159 to 162. *Bryozoans* also were abundant.

The earliest species of Cephalopods had straight shells, like that of a Nautilus (page 131) straightened out, — whence the name *Orthoceras*, meaning *a straight horn*. One, from the Trenton limestone, is represented in Fig. 163; it has partitions like those in the shell of the Nautilus.

In the Orthoceras, as in the Nautilus, a tube called the *siphuncle*, meaning *little siphon*, passes from the outer chamber through the partitions and all the chambers; and the hole in one of the partitions is shown in Fig. 163 *a*. There were also coiled species of the group, in the Trenton formation.

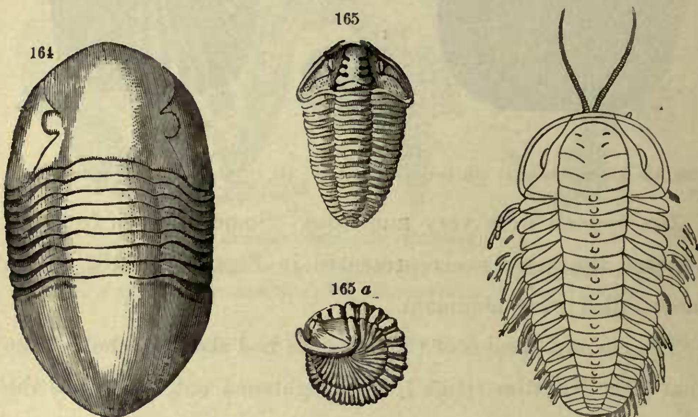
FIG. 163.

Cephalopod.

Orthoceras junceum.

The *Articulates* included Worms and Crustaceans, as in Cambrian time. One of the large Trilobites, an *Asaphus*, is represented in Fig. 164; its length was about 8 inches.

FIGS. 164–166.



Trilobites.

Fig. 164, Asaphus platycephalus; 165 *a*, Calymene callicephala; 166, Triarthrus Beckii, the specimen showing the legs.

Another common species, a Calymene, is shown, reduced to half the natural size, in Fig. 165. It is often found rolled into a ball (Fig. 165 *a*). Another species from the Utica slate, a *Triarthrus*, is represented in Fig. 166; it shows that Trilobites had legs, although the specimens from most localities show none. There were also many species of Ostracoids, or Bivalve Crustaceans.

The Insects of the Trenton period are known thus far only from two specimens, one found in Sweden, and one in France. As both are well authenticated, it is safe to conclude that Insects were in great numbers over the land of all the continents. It is probable also that the land had its Myriapods, although the first specimen has not yet been found. Insects are little likely to become buried in marine deposits. Coming within reach of the seashore waves, they would at once be ground up.

The earliest remains of *Vertebrates* have been found in Trenton rocks of Colorado. They are chiefly bony scales from the covering of *Fishes.* They are related to those found in rocks of the Upper Silurian and Devonian eras. (See pages 169, 179.)

Observations on the Early Paleozoic.

1. **Life.** — The life of the Early Paleozoic, as the preceding review shows, was almost all marine. It was made up largely of the best of limestone-makers, that is, species which secrete a large amount of lime carbonate, — as the Crinoids, species consisting chiefly of calcareous disks; Bryozoans, which are as much stone as the Crinoids; Brachiopods, which have thick calcareous shells; and Corals. These

kinds owe their fine preservation as fossils to their calcareous skeletons. Other kinds, like Worms, and shell-less Mollusks and Radiates, of which there were doubtless great numbers, left no record of themselves.

The early species were largely stationary life, that is, were attached to the sea-bottom or some support. Such were all the Crinoids, Bryozoans, and Corals, and most of the Brachiopods. Moreover, some Mollusks, as the Mussels, live attached to rocks through life by a byssus of horny threads. The locomotive species were the Trilobites, Gastropods, Orthocerata and related Cephalopods, and the Fishes. The Cephalopods may have added much to the activity of the seas; for the species are not snail-like in pace, like Gastropods, but are fleet movers, like Fishes. Yet these ancient species, with their unwieldy shells, must have been slow compared with the naked Cephalopods of later time, and therefore easy game for the Fishes.

2. **Mineral Oil and Gas.** — A large amount of mineral oil and gas is afforded in some regions by the Trenton formation and chiefly the limestone. At Findlay, and some other places in Ohio, borings are made to a depth of several hundred feet, through the overlying rocks, and then for 10 to 50 feet into the limestone; the gas comes up with a rush and continues to escape for years. From one boring over a million cubic feet of gas have been obtained per day. The gas is used both for lighting houses and for fuel. In other cases oil is obtained, which when purified becomes

kerosene. The oil and gas have nearly the same composition, differing little from that of common burning gas. They were produced by the decomposition of the animal or vegetable substances in the rock, afforded by the dead plant or animal life of the seas.

Mountain-making.

The close of the Early Paleozoic, that is, of the Trenton Period, was a time of upturning and mountain-making in North America, Great Britain, and Europe. The Taconic Mountains were then made, a range 500 miles long, extending along the western and northwestern border of New England, from Canada to northwestern Connecticut and Putnam County in eastern New York.

The rocks — which originally included much limestone, and also various fragmental rocks, shales, sandstones, and conglomerates overlying and underlying the limestone — were pressed up into folds; and at the same time they were crystallized by the heat produced by the upturning, and thus changed to metamorphic rocks. The fossiliferous limestone was altered to white and clouded crystalline or architectural marble, (of which Canaan in Connecticut, Lee in Massachusetts, and Rutland in Vermont afford noted examples); the quartzose sand-beds, to quartzyte; the mud-beds and shales to gneiss, mica schist, and other crystalline rocks. The upturned beds that were then made into a mountain range include all of the Early Paleozoic formations from the bottom of the Cambrian to the top of the Lower Silurian, and probably had a thickness in some parts exceeding 20,000 feet. As described for the Appalachian range on pages 114, 203, these beds were laid down over a gradually subsiding area, and the syncline or trough had a depth equal to the thickness of 20,000 feet. Thus the material for the mountain range was first deposited; and then the range was made out of this prepared material. In the West, where there was no mountain-making at this era, in Illinois the thickness of the Cambrian and Lower Silurian rocks is only 800 feet, and in Missouri only 2200 feet.

It is probable, also, that another Taconic mountain range was formed at the same time, commencing in the eastern part of Canaan, Connecticut, and continuing southward through Westchester County, New York, to Manhattan Island; and still another, if not a continuation of the last, from the vicinity of Philadelphia to Buckingham County, Virginia (where the crystalline rocks have afforded fossils), and beyond this southwestward. The Taconic revolution, in this view, left its marks in mountains and in crystalline rocks along the whole Atlantic border, and the two or three Taconic mountain ranges constitute together a long Taconic mountain system.

Moreover, a large part of this Atlantic border was simultaneously lifted above the sea level. This is proved by the fact that along this border south of New York no marine deposits are known, either of the Upper Silurian, or of any following formation earlier than the Cretaceous, the last period of the Mesozoic.

In Great Britain the Lower Silurian formations, which are throughout conformable, are upturned so as to lie unconformably beneath the beds of the next era—the Upper Silurian.

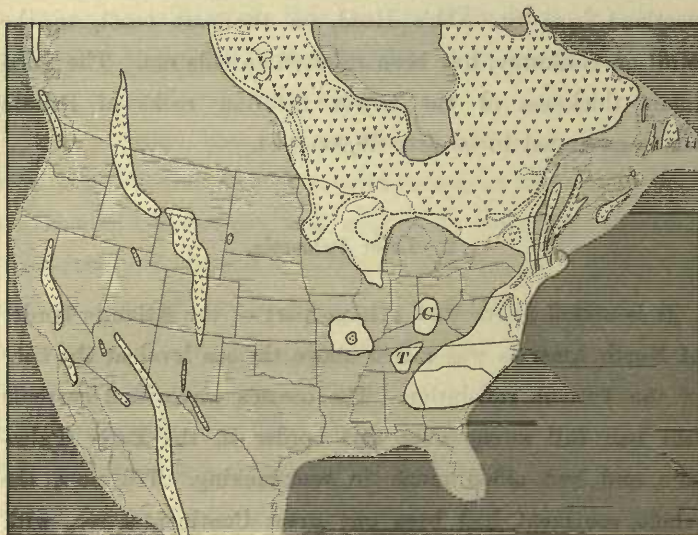
The elevation of the Westmoreland Hills, of the mountains in North Wales, and of the range of Southern Scotland from St. Abb's Head, on the east coast, to the Mull of Galloway, has been referred to this era. The maximum thickness of the Lower Silurian rocks of Britain has been stated to be over 40,000 feet.

2. Later Paleozoic.

It is stated above that a large part of the Atlantic border of North America was raised above the sea level at the time of the Taconic revolution. The ocean's waves and currents had had full sweep over this border in the Early Paleozoic, and had aided much in rock-making. Till now, the whole continent had been one great Continental sea, with a few islands over its surface. But the uplift placed a barrier to the Atlantic Ocean on the east, which extended south nearly to the Florida boundary; and after this epoch, in Later Paleozoic time, the waters of the Continental Interior behind this barrier had to do their geological work without Atlantic aid. To the westward, these waters extended to the Pacific. To the southward there was complete connection, as before, between the Atlantic and Pacific.

This eastern barrier of the continent is shown on the map, Fig. 167. The Gulf of St. Lawrence was still outside the barrier, and marine channels or bays extended down from it over New England; but dry land made the barrier complete between New York and Canada.

FIG. 167.



North America at the Opening of the Later Paleozoic.

1. *Upper Silurian Era.*

The era of the Upper Silurian is divided into three periods. Beginning with the earliest, they are: (1) the NIAGARA, (2) the ONONDAGA, and (3) the LOWER HELDERBERG.

Rocks.

1. **Niagara Period.** — This period is especially noted for its great fossiliferous limestone formation. It was named from its occurrence at Niagara Falls. The Niagara formation at Niagara River and elsewhere in western New York, and also along the region of the Appalachians, includes, *first,* a thin laminated sandstone stratum, called the Medina sandstone; *second,* other sandstones associated with shales and limestones, the *Clinton* group, in which occurs, in many localities, a bed of red iron ore; *third,* the *Niagara* shale and limestone, the strata at Niagara Falls, where the upper 80 feet are limestone and the lower 80 feet shale. Niagara shale has little extent to the west of New York, while the limestone spreads very widely, reaching into Iowa and Tennessee.

The layers of the Medina sandstone often have ripple-marks, mud-cracks, wave-marks, and other evidences of mud-flat or sand-flat origin, showing that central and western New York, with the region to the southwest, was then an area of great mud and sand flats; but later these interior waters were more open and clearer; so that there was less sediment, and the life required for making limestone flourished.

In Great Britain the Wenlock shale and limestone are of the age of the Niagara shale and limestone. They are in view between Aymestry and Ludlow, near Dudley, and elsewhere. The limestone, like the Niagara, is full of fossils.

2. **Onondaga Period.** — This period is noted for its salt deposits. Its clayey rocks, without fossils, and its salt show that central New York, and the borders of Canada to the west, with part of Ohio, were then the site of great salt basins, where sea-water evaporated, impregnating the mud of the shallow sea with salt, or making deposits of rock salt. The brines of Salina and that vicinity in New York are salt-water wells, obtained by boring down to this saliferous rock. But farther south and west in New York and at Goderich in Canada, and also near Cleveland, in Ohio, there are beds of rock salt, some of them 40 to 80 feet thick.

In the Onondaga formation, and in the overlying Lower Helderberg, there occur occasionally large local beds of gypsum, or calcium sulphate. Part of these beds, if not all, were made by the action, on beds of limestone, of waters holding sulphuric acid. Some of them may be, like the salt-beds, the direct result of the evaporation of sea-water. There are many sulphur springs in the western part of New York, whose waters give out sulphuretted hydrogen (or hydrogen sulphide) which were produced by the decomposition of minerals containing sulphur in the rocks below; and not unfrequently sulphuric acid has resulted from the oxidation of the sulphuretted hydrogen, making acid springs.

3. **Lower Helderberg Period.** — This period, which followed the Onondaga, was noted for a return of the conditions required for making fossiliferous limestone, showing that the waters had deepened over New York, especially to the eastward, that the

salt-making basins had consequently disappeared, and that once more there were clearer waters and abundant life. The name, *Lower Helderberg,* is from the Helderberg Mountains, southwest of Albany, where the beds occur.

The formation thins out to the westward in New York, being thickest in the vicinity of the Hudson River valley. Moreover, it appears east of the river in Becrafts Mountain near Hudson, and probably extended northward to the St. Lawrence; for rocks of the period are found near Montreal. They appear to be evidence, therefore, that although the waters of the St. Lawrence Bay were cut off from those of New York during the Niagara and Onondaga periods, the two were connected temporarily during this last period of the Upper Silurian. The beds also extend southwestward along the Appalachians.

Following the Wenlock group in Great Britain there is the Ludlow group, consisting of sandstones, shales, and the Aymestry limestone, corresponding in age with the later part of the American Upper Silurian.

Life.

1. **Plants.** — The first American species of land plants have been obtained from beds of the Upper Silurian. The species were not Mosses, nor Grasses, but species of the Ground Pine tribe or Lycopods, the *highest* division of Cryptogams. They are described beyond, in the account of the Devonian plants.

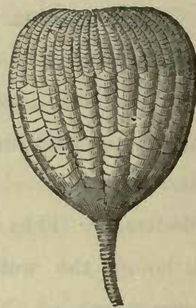
2. **Animals.** — Among the animals of the era there was the same preponderance of Corals and Crinoids among Radiates, of Brachiopods and Bryozoans, and of Trilobites among Crus-

Figs. 168–170.

168

169

170



Corals; Crinoid.

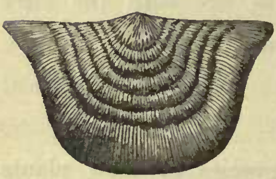
Figs. 168, 169, Corals: 168, Zaphrentis bilateralis; 169, Halysites catenulatus; Fig. 170, Crinoid: Ichthyocrinus lævis.

taceans, as in the Lower Silurian. There were also Fishes in the seas; and Scorpions, as well as Insects, over the land.

A few figures of Invertebrates are here given. Figs.

Figs. 171–173.

171



173

172

Brachiopods.

Fig. 171, Leptæna rhomboidalis; 172, side view of Spirifer Niagarensis; 173, Orthis biloba; 173 *a*, enlarged view of same.

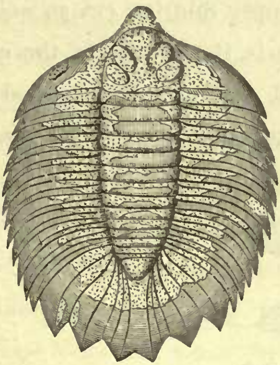
168, 169, represent two of the Corals of the Niagara period; Fig. 168, related to the Coral of the Lower Silurian, shown in Fig. 153; Fig. 169, a Coral imbedded in limestone, which looks, in a section of the limestone, a little like a chain, or a string of links, and has hence been called Chain-coral. Fig. 170 represents one of the Niagara Crinoids.

Some of the common Brachiopods of the Niagara group are represented in Figs. 171–173.

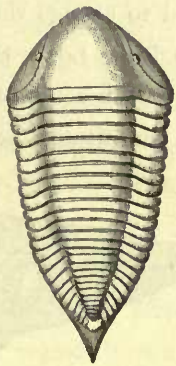
The following are figures of two of the larger Trilobites. Both figures are reduced views, Fig. 174 being but one third the natural length, and Fig. 175 one fourth.

Figs. 174, 175.

174



175



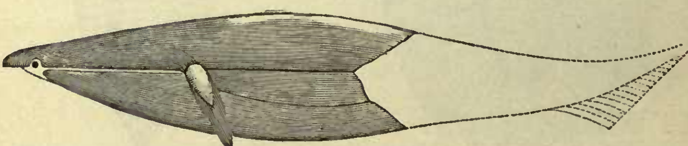
Trilobites.

Fig. 174, Lichas Boltoni ($\times \frac{1}{3}$); 175, Homalonotus delphinocephalus ($\times \frac{1}{4}$).

Of Insects only *Cockroaches* have yet been found. But these species had a better chance of preservation than most others because they frequent damp places; and this is a good reason for the survival of their remains.

Remains of Fishes have been found in the Onondaga beds. They are of the kind called *Placoderms,* having the anterior part of the body covered with bony plates, as illustrated in Fig. 176. Placoderms were common also in the Devonian. Remains supposed to be those of Fishes have also been found in the Clinton division of the Niagara. In England, Upper Silurian beds contain remains of Fishes related to the Sharks, and to the Ganoids. Ganoids differ from most modern Fishes in having bony scales or plates (Figs. 191–193). A few species are now living in American rivers and lakes. The living species of the seas, as the transitions in the fossils of the successive beds show, continued to change through the Upper Silurian era as well as through the Lower Silurian; that is, the species of the early part had nearly all disappeared and new species had become substituted before the later part of the era began;

Fig. 176.



Placoderm Fish.
Restoration of Palæaspis Americana.

and each of the successive subdivisions in the rocks indicates some old feature lost during its progress or in the transition, and some new feature gained. The transition from the Upper Silurian to the Devonian era was gradual.

2. *Devonian Era.*

The term Devonian was first applied to the rocks of the era in Great Britain by Sedgwick and Murchison, and alludes to the region of South Devon, where the rocks occur and abound in fossils. The era is divided into: (1) the EARLY or LOWER DEVONIAN, (2) the MIDDLE DEVONIAN, and (3) the LATER or UPPER DEVONIAN. The Devonian areas are those vertically lined on the North American map, page 136.

ROCKS.

1. **Early or Lower Devonian.**—The Lower Devonian formation has, at its base, *first*, the Oriskany sandstone, which has most thickness in eastern New York, like the beds of the Lower Helderberg. Next follows the Corniferous limestone, which is the great limestone of the Devonian, just as the Niagara was of the Upper Silurian, and the Trenton limestone was of the Lower Silurian. It spreads through New York from the Helderberg Mountains south of Albany, where it has been called the *Upper Helderberg* limestone, and stretches on westward to the Mississippi, and beyond into Iowa and Missouri. In New York and along the Appalachian region, it is underlaid by a sandstone or grit rock.

The Corniferous limestone is in some places a *coral-reef* rock, as plainly as any coral-reef limestone in modern tropical seas. At the Falls of the Ohio, near Louisville, Kentucky, it consists of an aggregation of Corals, many of large size, and some are standing in the position of growth.

The limestone often contains a kind of flint called hornstone; and, as the Latin for *horn* is *cornu*, the limestone was thence named the Corniferous limestone. The Devonian deposits above this limestone are mostly sandstones and shales.

2. **Middle Devonian.** — The Middle Devonian includes the Hamilton beds. They are mainly fragmental deposits in southern New York and along the Appalachian region to the southwest; but in parts of the Interior region they include limestones. The flagging stone so much used in New York and the adjoining states is an evenly laminated argillaceous sandstone, from the Hamilton beds at Kingston and other places on the Hudson River.

3. **Upper Devonian.** — The Upper Devonian comprises the Portage and Chemung formations, which were thus named from localities in New York. They consist chiefly of sandstones with some shale in New York and Pennsylvania; but in the Interior region the rock is mainly a black shale of little thickness. The Catskill red sandstone of eastern New York and Pennsylvania is a coarse sea-border formation, made during the Portage and Chemung epochs.

In Great Britain the Devonian formation includes a great thickness of red sandstone in Scotland, Wales, and England, which was formerly distinguished as the "Old Red Sandstone." In South Devon there are limestone and shales in place of red sandstone, and hence a greater abundance of fossils. In the Eifel, Germany, the Eifel limestone is a Devonian coral-reef rock of the age of the Corniferous. Devonian sandstones cover a large area in Russia.

Life.

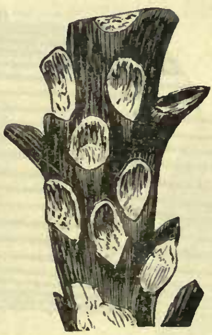
1. **Plants.** — The plants included, besides Seaweeds, various terrestrial kinds; and among them, in the middle and later Devonian, large forest trees.

These early species were mostly the higher Cryptogams or

Figs. 177, 178.

177

178



Ferns.

Fig. 177, Neuropteris polymorpha; 178, Tree-fern, Caulopteris antiqua.

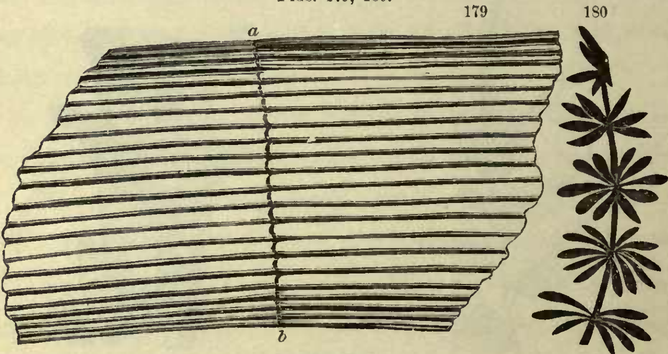
Flowerless plants, but included also some Flowering plants. Of the former there were the following kinds: —

1. *Ferns.* — Some of them were Tree-ferns. A portion of one of the Ferns is shown in Fig. 177, and part of the stem of a Tree-fern in Fig. 178.

2. *Equiseta.* — The modern Equiseta, or Horsetails (the latter term a translation of the former) have striated jointed stems, which may be pulled or broken apart easily at the

articulations. The ancient species had a similar character. A portion of one of these rush-like Devonian plants is represented in Fig. 179. One of the articulations of the stem is shown at *ab*. In allusion to its reed-like character it is called a *Calamites*, from the Latin *calamus, a reed.* The plant represented in Fig. 180 belongs to the Equisetum tribe; the word *Asterophyllites* means *star-leaf.*

Figs. 179, 180.



Equiseta.

Fig. 179, Calamites (Archæocalamites) radiatus; 180, Asterophyllites latifolius.

3. *Lycopods.* — The land plants most characteristic of the world in ancient time, were the Lycopods. The little trailing Ground Pines of our modern woods, so much used for decorating churches at Christmas time, are examples of Lycopods; the close resemblance to miniature Pine trees gave origin to the name. The earliest of the ancient Lycopods were of small size, but some of those of the Middle Devonian were large forest trees. Fig. 181 represents a part of the exterior of one of the Devonian Lyco-

pods. The plants are called *Lepidodendrids* (from the Greek for *scale* and *tree*), in allusion to a resemblance between the scarred surface and the scaly exterior of a reptile. The scars are the bases of the fallen leaves, and resemble the same on a dried branch from a Spruce tree. In the true Lepidodendrids the scars are in alternate order, as illustrated in Fig. 181. In another group, called *Sigillarids*, the scars are in vertical series, as in Fig. 182.

4. *Phænogams, or Flowering Plants.* — Among the Flowering plants there were trees allied to the Yew, Spruce, and Pine, kinds having the simplest of flowers, and the seed naked instead of in pods. In allusion to the latter character they are called *Gymnosperms*, meaning *having naked seeds.* The flowers and fruit are usually in cone-like groups, and in allusion to the cones a large part of Gymnosperms are

Figs. 181–183.

181

182

183

Lycopods; Gymnosperm.

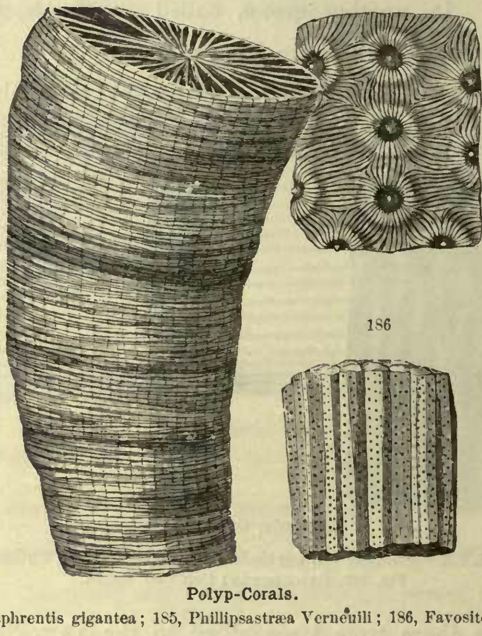
Figs. 181, 182, Lycopods; 181, Lepidodendron primævum; 182, Sigillaria Hallii; Fig. 183, Gymnosperm: Cordaites Robbii.

called *Conifers.* Fig. 183 is a leaf of a Cycad, a subdivision of the group of Gymnosperms which includes the modern Cycas and Zamia.

2. **Animals.**—Corals, Crinoids, Brachiopods, and Trilobites, were represented by numerous species, as in the preceding era.

FIGS. 184–186.

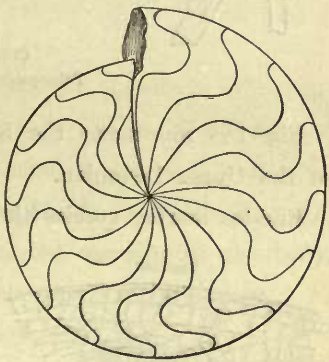
184 185 186



Polyp-Corals.
Fig. 184, Zaphrentis gigantea; 185, Phillipsastræa Verneuili; 186, Favosites Goldfussi.

Three of the Corals of the coral-reef limestone (Corniferous limestone) from the Falls of the Ohio, near Louisville, are represented in Figs. 184–186. Fig. 184 represents a specimen of one of the large simple Corals, broken at both extremities, and showing above the radiating plates of the interior. The top, when perfect, had a depression which was radiated with such plates, and to this the name of this ancient group of Corals, *Cyathophylloids*, alludes; it comes from the Greek for *cup* and *leaf.* Some specimens of the species are nearly three inches in diameter at top and a foot long; and, when living, the polyp or flower-animal when expanded was as large as a small-sized sunflower, and probably as brilliant in color. Fig. 185 shows the surface of a massive Coral whose polyps covered the surface like those of Fig. 14, on page 45. The other kind, Fig. 186, is one of the most common; the structure is columnar, suggesting that of a honeycomb, and hence its name, *Favosites,* from the Latin *favus,* a *honeycomb.*

FIG. 187.

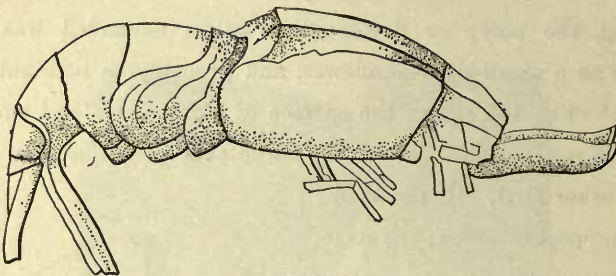


Cephalopod.
Fig. 187, Goniatites mithrax.

Among Cephalopods, besides species related to the Nautilus, or Nautiloids, there were other kinds of the tribe of *Ammonites*, or *Ammonoids*, a group which commenced just before the close of the Upper Silurian, and which is represented by very numerous species in Mesozoic time. The form of one of the Devonian species is shown in Fig. 187. It has the partitions or septa of the shell flexed, and hence the name *Goniatites*, from the Greek for *angle.* Besides the flexures on the sides shown in the figure, there is always one along the back of the shell. Moreover, the siphuncle, instead of being central, or nearly so, as in the Nautiloids, is close to the back of the shell.

Among Crustaceans there were *Barnacles* and *Shrimps*.

FIG. 188.

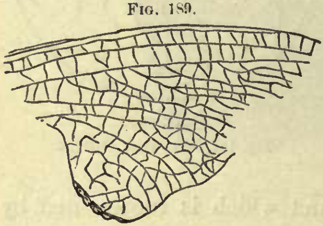


Crustacean.
Palæopalæmon Newberryi.

Fig. 188 represents the Shrimps from the Portage beds of the Upper Devonian.

Besides marine species there were also *Insects* among terrestrial Articulates. Fig. 189 represents a wing of one of the May-flies of the Devonian world; a gigantic species much exceeding any now known. It measured five inches in spread of wings. The May-flies or Ephemeræ are species that live in the water during the young or larval state, and, when mature, fly in clouds over moist places. One of the Devonian species could make the shrill sound of a Locust.

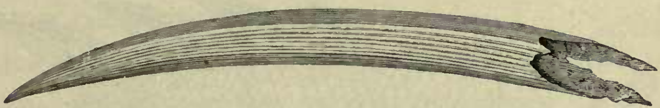
FIG. 189.



Platephemera antiqua.

The Vertebrates included, as far as now known, only Fishes. The remains of the Fishes are teeth; large spines that formed the front margin of the fins; scales; plates covering the head or the whole body of armor-clad species or Placoderms, but never the entire backbone (vertebral column), as

Fig. 190.



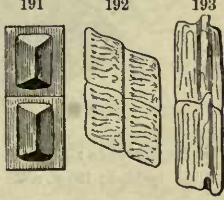
Fin-spine of a Shark.

this was mainly or wholly cartilaginous and not bony, and hence decayed on burial.

The species included are (1) *Sharks;* (2) *Gars,* or *Lepidoganoids;* (3) *Placoderms;* and (4) *Dipnoans.* The Gars and Placoderms are both included under the name *Ganoids.*

1. *Sharks.* — The remains of the Sharks are either the teeth, the shagreen, or hard, rough-pointed covering of the body, or the large spines with which the front margin of the fins is sometimes armed. Fig. 190 represents one of the fin-spines of a Shark of the Corniferous period, two thirds the full length. The Shark was one of great size, as the length of the spine indicates. Some of the Sharks had rather blunt cutting teeth; but the most common kind, related to the living *Cestracion* of Australian seas, had a pavement of bony pieces over the inner surface

Figs. 191–193.

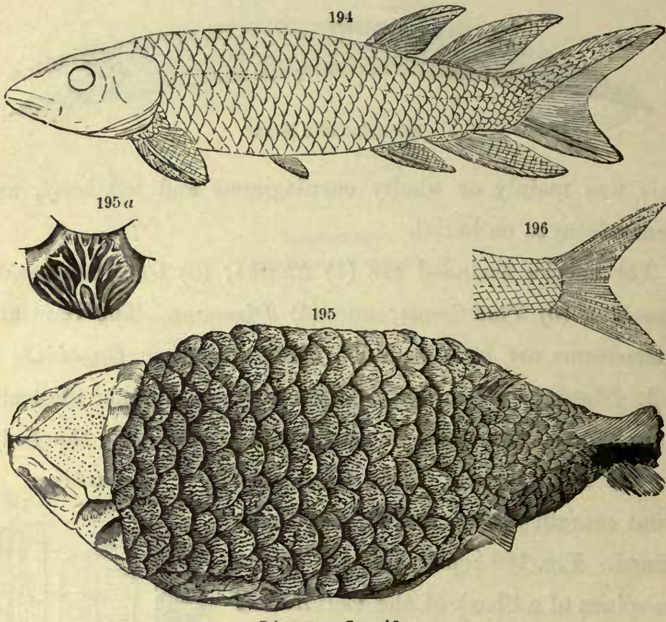


Scales of Ganoids.

of the lower jaw, making the mouth a formidable grinding apparatus, fit for cracking Brachiopods and the like.

2. *Gars, or Lepidoganoids.*—The Gar-pikes of the Mississippi and the Great Lakes, now a rare kind of Fish in the world, are examples of the type of Fishes that was exceedingly abundant

Figs. 194–196.

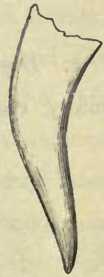


Dipnoan; Ganoids.

Fig. 194, Dipnoan: Dipterus macrolepidotus (× ½); Figs. 195, 196, Ganoids: 195, Holoptychius; 195 *a*, scale of same; 196, tail of a modern (homocercal) Ganoid.

in species in the Devonian Age. The scales of Gars are bony and shining, unlike those of ordinary modern Fishes, and to this, Agassiz's name, *Ganoid* (from the Greek for *shining*), refers. In many species the scales are set side by side with a special arrangement for interlocking at one margin after the fashion of the tiles on a roof; while in others they are put on more like shingles, or in the way common in ordinary fishes. Figs. 191, 192 represent two kinds of tile-like scales; and 193, the under surface of two of the latter, showing how they are secured to one another. Fig. 195 represents a specimen of the Ganoid fishes of the Devonian.

FIG. 197.



Ganoid.
Tooth of an Onychodus.

Some of the Ganoids of the Middle Devonian whose remains have been found in Indiana and Ohio were of great size. One of them had jaws a foot to a foot and a half long, with teeth in the lower jaw (Fig. 197) two inches or more long.

The teeth of Ganoids are usually very sharp. Sometimes they are small and fine, and grouped so as to make a brush-like surface; but often they are very large and stout. The material of the interior of the teeth, called dentine, is often intricately folded, and, in allusion to the passages of a labyrinth, such teeth are said to have within a *labyrinthine* structure. A simple form of this labyrinthine structure is represented in Fig. 198.

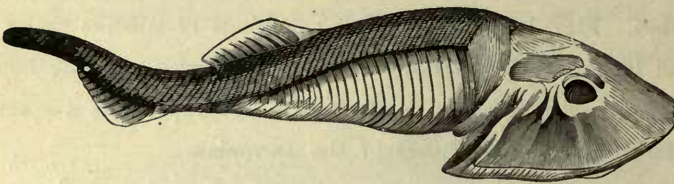
FIG. 198.

Section of Tooth of Lepidosteus osseus.

3. *Placoderms.* — One of the Placoderms, a Cephalaspis, is represented in Fig. 199. Other species are shown in Figs. 200, 201. The body in Fig. 200 is incased in bony pieces, and the pectoral fins of the fish were like arms; but they made

very poor limbs for a fish, as they were unfit for swimming, and could be used only for crawling over the bottom.

Fig. 199.

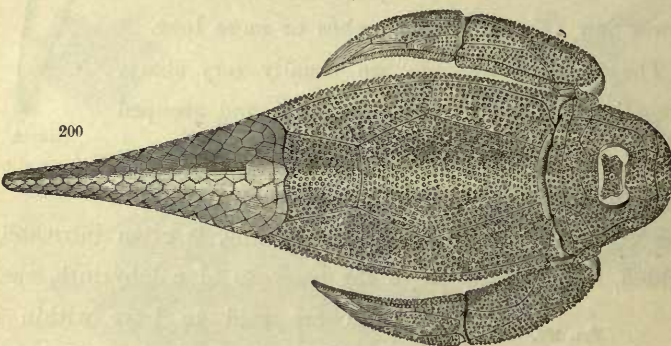


Cephalaspis Lyellii.

4. *Dipnoans.* — These Fishes resemble the Ganoids in many respects, but differ in having the air-bladder devel-

Figs. 200, 201.

200



201

Placoderms.

Fig. 200, Pterichthys Milleri ($\times \frac{2}{3}$); 201, Coccosteus decipiens ($\times \frac{1}{4}$).

oped as a lung, and the auricle of the heart divided into two. Fig. 194 represents a Devonian Dipnoan. The tail in

Fig. 194 has a peculiarity that belonged to all of the ancient Fishes; that is, the vertebral column extends to its extremity. In Mesozoic and Cenozoic species and modern Gars the vertebral column stops at or near the commencement of the tail-fin, as in Fig. 196.

The facts reviewed with reference to the life of the Devonian teach that during the progress of the age the marshes and dry land were covered with jungles and forests; that the trees were without conspicuous flowers, and the most of them with no true flowers at all; that the seas were brilliant with living Corals, as well as Crinoids, and abounded in Brachiopods and Trilobites; that they also had their great fishes, — Sharks, Gars, and Placoderms. The land, too, had its swarms of Insects, and its Scorpions and Myriapods, and perhaps also its Spiders to spread their webs for the May-flies, although no relics of them have yet been found.

Mountain-making.

The Devonian age passed quietly for the larger part of the North American continent, without any tilting of the rocks; yet not without wide, though small, changes of level, varying the limits and depth of the Interior sea, such changes of level and of limits being indicated by the varying limits of the rocks, all of which are of marine origin. This quiet was not interrupted between the Devonian and Carboniferous eras, so far as yet discovered, except to the northeast in the region of New Brunswick, Nova Scotia, and northeastern Maine. There an upturning and flexing of the beds occurred, and, as a result, some mountain-making.

The southward extension or growth of the dry land of the continent continued; and, by the close of the Devonian, the shore line probably crossed the southern portion of what is now New York State, where is the southern limit of the outcropping Devonian, so that all of Canada except the southwest extension north of Lake Erie, nearly all of New York, and much the larger part of New England, were above the sea level, together with Wisconsin and the borders of the adjoining states. There was probably also a peninsula extending from northern Illinois to the Cincinnati region, and an island about an Archæan area in Missouri. See map, page 136.

3. *Carbonic Era, or Era of Amphibians.*

The Carbonic era was the time when the most extensive coal-beds of America and Europe were made. The name *Carbonic* is from the Latin *carbo, coal.*

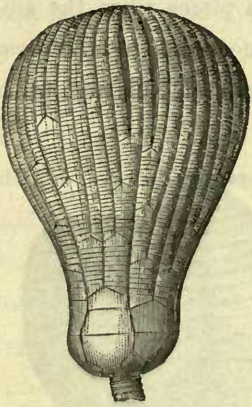
Rocks.

1. **Subcarboniferous Period.** — The era commenced with a marine period, the Subcarboniferous, in which a large part of the North American continent was under the sea, though not at great depths, and Great Britain and Europe also were to a large extent submerged. During it, limestone strata, with some intervening sand-beds, were in progress in portions

of Great Britain and Europe, and over much of the Mississippi basin or the Interior region of North America; and, at the same time, great fragmental deposits, making sandstones, shales, and conglomerates, were laid down along the Appalachian region from the borders of New York southwestward, the thickness of which was five times as great as that of the limestone strata.

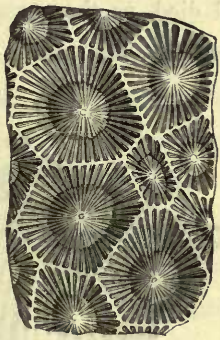
Figs. 202–204.

202



203

204



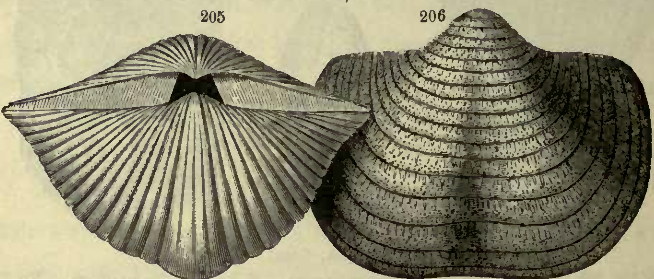
Crinoids; Coral.

Figs. 202, 203, Crinoids: 202, Woodocrinus elegans; 203, Pentremites pyriformis; Fig. 204, Coral: surface of Lithostrotion Canadense.

The map of North America on page 164, Fig. 167, gives a general idea of the Continental land and its great waters. The chief change that had taken place during the Upper Silurian and Devonian was a spreading of the northern shore line in New York far southward to, or nearly to, its southern boundary; in Ohio, to and beyond the Cincinnati island (C, Fig. 167); and in Wisconsin to northern Illinois and Iowa. Farther south and west there was an open sea.

The limestone was formed to a great extent of Crinoids, and though Corals, Brachiopods, and other species contributed to its material, it has been called *Crinoidal limestone.* The Crinoids were of numerous species and very various forms. One of the most perfect specimens is represented in Fig. 202, only the stem below being wanting. The figure shows the numberless stony pieces — really blocks of limestone material — of which it consists, and which ordinarily fell to pieces when the animal died, as there was little animal membrane to hold them together. The animal opened out its arms at will, and when

Figs. 205, 206.



Brachiopods.

Fig. 205, Spirifer increbescens; 206, Productus punctatus.

expanded, the breadth of the flower-like summit in this species was about three inches. The stem below, when entire, was probably a foot or more long. The little disks of which the stem of the Crinoid consists, looking like button-molds, are common fossils in the limestones. On page 50, Fig. 34, a piece of Crinoidal limestone is represented which consists almost solely of the broken stems of Crinoids. Some of the stems are an inch in diameter. Fig. 203 represents a Crinoid without arms, called *Pentremites.*

There were also Corals; and a top view of the most common of these is represented in Fig. 204. Brachiopods also were abundant; figures of two of them are given in Figs. 205, 206.

2. **Carboniferous Period.** — After the Subcarboniferous period began the true Coal period, or that of the *coal-measures.*

The rocks of the coal-measures, which alternate with the coal-beds, are sandstones, shales, conglomerates, and occasionally, especially in the Interior region of the continent, limestones. At base, there is generally a conglomerate called the *millstone-grit.* The coal-beds are evidence of long periods of emerged land, free from briny waters, where marshy lands were densely covered with vegetation; and the intervening fragmental and limestone strata prove a new submergence either beneath fresh waters or salt, and generally for the region west of Pennsylvania, the latter, as the fossils show.

The geography of the continent during times of emergence and wide-spread foliage may be learned approximately from the map on page 136 (since at those times the Archæan and Paleozoic areas must have been mainly dry land); and the positions of the great coal-marshes, though narrowed by erosion and a covering of later strata, from the black areas on the map. The easternmost is in New Brunswick, Nova Scotia, and western Newfoundland; the westernmost, just west of the Mississippi, from Iowa to Texas; the region farther west continued to be an area of salt water, producing only *marine* Carboniferous rocks.

The most northern area, the *Acadian*, covers part of Newfoundland, Nova Scotia, and New Brunswick; a *second*, of very small extent, is in Rhode Island; a *third*, the *Alleghany*, reaches from near the southern boundary of New York over part of Pennsylvania, Ohio, Kentucky, and Tennessee to Alabama; a *fourth* is in central Michigan; a *fifth*, the *Eastern Interior*, covers parts of Illinois, Indiana, and west Kentucky; a *sixth*, the *Western Interior*, parts of Iowa, Missouri, Kansas, Arkansas, and Texas. The last two were originally one, but the Mississippi Valley now separates them. It has been estimated that the area of the workable coal-beds of the United States is at least 120,000 square miles. The coal area of Nova Scotia and New Brunswick is 18,000 square miles.

The principal coal areas of England are those of South Wales; the great Lancashire region east of Liverpool (B, Fig. 230, p. 212) and Manchester (C); the Derbyshire coal region farther east; and on the northeastern coast, the Newcastle coal-field (D). There are also coal-fields in Scotland between the Grampian range on the north and the Lammermoor Hills on the south; and others, in Ulster, Connaught, Leinster (Kilkenny), and Munster, in Ireland. There are valuable coal-fields of smaller extent in Belgium, France, and Spain, and others in Germany and southern Russia.

The greatest thickness of the coal-measures in Pennsylvania is 4000 feet; in Illinois, 1200 feet; in Nova Scotia, about 15,000 feet. In Great Britain it is 7000 to 12,000 feet in South Wales, and contains 100 beds of coal; 7000 to 8000 feet in Lancashire, with 40 beds of coal over one foot in thickness; 2000 feet at Newcastle, with about 60 beds of coal. The aggregate thickness of the coal-beds of a region is not over *one fiftieth* of that of the coal-measures.

The coal-beds vary in thickness from less than an inch to 30 or 40 feet. The "mammoth vein" of the anthracite region in Pennsylvania is 29 feet thick at Wilkesbarre; but there are some layers of shale in the course of it,—a common fact in all coal-beds. Some coal-beds contain too much earthy matter to be of any value.

The mineral coal is of different kinds. That of eastern Pennsylvania and of Rhode Island is *anthracite*, while that of the rest of the country is almost wholly *bituminous coal.* Anthracite is a firm, lustrous coal, burning with but little flame, while the *bituminous* coal, as that from Pittsburg and the states west, is less firm and usually of less luster, and burns with much yellow flame. The flame is due mainly to the fact that part of the carbon is combined with hydrogen (or with hydrogen and oxygen) into a compound that, when heat is applied, becomes a combustible gas. Some bituminous coals — especially those compact coals, scarcely shining, called *cannel coal*—afford 50 per cent or more of volatile matter; while anthracite yields very little, and this is mostly the vapor of water.

Coals always contain some impurity, which is the "ash" and "clinkers" of a coal-fire. This ash or earthy material was largely derived from the plants themselves, and for the best coals wholly so; but in other cases it is part of the detritus that was from time to time drifted over the beds of vegetable débris by the winds, or washed over by the waters. The coal-beds always contain a little sulphur, — enough to give a sulphur smell to the gases from the burning coal; and the most of it exists in the state of *pyrite*, a compound of iron and sulphur.

The layer of rock under a coal-bed is often a clayey layer, called the underclay, and it is frequently full of the underground stems or roots of plants. The trunks sometimes project from the top of a bed of coal, as shown in Fig. 86, page 109. Many logs or great trunks lie in the strata that intervene between the coal-beds, which were once floating logs; and multitudes of ferns and flattened stems or trunks of these and other plants are often spread out in the shales, and especially in the bed of rock directly over a coal-bed. Moreover, the coal itself, even the hardest anthracite, has sometimes impressions of plants in it, and, more than this, contains throughout its mass vegetable fibers in a coaly state which the microscope can detect.

Coal was made from plants, and each coal-bed was originally a bed of vegetable material, accumulated in nearly the same way as the peat-beds of the present time. (See, on this point, page 57.) The plant-bed having increased until several times thicker than the coal-bed to be made out of it, was finally covered with beds of clay or sand; and while thus buried it gradually changed to coal.

Plants when dried are one half *carbon* — the chief material of charcoal — the rest being mostly the two gases, oxygen and hydrogen; after the change to coal, seven tenths to nine tenths or more of the whole is carbon.

3. **Permian Period.** — The coal-measures are followed in Europe by a series of red sandstones and clayey rocks or marlytes, with a magnesian limestone, constituting the *Permian* group — so called from the district of Perm, in Russia. In North America the Permian rocks include the sandstones and shales at the top of the coal-measures in Kansas, Pennsylvania, and Texas.

Life.

1. **Plants.** — The plants were similar in general character to their predecessors in the Devonian age, though mostly different in species and partly in genera. Of the higher Cryptogams, called *Acrogens* (or *upward growers*, as the word from the Greek signifies), because they can grow into trees, there were, as in the Devonian, (1) *Ferns*, (2) *Equiseta*, (3) *Lycopods;* and of the Phænogams, or flowering plants, *Gymnosperms*, or trees of the Pine and Cycad tribes. The trees and shrubs grew luxuriantly over the almost endless marshes of the continent, and spread beyond them, also, over the higher lands.

The features of the vegetation and of the ordinary landscape are shown in the following ideal sketch, Fig. 207.

The tree at the center is a Tree-fern, and there are smaller Ferns below. The tree near the left side is a Lycopod of the ancient tribe of Lepidodendrids; in the left corner there

Fig. 207.

Carboniferous Vegetation.

are Equiseta. The region is represented as a great marshy plain with lakes. The lakes of the Carboniferous era probably had their many floating islands of vegetation, carrying large groves like the floating islands of some lakes in India.

A portion of one of the Ferns is shown in Fig. 208, and of another in Fig. 209. Fig. 210 represents one of the Equiseta, a species of *Calamites* (page 174); plants with jointed stems that grew often to a height of 20 feet, and

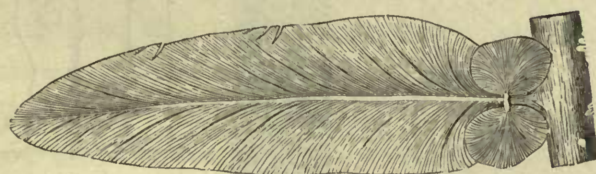
FIG. 208.

Fern.

Sphenopteris Gravenhorstii.

sometimes were a foot in diameter, very unlike the little Horsetails of modern time.

FIG. 209.

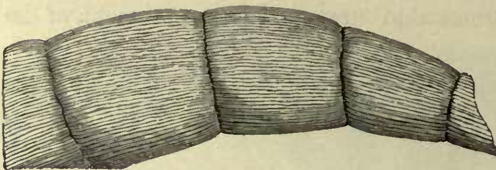


Fern.

Neuropteris hirsuta.

The Lycopods, of the tribe of Lepidodendrids, had the aspect of Pines and Spruces, and were 40 to 80 feet or more in height. On some, the slender pine-like leaves were a foot or more long. Figs. 211, 212 show the scars of the outer surface of two of the Lepidodendrids arranged, as

FIG. 210.

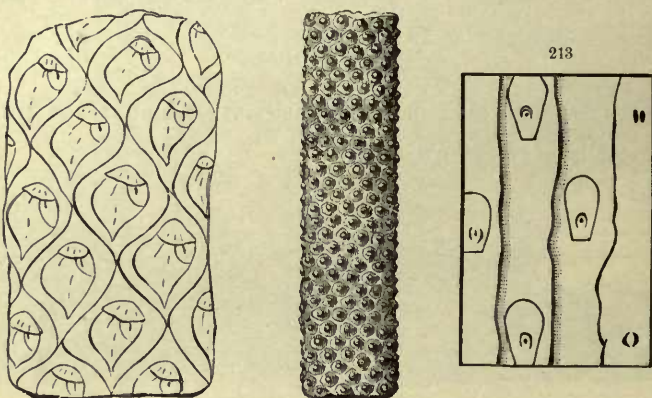


Equisetum.
Calamites cannæformis.

usual, in alternate order; and Fig. 213, those of a Sigillaria in vertical series. The resemblance of the scars in the latter

FIGS. 211–213.

211 212 213



Lycopods.
Fig. 211, Lepidodendron clypeatum; 212, Halonia pulchella; 213, Sigillaria Sillimani.

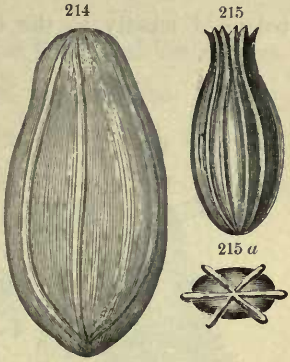
to an impression of a seal suggested the name *Sigillaria*, from the Latin *sigillum, seal.*

The cones of the Lepidodendrids and the nuts of the

Gymnosperms also occur in the beds. Two of these nuts are represented in Figs. 214, 215. They are supposed to have belonged to trees related to the modern Yew tree.

Many of the North American species of plants have been found also in Europe. There are also coal regions in the Arctic islands which have afforded some of the same species of plants that were growing in Europe and America, showing great uniformity in the climate of the era; a fact sustained also by the occurrence in the Arctic deposits of many fossil shells and corals identical with some then living in the seas of Europe and America.

FIGS. 214, 215.



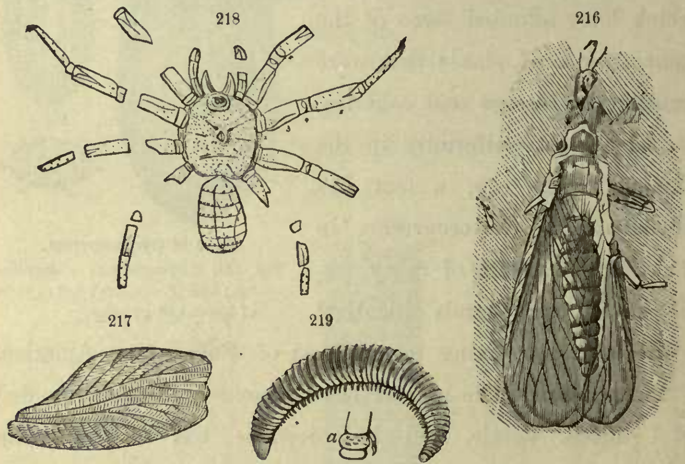
Nuts of Gymnosperms.
Fig. 214, Trigonocarpus tricuspidatus; 215, T. ornatus; 215 *a*, view of lower end of same.

2. **Animals.** — The seas of the Carboniferous age abounded in Crinoids, Corals, and Brachiopods; but in the group of Articulates, while there were many kinds of Worms and Crustaceans, Trilobites were few. Trilobites had been replaced by other Crustaceans. Examples of the Crinoids, Corals, and Brachiopods of the earlier part of the era are figured on pages 185, 186.

The land had its Insects, true Spiders, Scorpions, and Myriapods, and also its land Snails; and among the Insects there were May-flies, Cockroaches, Crickets, and Beetles. A view of one of the May-flies, of natural size, is shown in Fig. 216; of the wing of a Cockroach, in Fig. 217; of a Spider, from Morris, Illinois, in Fig. 218; and of a Myriapod, from Nova Scotia, in Fig. 219.

Fishes were in great numbers and of large size, and they belonged mostly to the two grand divisions that were espe-

FIGS. 216–219.



Terrestrial Articulates.

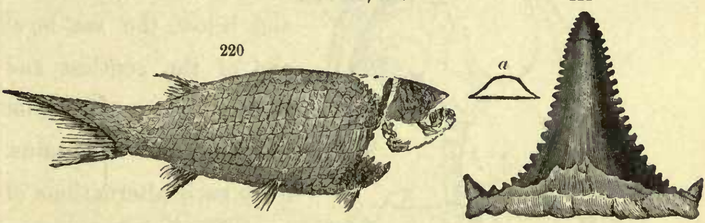
Figs. 216, 217, INSECTS: 216, Miamia Bronsoni (× 1); 217, Eoblattina venusta, wing of a Cockroach; Fig. 218, SPIDER: Arthrolycosa antiqua; Fig. 219, CENTIPEDE: Xylobius sigillariæ.

cially characteristic of the Devonian, — the *Sharks* (called also *Selachians*, from the Greek for *cartilage*, the Sharks being fishes with a cartilaginous skeleton) and the *Ganoids*. Some of the Sharks were larger than any modern species. One of the Ganoids of the coal-measures is represented in

Fig. 220. It has the vertebrated tail, characteristic of all Paleozoic fishes. Fig. 221 shows the form and size of the teeth of one of the Sharks of the Subcarboniferous beds of Illinois.

Besides Fishes there were the first of terrestrial Vertebrates, *Amphibians;* and, before the close of the Permian, *Reptiles.* Footprints of an Amphibian have been described from the

Figs. 220, 221.



Fishes.

Fig. 220, Ganoid: Eurylepis tuberculatus, from the coal-formation in Ohio; Fig. 221, Selachian: tooth of Carcharopsis Wortheni; *a*, profile section of same.

Subcarboniferous beds of Pennsylvania, indicating a large animal having a tail,—the tail having made its mark on the mud-flat over which the animal marched. In the Carboniferous beds of Illinois, Ohio, and Nova Scotia, skeletons have been found. One of them, from Ohio, is represented in Fig. 222. It has the broad cranium that is found in the Frog and Salamander; but while modern species have a naked skin, the Carboniferous kinds were furnished with scales and bony plates. They had also sharp teeth very much like those of Ganoid fishes.

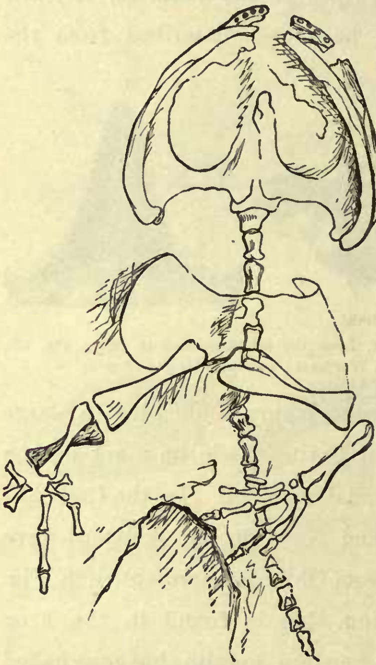
Fig. 223 represents the skull of one of the true *Reptiles* from the Middle Permian of Saxony.

No remains of *Birds* or of *Mammals* have yet been found in any Paleozoic rocks.

Changes of Level during the Progress of the Carbonic Era.

Changes of level were going on over the North American continent throughout the era; but they were alternating oscillations above and below the sea level and of the gentlest and slowest kind possible, not upliftings into mountains. Just such alternations of level had been in progress through all the preceding ages; but the Carboniferous movements were peculiar in this, that the continent over its broad surface was just balancing itself near the water's surface, part of the time bathing in it, and then out in the free air, and so on, alternately; while in former times, the oscillations seldom carried the Interior Continental region out of the water, or if they did, only portions at a time. It was peculiar also in the fact that

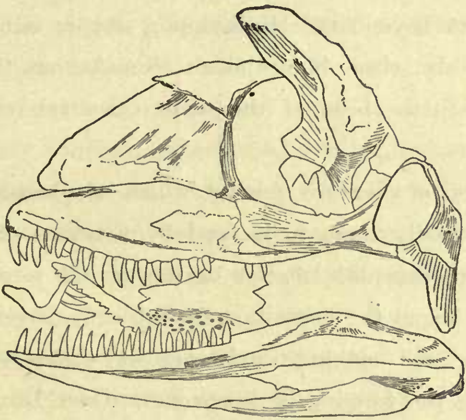
Fig. 222.



Amphibian.
Pelion Lyellii.

the wide continent lay quiet above the sea level, with a nearly even surface, *for very great periods of time,*—sufficiently long to make beds of vegetable débris thick enough for coal-beds. Many of the coal-beds are *six* feet thick, and some *twenty* or more; and even six feet would require, according to an estimate that has been made, a bed of vegetable débris *thirty* feet thick for bituminous coal, and a much thicker one for anthracite.

FIG. 223.



Reptile.

Skull of Palæohatteria longicaudata.

The Interior of the continent from eastern Pennsylvania to central Kansas was a region of vast jungles, lakes with floating grove-islands, and some dry-land forests, and the débris of the luxuriant vegetation produced the accumulating plant-beds. A Cincinnati area of emerged land then divided the continental marsh from northern Illinois southeastward through Kentucky; but farther south the eastern and western portions were probably united. The Michigan coal area was an independent marsh region. The Green Mountains separated the Pennsylvania area from those of Rhode Island and Nova Scotia. The two latter were probably connected along the region of the Bay of Fundy and Massachusetts Bay and also with the coal area of western Newfoundland.

The changes of level could hardly have carried up evenly all parts of the Interior marsh region from Pennsylvania to beyond the Mississippi; and it is evident that they did not, since it is difficult to make out the parallelism between the beds of the eastern, central, and western portions.

The era of verdure during which a plant-bed was in progress finally came to its end by a return of the water over the Continental Interior destroying the terrestrial life; and then began the deposition of sediment (covering up the plant-beds and making sandstones or shales or conglomerates), or the forming of limestones. Over Illinois and to the south and west, the encroaching waters were salt; for the beds contain marine fossils. But over Pennsylvania they were most of the time fresh.

Finally, the continental surface, or wide portions of it, again emerged slowly, putting an end to aquatic life, and opening a new era of verdure. Such alternations continued until all the successive coal-beds were made, some of them affecting perhaps the whole breadth of the Interior coal area, others more local. Thus the era was one of constant change; yet change so gradual that only a being whose years were thousands or tens of thousands of our years would have been able to discover that any change was in progress.

In Nova Scotia the oscillations went on until nearly 15,000 feet of deposits were formed; and in that space there are 76 coal-seams and dirt-beds; and therefore 76 levels of marshes and verdant fields, between others when the waters covered the land. But over that region the waters submerging the region were mainly fresh or brackish waters, since no marine shells exist in the beds, while there are land and fresh-water shells and bones of amphibians. The area in the Carboniferous period was an immense delta at the mouth of the St. Lawrence, then the only great river of the continent, and the submergences were connected with the floods of the stream as well as with changes of level in the earth's crust.

The Permian period, or the closing part of the Carboniferous age, was an era of general submergence, without long eras of verdure or the formation of plant-beds.

Geographical Progress during Paleozoic Time.

In the history of Archæan time the fact is brought out that the North American continent was largely outlined and the courses of its mountain chains determined before Paleozoic time began. Later history has shown that the continent-making which followed was not a building up from deep-sea foundations, but a building outward over shallow Continental seas from the borders of the emerged Archæan lands, and largely within waters that had Archæan ridges as confines. Through the Early Paleozoic, rock-making reached to the borders of the Continental areas. But at the time of the Medio-Paleozoic upturning, when the Taconic Mountain system was made (see map, page 164), a broad sea-border barrier was produced by an emergence which shut off the Atlantic. Consequently, no rock deposits were made during the Later Paleozoic along this border north of Florida, except in local gulfs over New England and Canada. Rock-making in eastern North America was largely Interior Continental work. It produced a gradual extension of the foundation rocks westward, and finally their partial emergence.

Over the Rocky Mountain slopes also there was rock-making; but the larger part of western North America, even to the Pacific, continued to the end of Paleozoic time a wide sea.

The Post-Paleozoic Revolution.

From the beginning of Paleozoic time to its close all changes over the Appalachian region west of the Archæan ridges, southwest of New England, and over the great Interior region of the continent, had gone on quietly. There were gentle oscillations of the surface and slight displacements, but nowhere a general upturning.

These ages of quiet and regular work in rock-making were very long, for Paleozoic time includes at least *three fourths* of all time after the beginning of the Cambrian era.

Over the *Appalachian* region from New York southward, the Cambrian, Silurian, Devonian, and Carboniferous deposits have great thickness. The maximum amount in Pennsylvania has been estimated at 40,000 feet, or *over seven miles.* But over the Interior region, where limestones were the most of the time forming, the thickness is from 3000 to 4000 feet. These Appalachian deposits, ten times thicker than those of the Interior, were accumulating there for the making of a range of mountains; and at the close of the Paleozoic all was ready and the mountains were made.

An account of the making of the Appalachian range has been given on pages 114, 115. It is there stated that the 40,000 feet of deposits were accumulated in a gradually forming trough made by the slow sinking of the earth's crust, the several rocks of the series bearing evidence that they were made in shallow waters. The last in the series, the Carboniferous and Permian beds, were spread out horizontally just above or just below the surface; the coal-measures proving that there were wide emergences during their progress. The amount of subsidence, therefore, was in some places 40,000 feet. The breadth of the trough was nearly 100 miles and its length about 900.

The catastrophe consisted in (1) the folding, (2) the fracturing, (3) the solidifying, and in part (4) the crystallizing of the beds; and also (5) the change, in eastern Pennsylvania, of bituminous coal to anthracite.

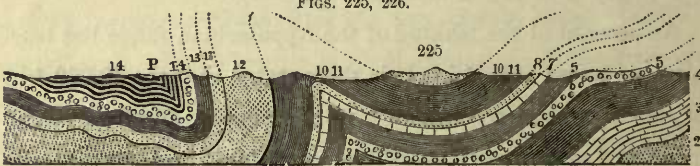
The folds were numerous, and involved the whole breadth of the region; and if their tops had not since been worn off by the action of water, some of the folds would now rise over 10,000 feet above the sea level. Their characters are shown in Fig. 224, of a section from Virginia, extending

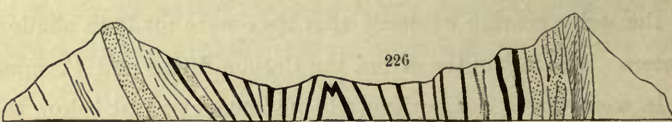
Fig. 224.

Section from the Great North, to the Little North, Mountain, through Bore Springs, Virginia.

from the southeast on the right to the northwest on the left, over a distance of six miles. It presents an example,

Figs. 225, 226.





Sections of the Coal-measures.

Fig. 225, on the Schuylkill, Pa.; P, Pottsville on the Coal-measures; 14, the Coal-measures; 13, Subcarboniferous; 12–8, Devonian formations; 7, 5, Upper Silurian; 4, 3, Lower Silurian; 2, Cambrian. Fig. 226, Anthracite region, near Nesquehoning, Pa.; the black lines coal-beds.

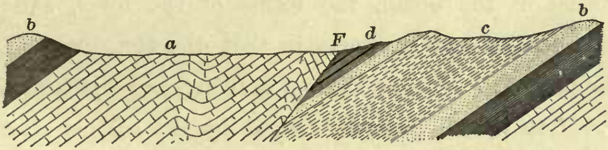
as explained on page 110, of the denudation the country has undergone, as well as of the folding.

The coal-formation was involved in the folds, a fact which proves that the folding began after the coal-beds were formed. Fig. 225 is a section of the vicinity of Pottsville, Pennsylvania, P being the position of Pottsville on the coal-measures. Fig. 226 represents another from near Nesquehoning, Pennsylvania, showing the anthracite beds doubled up, and in part vertical.

The folds are steepest and most numerous to the south-eastward, or toward the ocean, and diminish to the north-westward (see Fig. 224).

The folds generally have the western slope steepest, as if pressure from the direction of the ocean had pushed them westward; and sometimes the tops have thus been made to overhang the western base (Fig. 225).

FIG. 227.



Section of the Paleozoic Formations of the Appalachians, in Southern Virginia, between Walkers Mountain and the Peak Hills (near Peak Creek Valley.)

F, fault; *a*, Lower Silurian limestone; *b*, Upper Silurian; *c*, Devonian; *d*, Subcarboniferous, with coal-beds.

The rocks were also fractured on a grand scale, and those of the eastern side of the fracture shoved up so as to make faults in some cases of more than 10,000 feet. Fig. 227 represents one of these great faults. The fault is at F; to the right of F, at *d*, is the Subcarboniferous, and to the left, a bent-up Lower Silurian limestone; so that a Lower Silurian rock is brought up to a level with the Subcarboniferous, a lift, according to Lesley, of 20,000 feet.

The rocks were solidified through the aid of the heat caused by the movement of the rocks; and by the same means the change of the coal to anthracite was caused. This change to anthracite took place where the rocks are upturned or disturbed, and therefore where more or less heat had been produced by the movements.

While there was so much folding and fracturing, there was no chaotic confusion of the rocks produced, the stratification being perfectly retained.

It follows from the facts (1) that the force acted quietly, or with extreme slowness, for otherwise confusion would have been produced; and (2) that the pressure acted from the direction of the ocean, the forms of the folds, and their great numbers and steepness in that direction, proving this.

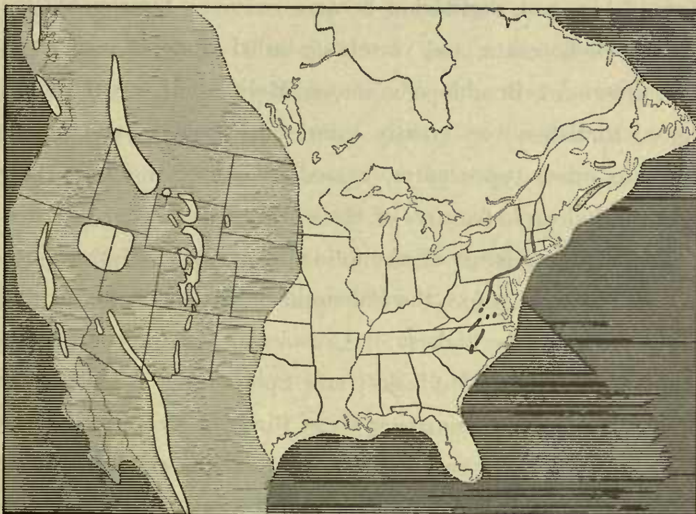
On page 115 all this folding, faulting, and uplifting is attributed to lateral pressure caused by the earth's slow contraction from cooling.

Owing to this pressure, and the weakening of the bottom of the great trough or syncline by the high heat of the earth's interior, there was a yielding below and a collapse, and thereby a pressing together of the thick deposits, folding and breaking them; and also a raising of the upper surface above its previous level, because the width of the base on which they rested was narrowed by the collapse.

Besides an Appalachian range, there was made at this time in eastern North America a Nova Scotia range from Newfoundland to Rhode Island, since largely denuded; and in Arkansas a Ouachita range. The three constitute the Appalachian Mountain system.

The end of Paleozoic time was thus marked by the making of great mountain ranges. Beyond this there was the emergence of the eastern half of North America, leaving the western half under water for completion and emergence at the close

Fig. 228.



Map of North America after the Post-Paleozoic Revolution.

of Mesozoic time, as exhibited on the accompanying map, Fig. 228.

Mountains were made in Europe and Great Britain at the same time with those of the Appalachian Mountain system, so that the close of Paleozoic time has its mountain boundary elsewhere besides in America.

Changes in Paleozoic Life at the Close of the Era.

In Paleozoic time Crinoids, Brachiopods, Cyathophylloid Corals, Orthocerata, Trilobites, vertebrate-tailed Ganoid Fishes, among animals, and Lepidodendrids, Sigillarids, and Calamites, among plants, were characteristic species in each of the classes to which they belong. With the close of it, Trilobites, Lepidodendrids, and Sigillarids became extinct; Cyathophylloid Corals, Orthocerata, and vertebrate-tailed Ganoids nearly so; and, afterward, Brachiopods among Molluscoids, and Crinoids among Radiates, were greatly inferior in numbers and importance to other types of more modern character. It is thus that the Paleozoic features of the world passed by.

The characteristics of the following age, the Mesozoic, had in part appeared before the Paleozoic ended; for Shrimps and perhaps Crabs, the highest of Crustaceans, had appeared, and Ammonoids among Mollusks; and Spiders and Insects, some of the latter even emulating large Birds in size, they having a spread of wing of two or three feet. There were also, along the water margins, Amphibians and the earliest of Reptiles, as precursors of Mesozoic life. Moreover, among plants, Cycads, which had their maximum display in Mesozoic time, were well represented by their earliest species in the later Paleozoic.

The extinction of species at the close of the Palcozoic was so nearly universal that, thus far, no species of the Permian period have been found in rocks of later date. But the rocks now in view were those that were made over the Continental seas, and, more correctly, over only portions of those seas; and hence they give no facts as to the species of the ocean, but an imperfect record of those of the Continental seas.

III. MESOZOIC TIME.

MESOZOIC TIME, or the Reptilian era, is divided into three periods: (1) the TRIASSIC, named from the Latin *tria*, *three*, in allusion to the fact that the rocks in Germany have three subdivisions; (2) the JURASSIC, named after the Jura Mountains between France and Switzerland, (3) the CRETACEOUS, named from the Latin *creta*, *chalk*, the formation including the chalk-beds of England and Europe.

The Mesozoic areas, on the map, page 136, are lined obliquely from the left above to the right below.

1. *Triassic and Jurassic Periods.*

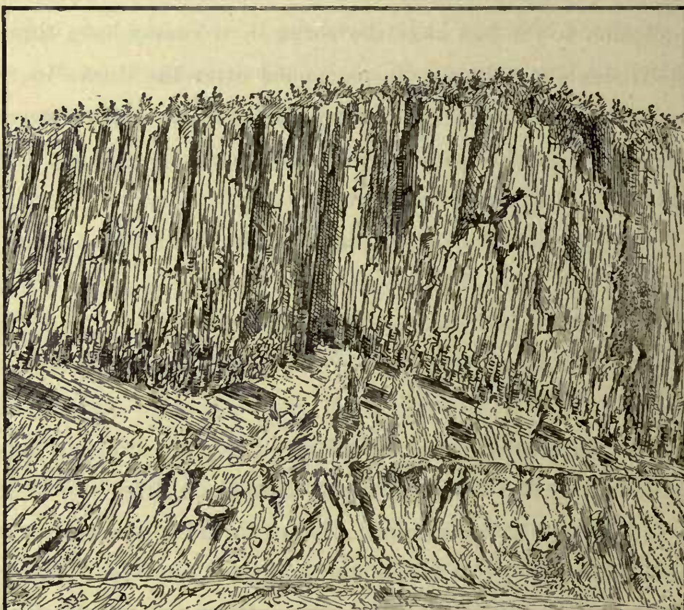
ROCKS.

These Triassic rocks on the Atlantic border occupy long, narrow areas, parallel with the Appalachian chain, from the Gulf of St. Lawrence southwestward. One of them lies along the east side of the Bay of Fundy; another, in the Connecticut valley from northern Massachusetts to New Haven on Long Island Sound; another, commencing at the north extremity of the region of the Palisades, extends through New Jersey and Pennsylvania into Virginia; and others occur in Virginia and North Carolina. These areas are indicated on the map on page 136.

The rocks are mainly red sandstones. In Virginia, near Richmond, and in the Deep River region, North Carolina, there are beds of mineral coal; and those of the Richmond basin have long been worked.

The beds contain no marine fossils; the few species that occur are either brackish-water, freshwater, or terrestrial. It hence follows that the long narrow ranges of sandstone were

Fig. 229.



West Rock, New Haven, Conn.

The columnar trap resting on upturned sandstone.

formed in valleys, parallel with the Appalachians, into which, for some reason, the sea did not gain full entrance; and the characters of the deposits show that they were made in some cases in great marshes, in others in the waters of lakes, estuaries, or river valleys.

Besides fragmental rocks, or those of *aqueous* origin, there were also dikes and ridges of *igneous* origin, called ordinarily *trap* dikes or ridges, from the rock constituting them.

The trap of the various regions stands up with a bold columnar front, as well exhibited in the Palisades, on the Hudson. An example is here represented in Fig. 229, from West Rock, in the vicinity of New Haven, Connecticut.

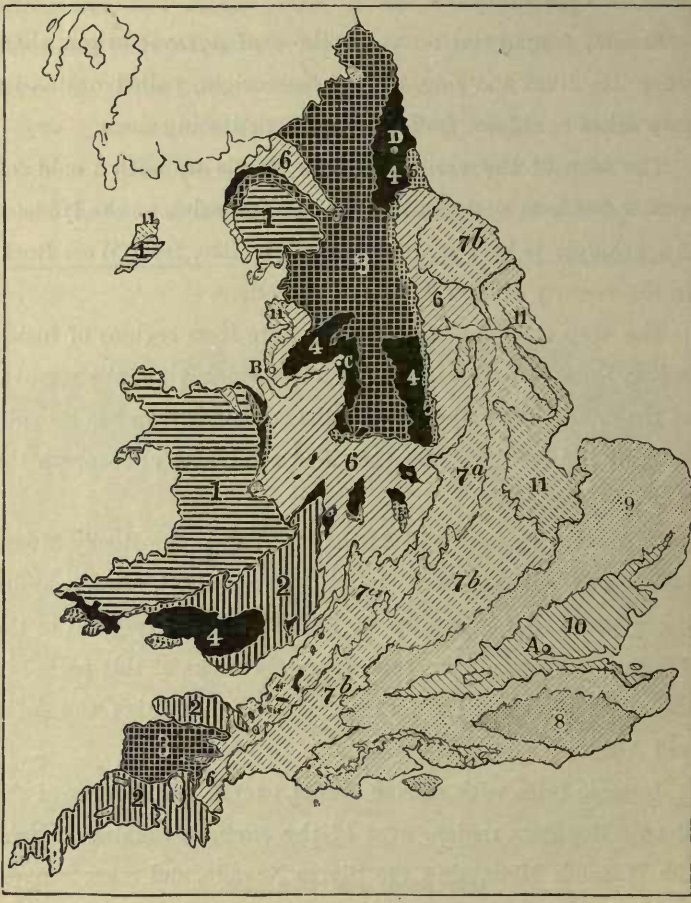
The trap came up in a melted state from regions of fusion below, through fissures. In the West Rock view, the removal of the débris below the base of the columnar trap has brought to light the fact that the stratified sandstone underneath the trap is upturned.

In western Kansas, and farther west over the Rocky Mountain region, red sandstone strata of great extent, often containing gypsum, but generally without fossils, are referred to the Triassic. Fossils have been found in rocks of this period in the Sierra Nevada, California, and also in British Columbia and Alaska.

Jurassic beds, with marine fossils, overlie the Triassic of the Rocky Mountain region, west of the summit, making in part the Wasatch Mountains, the Sierra Nevada, and other ranges.

In Great Britain the Triassic beds (No. 6 on the accompanying map, Fig. 230) were red argillaceous sandstones and clay rocks (marlytes) formed in a partly confined sea-basin. At Cheshire they contain a bed of rock salt derived from the

Fig. 230.

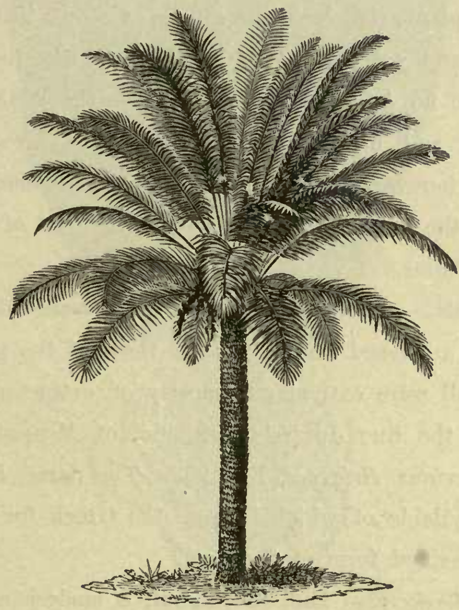


Geological Map of England.

The areas lined horizontally and numbered 1 are Siluro-Cambrian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oölyte (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London; B, Liverpool; C, Manchester; D, Newcastle.

evaporation of the waters of the sea-basin. The Jurassic rocks consist, below, of a limestone called the *Lias* (No. 7 *a*); other limestones above, called *Oölyte* (7 *b*), part of which is a coral-reef limestone, showing that there were coral-reefs in the British seas of the era; and near and at the top of the series, fresh-water or soil beds, called the Portland dirt-bed. The Oölyte is

Fig. 231.



Modern Cycad. — Cycas circinalis ($\times \frac{1}{20}$).

so named from the occurrence of beds of concretionary limestone, made up of minute spherical concretionary grains of the size of the roe of a small fish, the word coming from the Greek for *egg*.

As the Jurassic ended there were large areas of dry land and marshes in southeastern England.

Life.

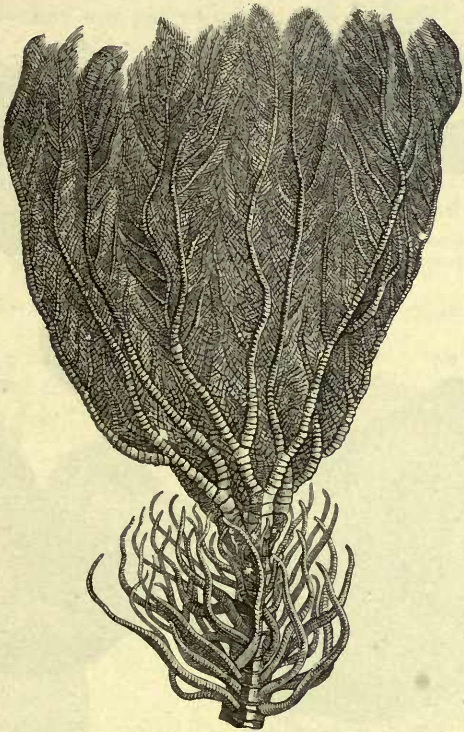
1. **Plants.** — The forests of Early and Middle Mesozoic time, while failing of Lepidodendra and related trees of the Coal era, abounded in Tree-ferns and Gymnosperms, and especially *Cycads,* — plants that look like Palms, as shown in Fig. 231 on page 213, and yet are true Gymnosperms, like the Conifers. There were no Angiosperms, — trees like the Willow, Maple, Oak, Elm, and others having net-veined leaves. Consequently, wherever Tree-ferns and Cycads predominated, the aspect of the forest was very much like that of a modern grove of Palms.

2. **Animals.** — The Corals and other *Radiates* had, for the most part, a general resemblance to those of the present era, although all were extinct and mostly of extinct genera.

One of the fine Jurassic Crinoids, of Mesozoic type, is the *Pentacrinus Briareus,* Fig. 232. The name *Pentacrinus,* the first syllable of which is from the Greek for *five,* refers to the five-sided form of the stem.

The *Mollusks* also had, in general, a modern aspect; and yet many kinds were especially Mesozoic in type. Some of these, among the Jurassic Lamellibranchs, are represented in Figs. 233–237. Fig. 233, a Gryphæa, is related to the Oyster, but has the beak incurved, as the name implies. Fig. 234 is another oyster-like species having the beak curved to one side, an Exogyra, the name referring to the bend in the beak. Fig. 235 is a true Oyster; Fig. 236, a Trigonia, the shell being approximately three-

FIG. 232.



Crinoid.
Pentacrinus Briareus.

sided. Fig. 237 is a Diceras,—a shell in which both valves are prolonged into a horn-like form, the name meaning *two horns*. *Cephalopods* were very abundant. The chambered shells of this tribe were in vast numbers under the type of *Ammonoids*, while there were also many Nautiloids. Fig. 238 represents a front view, and 239 a side view, of one of

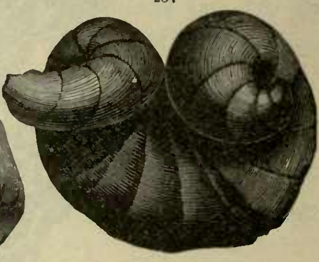
FIGS. 233-237.

233 235

234

236

237

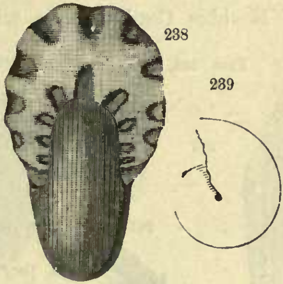


Lamellibranch Mollusks.

Fig. 233, Gryphæa incurva; 234, Exogyra virgula; 235, Ostrea Marshii; 236, Trigonia clavellata; 237, Diceras arietinum.

the earlier of the Ammonoids, — a Triassic species. The animal occupied the outer chamber of the shell, as in the Nautilus (Fig. 121, page 131). Fig. 238 shows the bottom of this outer chamber. Around its sides there are pocket-like depressions into which the mantle of the animal descended to enable it to hold on to its shell. Two other species of Ammonoids are represented in Figs. 240–242. Fig. 241 shows the pockets in the outer chamber of 240. The pockets are depressions in the partitions at their margins. Fig. 242 represents a species with the outer whorl unbroken and much prolonged. In the Devonian Ammonoids, called *Goniatites*,

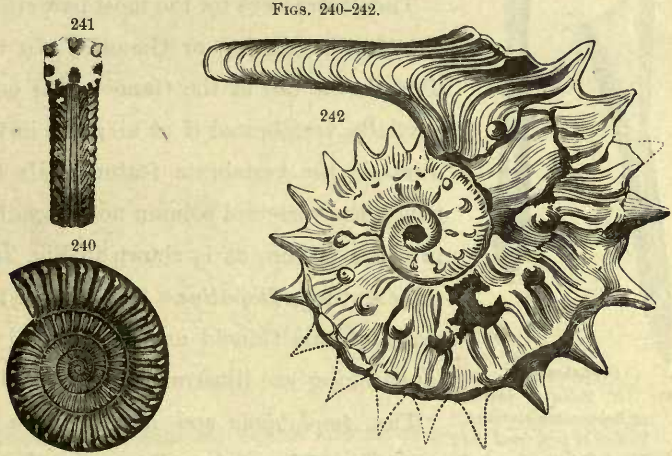
Figs. 238, 239.



Cephalopod.

Fig. 238, Ammonites tornatus; 239, side view of same, reduced one half.

Figs. 240–242.



Cephalopods.

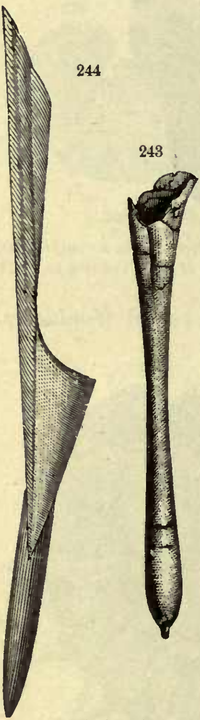
Fig. 240, Ammonites Buckiandi, from the Lias; 241, same in profile, showing outer chamber and its pockets; 242, A. Jason, from the Oölyte.

the pockets were simple in outline; while those of the later *Ammonoids* are mostly very complex. Fig. 268, page

231, shows the flexures in the pockets of a Cretaceous species.

Besides Cephalopods with external shells, there were also numerous species, related to the modern Squid (Fig. 120, page 130) in having an internal bone along the back, to give the body rigidity. This bone, but broken at the top, is represented in Fig. 243, and a perfect one in Fig. 244.

Figs. 243, 244.



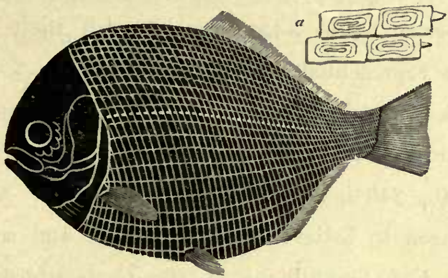
Cephalopods.
Fig. 243, Bone or osselet of Belemnites clavatus, broken at top, from the Lias; 244, the bone of a Belemnite having its upper extremity perfect.

The *Vertebrates* included Birds and Mammals, besides Fishes, Amphibians, and Reptiles.

The *Fishes* were for the most part either Selachians (Sharks) or Ganoids. In the Triassic the tail of the Ganoids was only partially vertebrated if at all; and in the Jurassic the vertebrate feature fails entirely, the vertebral column not extending into the tail-fin, as is shown in Fig. 245, representing a *Dapedius.* The form of the scales of this Ganoid and the method of interlocking are illustrated in Fig. 245 *a.*

The *Amphibians* and *Reptiles* were of great size and variety. Respecting American Triassic species much has been learned from their footprints on the surfaces of the finer layers of the sandstone of the Connecticut Valley. Some of the largest of the Reptiles walked as bipeds on feet that made tracks 16 to 20 inches long and nearly as broad, and had a

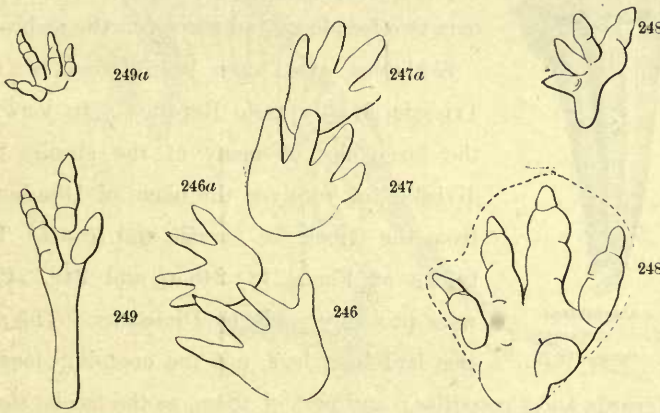
FIG. 245.



Ganoid Fish of the Genus Dapedius.

stride of three feet. Fig. 248 shows the form of the tracks. The impressions of the much smaller fore feet (Fig. 248 *a*)

FIGS. 246–249.



Tracks of Amphibians and Reptiles from the Connecticut Valley Sandstone.
Figs. 246–247, AMPHIBIANS: 246, 246 *a*, Anisopus Deweyanus (× ½); 247, 247 *a*, A. gracilis (× ⅔). Figs. 248–249, REPTILES: 248, 248 *a*, Otozoum Moodii (× $\frac{1}{18}$); 249, 249 *a*, Anomœpus scambus (× ⅓).

are occasionally found, showing that this huge biped sometimes brought them to the ground. Twenty-two consecutive tracks of the hind feet of one of these bipeds were laid open in 1874 at the Portland quarries, Connecticut. The feet, as is shown in the figure, were 4-toed.

Other species made 3-toed tracks with their hind feet, bird-like, as represented in Fig. 249.

The tracks of Amphibians also occur in the same region, and the hind and fore feet of some of them are represented in Figs. 246, 246 *a*, and 247, 247 *a*. All the Amphibians, there is reason to believe, had large teeth and scale-covered bodies, like the Amphibians of the Carboniferous age. A tooth of a related four-footed species from Europe is shown two thirds the natural size in Fig. 250. The head of the Amphibian that was thus armed was over two feet long, and three fourths as broad.

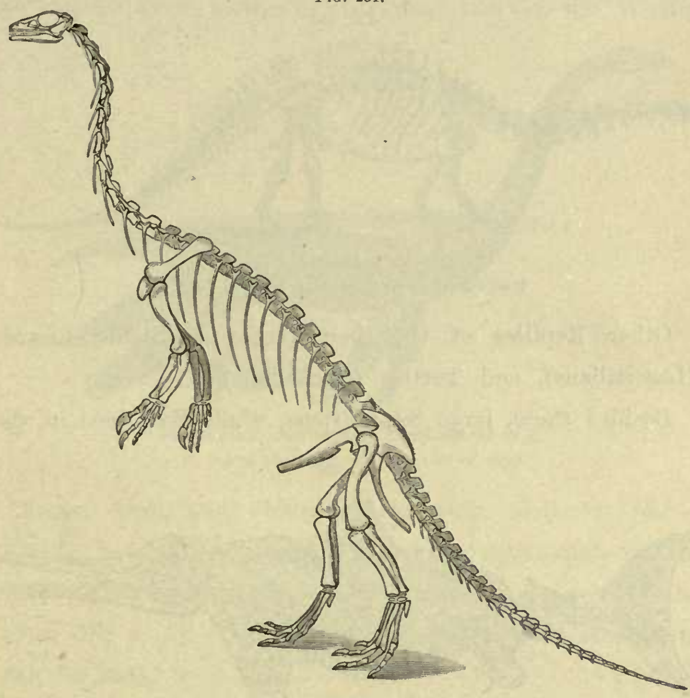
FIG. 250.

Amphibians.
Tooth of Mastodonsaurus. (× ⅔).

Skeletons also have been found of the Triassic and Jurassic Reptiles. In view of the large size of many of the species one division has received the name of Dinosaurs, from the Greek for *terrible* and *lizard*. The tracks of Figs. 248, 248 *a*, and 249, 249 *a*, were probably made by Dinosaurs. The species had long legs, not the creeping legs of Lizards and Crocodiles; and part of them, as the tracks show, walked in biped fashion, like Birds. Moreover, many of the bird-like kinds have the hind feet 3-toed, and so precisely like those of Birds that they were at first called bird-tracks.

The restored skeleton of one of the Reptiles of the Connecticut Valley, having hind feet with three well-developed toes, the innermost toe being small, and the outermost rudimentary, from a quarry not far from Hartford, is represented one twelfth the natural size in Fig. 251; and in Fig. 252, one

FIG. 251.



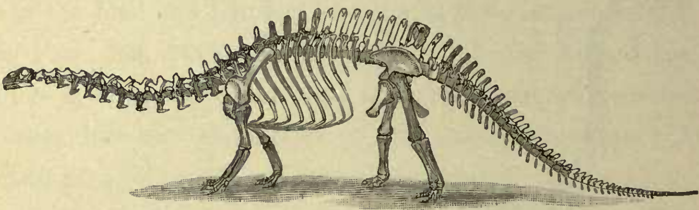
Dinosaur.

Restoration of Anchisaurus colurus Marsh ($\times \frac{1}{12}$).

of the 5-toed Reptiles, quadruped-like in locomotion, and 30 feet long, from the Jurassic beds of the Rocky Mountains. The *Megalosaur* was a related huge carnivorous species 25 to 30 feet long; and the *Iguanodons* and *Hadrosaurs,* equally large, were vegetable eaters.

The resemblance of the bipedal Dinosaurs to Birds was not merely in attitude and external form, but extended to a number of anatomical details in the pelvis and the hind limb.

FIG. 252.

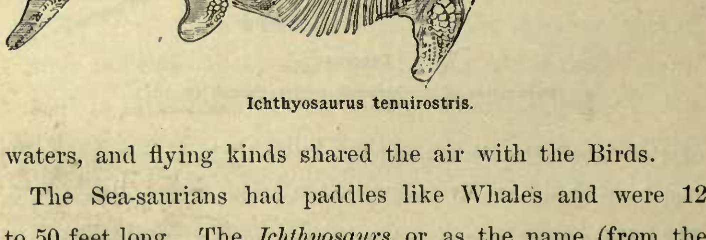


Dinosaur.
Restoration of Brontosaurus excelsus (× $\frac{1}{80}$).

Other Reptiles of the time were Crocodilians, Lizards (Lacertilians), and Turtles (Chelonians).

Besides these, large Sea-saurians, whale-like, lived in the

FIG. 253.



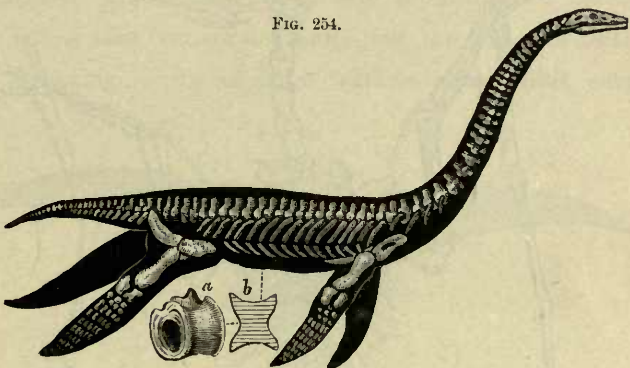
Ichthyosaurus tenuirostris.

waters, and flying kinds shared the air with the Birds.

The Sea-saurians had paddles like Whales and were 12 to 50 feet long. The *Ichthyosaurs,* or, as the name (from the

Greek) signifies, Fish-lizards (Fig. 253), had a short neck, very large eyes, and thin vertebræ that were concave on both sides, resembling those of Fishes. Recently discovered specimens have shown that they possessed a large caudal fin, and smaller fins along the back, giving the body an aspect even more fish-like than that of the Whales.

Fig. 254.



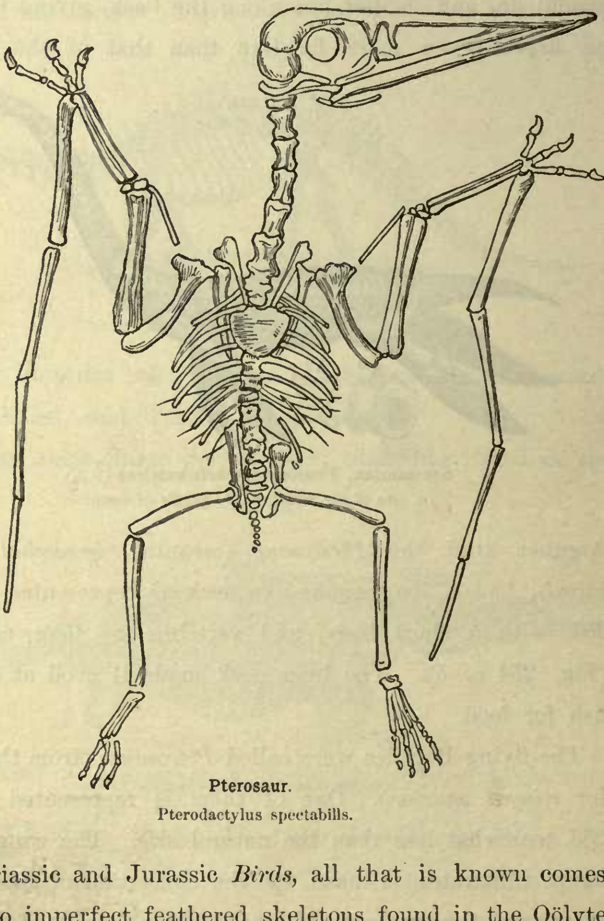
Sea-saurian, Plesiosaurus dolichodeirus ($\times \frac{1}{80}$).
a, one of the vertebræ; *b*, profile of same.

Another kind, the *Plesiosaur* (meaning, *somewhat like a lizard*), had a long snake-like neck as represented in Fig. 254, with a short body, and vertebræ as long as broad (Fig. 254 *a*, *b*). The long neck made it good at catching fish for food.

The flying Reptiles were called *Pterosaurs* (from the Greek for *winged saurian*). One of them is represented in Fig. 255, somewhat less than the natural size. The wing, as the figure illustrates, is made by the elongation of one of the fingers and the expansion of the skin from the side of the body.

Another species, from Solenhofen, Bavaria, had a long tail, with a bladed extremity, for use as a rudder; it is represented on the wing, in Fig. 256, from a restoration by Professor Marsh.

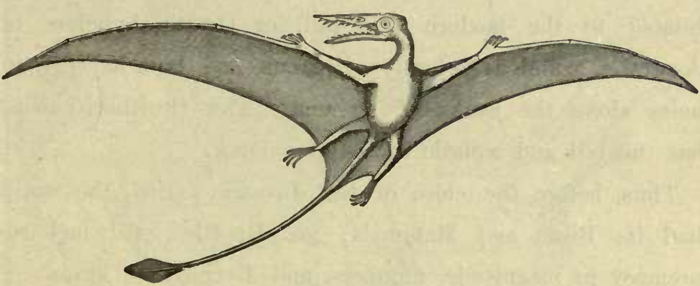
Fig. 255.



Pterosaur.
Pterodactylus spectabilis.

Of Triassic and Jurassic *Birds*, all that is known comes from two imperfect feathered skeletons found in the Oölyte of Solenhofen, and a fragment of a skull from Wyoming. Yet, as the remains of Birds are the rarest of fossils — because they are fragile terrestrial species, and good food for all carnivorous life — these few specimens are good evidence that not only Europe, but also the other continents, abounded in Birds during the Jurassic period, if not earlier. These early Birds were reptile-like in having teeth, and a long vertebrated tail; but the tail was feathered, it having a row of large feathers along either side;

FIG. 256.

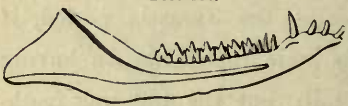


Rhamphorhynchus phyllurus (× ¼).

they also had the metacarpal bones free, as in Reptiles, not grown together, as in modern Birds.

Remains of Mesozoic *Mammals* have been found in the Triassic beds of Germany and North Carolina, and in the Jurassic of England and Wyoming. Fig. 257 represents a jaw-bone from North Carolina, twice the natural size. The species are of the lower divisions of Mammals, the *Monotremes* and *Marsupials*, and they are all small, like Rats and Mice. Examples of modern Marsupials are the Kangaroo of Australia and the Opossum of America. They are *semi-oviparous* species, that is, kinds whose young are in an immature state when born, approximating in this respect to the egg-stage, an egg being an example of extreme immaturity. They are peculiar in having a pouch (*marsupium*, in Latin), on the under side of the body, for receiving the immature young. In addition to Marsupials, there were the still lower Mammals, the *Monotremes*, related to the modern Duck-bill, or Ornithorhynchus, of Australia, which is actually oviparous, and lays its eggs in holes along the banks of streams. The Ornithorhynchus has the bill and aquatic habits of a Duck.

Fig. 257.



Mammal.
Dromatherium sylvestre.

Thus, before the close of the Jurassic period, the world had its Birds and Mammals; yet Reptiles still had supremacy in magnitude, numbers, and diversity of kinds.

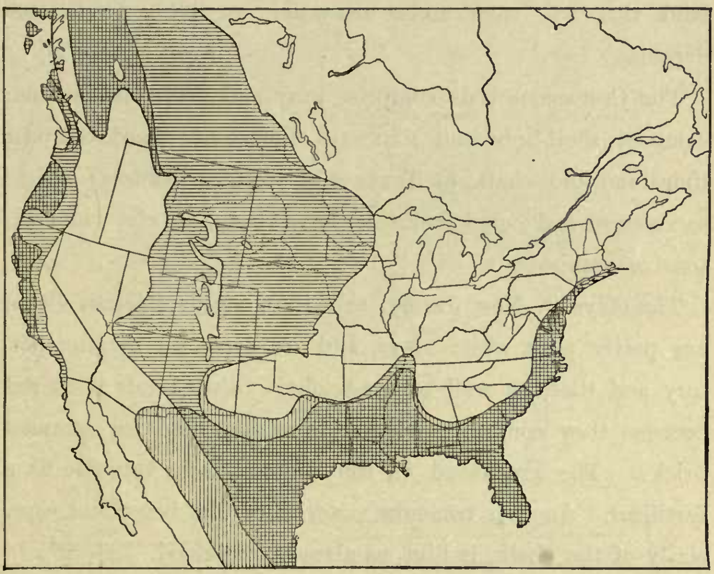
2. *Cretaceous Period, or Later Mesozoic.*

Rocks.

At the opening of the Cretaceous Period a subsidence of the Atlantic borders south of New York, and of the borders of the Gulf of Mexico was begun. At first, fresh-water deposits, called the Potomac formation, were made along the coast. But afterward, during the Middle and Later Cretaceous, as the subsidence increased, the waters of the Atlantic spread over the border, and beds with marine fossils were made.

This reappearance of marine conditions along the old coast was a great event in geological history; for the last preceding marine beds over the coast region were those of the Lower Silurian.

FIG. 258.



North America in the Cretaceous Period.

Vertical lining indicates submergence during the Lower Cretaceous; horizontal lining, submergence during the Upper Cretaceous; cross-lining, submergence throughout the Cretaceous.

The marine beds, moreover, spread widely over the northern and western border of the Gulf of Mexico; up the Mississippi Valley, to the mouth of the Ohio; from Texas northward over Kansas and a large part of the eastern slope and summit region of the Rocky Mountains, and probably to the Arctic Ocean. They extended also over the Pacific border west of the Sierra Nevada.

The outline of the continent at the time these marine beds were in progress is shown on the map on page 227, Fig. 258, the shaded portion being the part of the land that was then under sea-water, receiving Cretaceous deposits.

The Cretaceous beds comprise gray and green sandstones; compact shell-beds and "rotten" limestone; hard compact limestone and chalk in Texas and western Kansas; coarse sandstones and conglomerates; large beds of clay; and extensive coal-beds.

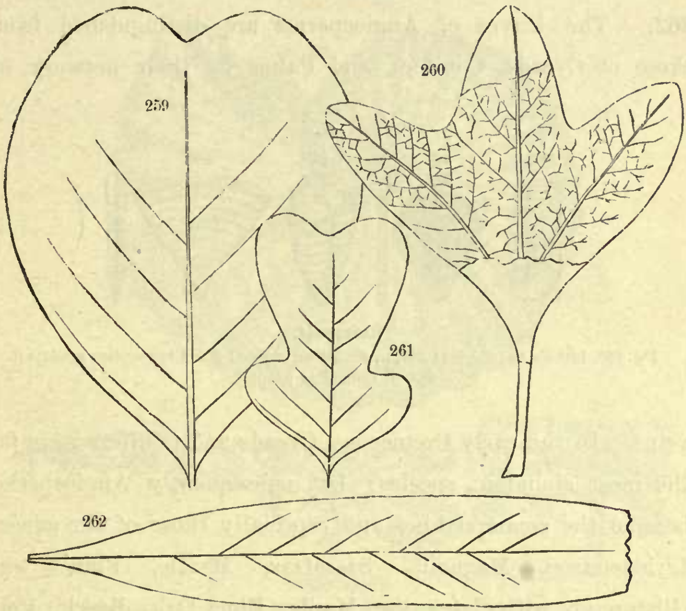
The clays in New Jersey, called Amboy or Raritan clays, are partly pure white clays, and are used for making pottery and tiles, as well as fire-bricks. Other kinds burn red because they contain iron, and these are used for common bricks. The greensand of the Cretaceous is valuable as a fertilizer. Another common material of the beds, and especially of the chalk, is flint, as already explained.

The coal-beds occur in the Upper Cretaceous. The coal is good bituminous coal, much like that of the Carboniferous period, and is mined at many places in Colorado, Utah, Montana; and also to the north in British America and to the west on Vancouver's Island, in British Columbia.

LIFE.

The Cretaceous period, the last of the Mesozoic, was a time of transition in the world's life, the Vegetation, the Fishes, and the Birds coming out under more modern forms, and Dinosaurs, Pterosaurs, and Ammonoids ending with it their career.

FIGS. 259-262.



Angiosperms (or Dicotyledons).

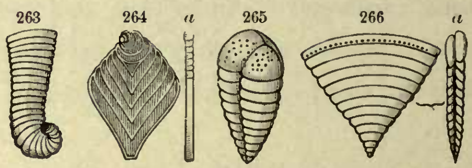
Fig. 259, Liriodendron primævum; 260, Sassafras cretaceum; 261, Liriodendron Meekii; 262, Salix Meekii.

1. **Plants.** — The great changes in the vegetation consisted in the introduction (1) of Palms and other related species, and (2) of plants of the tribe of Angiosperms.

The Angiosperms include the Willow, Elm, Maple, Currant, Rose, and thousands of species that are especially characteristic of the forests and prairies of the present day. They are called *Angiosperms* from the Greek for *vessel* and *seed*, the seeds being *covered*, as that of the Pea or Bean in its pod, of the Walnut in its husk, and so on.

Leaves of some of the species are represented in Figs. 259–262. The leaves of Angiosperms are distinguished from those of Cycads, Conifers, and Palms by their network of

FIGS. 263–266.



Rhizopods.

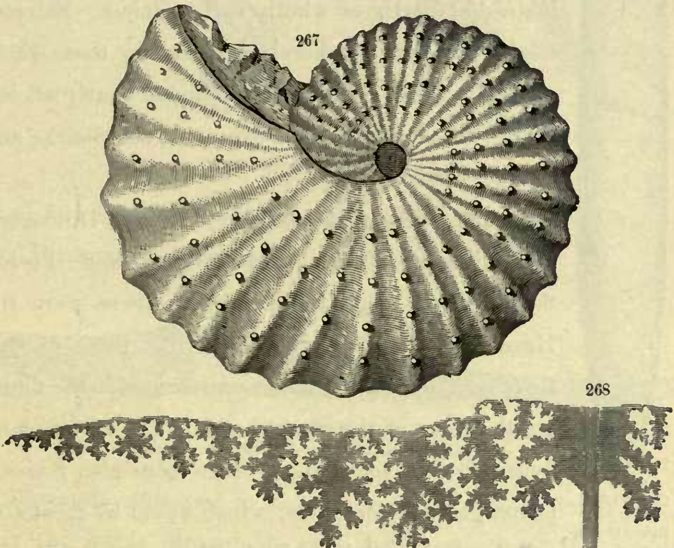
Fig. 263, Lituola nautiloides; 264, *a*, Flabellina rugosa; 265, Chrysalidina gradata; 265, *a*, Cuneolina pavonia.

veins. In the early Cretaceous, Cycads and Conifers were far the most abundant species; but subsequently Angiosperms became the common kind and especially those of the genera Liriodendron, Magnolia, Sassafras, Myrtle, Plane tree (Platanus), with later the Maple, Elm, Oak, Beech, Poplar, and other kinds. At this time appeared also the first of Palms.

The change was great in the foliage of the forests, and the world was also adorned for the first time with beautiful flowers, and enriched with edible fruits, — a promise of the better time when Birds and Mammals should be at the head.

2. **Animals.** — Among Protozoans, Rhizopods were very efficient species in rock-making, the chalk consisting chiefly of their minute shells. A few of the species are represented, much enlarged, in Figs. 263–266.

Figs. 267, 268.



Cephalopods.
Fig. 267, Scaphites Conradi; Fig. 268, series of pockets in Ammonites (Placenticeras) placenta.

Mollusks continued to include great numbers of Ammonoids, and Belemnites. One of the former is shown in Fig. 267, and the pockets in the partitions of the shell of another common species in the dark parts of Fig. 268.

Fig. 269 shows the form and size of a very common Belemnite from the Cretaceous beds of New Jersey.

FIG. 269.

Cephalopod.
Belemnitella Americana.

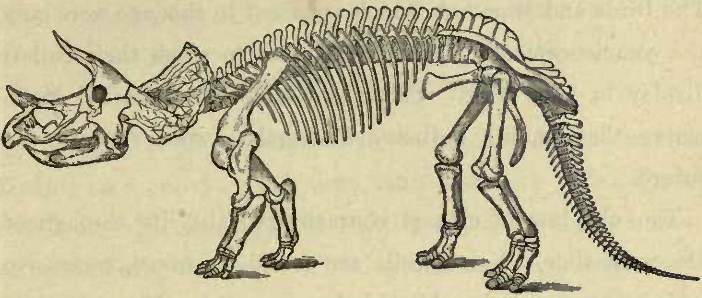
Fishes were represented still by Sharks and Ganoids. But with these existed the earliest unquestionable examples of the modern type of Fishes called Teleosts, so named from the Greek for *complete* and *bone*, the skeleton being bony throughout, instead of partly or wholly cartilaginous. Salmon, Perch, Herring, Mackerel, were among these earliest of Teleosts. The tribe includes nearly all the Fishes in modern waters excepting the Sharks and related kinds.

Reptiles were represented by various Dinosaurs, Crocodilians, Turtles, Sea-saurians, and Flying Saurians. Among the Dinosaurs there were the Horned Dinosaurs, having horns like those of Cattle (Fig. 270); for the horns represented in the figure are the cores of the actual horns. The species here figured was 15 feet long. There were also Sea-serpents, called *Mosasaurs*, which swam by means of paddles and were 15 to 50 feet long.

The Flying Saurians, or Pterosaurs, resembled much those of the Jurassic; but some of them were without teeth, like Birds. The largest had a spread of wing of 25 feet.

Birds were advanced in structure through the loss of the low-grade member, a long tail, and in acquiring the modern structure of the hand. But some of them still had teeth along the jaws, much like those of a Reptile (Fig. 271), and

Fig. 270.



Dinosaur.
Restoration of Triceratops ($\times \frac{1}{16}$).

some had biconcave vertebræ like a Fish. Among the toothless Birds were Cormorants and Waders.

Fig. 271.

Bird.
Jaw of Hesperornis regalis, showing the teeth.

Mammals continued to include, as far as discovery has gone, only the feeble Marsupials and Monotremes, and the fossils are mostly jaws, much like that figured on page 226.

Progress in Life During the Mesozoic.

Thus all the classes of Vertebrates had, in Mesozoic time, their species. In the Triassic, its first period, the Amphibians passed their climax in numbers, size, and grade, little being afterward known of the huge, scale-covered tribe. But during the following periods Reptiles had their time of greatest expansion, the earth, air, and waters being in their possession. The Birds and Mammals which appeared in this age were only the commencement of tribes that were to reach their fullest display in later time. Cattle and all other Placental Mammals — that is, all ordinary Mammals — were still in the future.

The old law of change characterized the life throughout Mesozoic time. New fossils are found in every successive rock-stratum, and also older kinds are missed. The system of life was in course of expansion by the introduction of new species and a casting off of the old.

Mountain-making in Mesozoic Time.

The Sierra Nevada and some ranges to the north in British America were made at the close of the Jurassic. The strata of the mountain region to the top of the Jurassic were folded up in the making of the mountains. But the height then attained, instead of being, as now, 14,000 feet or more, was probably less than 5000 feet. At the same time, or earlier, the Triassic rocks of the Atlantic border in the Connecticut River Valley and elsewhere were slowly upturned; and as the upturning made progress, great fissures, parallel in course nearly to the longer axis of the areas, were opened and the liquid trap rock came up. During the formation of the sandstone a slow subsidence was in progress, as is proved by the footprints on the surfaces of layers and other markings, these showing that the layers — originally mud-flats and sand-flats — were *successively* at the water level.

The Post-Mesozoic Revolution.

The close of the Mesozoic time was followed by mountain-making on a grander scale even than that with which Paleozoic time was closed and by equally extensive disappearance of species over the world. The mountains which were made at this epoch extend along the whole line of the summit region of the Rocky Mountains from near the Arctic Ocean to Central Mexico — a distance exceeding 4000 miles. They constitute the Laramide Mountain system, and include the Wasatch range of western Utah; other ranges to the north of Montana in British America; and others to the southward over a wide reach of country, through New Mexico and Mexico beyond.

It is also probable that in South America at this same time, another system of ranges of as great a length was made along the Andes, and that consequently the mountain-making movements of America at the close of the Cretaceous extended through nearly one third of the earth's circumference.

Until the beginning of these movements the Rocky Mountain region was mostly beneath the salt water; for the upper Cretaceous beds contain marine fossils. Further, during its later part, there were alternate emergences and submergences of the land which favored the making of the many great coal-beds.

With the completion of the mountains, the region of the great Interior Continental sea of Cretaceous time made its final emergence from the salt water, excepting perhaps the area of the Great Salt Lake of Utah and some other similar patches.

Emergence of the *eastern* half of North America was one of the great events at the close of Paleozoic time; and so the emergence of the *western* half marked the close of Mesozoic time. Moreover, the Mesozoic, like the Paleozoic, finished its rock-making work with the accumulation of great coal-beds — the western, like the eastern, of incalculable value to the country.

The disappearance of the life of the world at this crisis was so extensive that no marine species of the Cretaceous period have yet been certainly found in any rock of the following period. This is another great feature in which the Post-Mesozoic revolution was like the Post-Paleozoic. Here ended the Reign of Reptiles, all the characteristic Mesozoic kinds, the Dinosaurs, Sea-saurians, Pterosaurs or flying species, and others becoming extinct. The Ammonoids also, and the Belemnites, with many of the genera of other tribes of Mollusks, disappeared. Among plants, the Cycads, which were a prominent feature of the Mesozoic forests in the early Cretaceous, even on Arctic lands, later retreated southward and became confined to the warm temperate and tropical zones, where the few now existing are still to be found.

As in other such exterminations, the extinction of life was not universal. Large regions suffered little from the exterminating cause, as the survival of the genera and families prove. All that can be affirmed is, that the fossils of the Tertiary era, the next after the Cretaceous, contain, so far as yet discovered, no *marine* Cretaceous species.

IV. CENOZOIC TIME.

CENOZOIC TIME comprises two eras: —

1. The TERTIARY ERA OR THE REIGN OF MAMMALS.
2. The QUATERNARY ERA OR THE REIGN OF MAN.

1. *Tertiary Era.*

The Tertiary era is divided into three periods: (1) the EOCENE; (2) the MIOCENE; (3) the PLIOCENE. These terms, which are derived from the Greek, signify, severally, (1) the *dawn of recent time;* (2) the *less recent;* (3) the *more recent.*

The areas over which the marine Tertiary rocks of North America and England occur are shown on the maps, pages 136 and 212.

ROCKS.

As the salt waters had left the Continental Interior at the close of the Cretaceous, the marine rocks of the Tertiary were confined to the borders of the continent. But the Interior was still a region of extensive rock-making through the agency of vast *freshwater lakes.* The map on page 238, Fig. 272, shows the position of the *sea-border* Tertiary, and also of the great lakes and *lacustrine* beds of the Interior.

In the early Tertiary, the rivers of the eastern part of the continent, or those contributing waters and sediment to the Atlantic, may have had half or two thirds of their present

Fig. 272.

Map of North America in the Tertiary Period.

Vertical lining shows submergence in the Eocene; horizontal lining, submergence in later Tertiary; cross-lining, submergence throughout the Tertiary.

extent; but the Ohio and Mississippi were still independent streams, emptying together into an arm of the Mexican Gulf. The Missouri and other western streams were just beginning to be.

During the Eocene, or early Tertiary, the Rocky Mountains were but little elevated; for great lakes then occupied much of the summit region, in Utah, Colorado, Wyoming, and New Mexico. Later, as the land rose, these summit lakes disappeared, and there were great Miocene lakes over what is now the eastern slope of the mountains, from northern Nebraska to Mexico. On the map the Eocene lakes are marked by vertical, the Miocene by horizontal, lines.

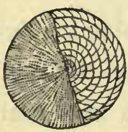
The North American Tertiary consequently comprises vast *freshwater* formations as well as *marine.*

Marine beds of the Eocene period were formed on the Atlantic border south of New York, and on the borders of the Mexican Gulf; but marine Miocene and Pliocene only on the Atlantic border, from New York to Florida, some change of level having excluded them from the Gulf border west of Florida. On the Pacific border also there are areas of marine Tertiary. At the base of the marine Eocene beds of the Lower Mississippi there are *Lignitic* beds, that is, beds containing lignite (a kind of mineral coal retaining usually something of the structure of the original wood) alternating with beds that are partly marine, the whole indicating that freshwater marshes there alternated with freshwater lakes and salt seas; for the Lignitic beds were once beds of vegetable débris such as are formed in marshes.

The *freshwater* Tertiary beds are the lacustrine formations of the great lakes of the Rocky Mountain region already mentioned. The most western are situated in Oregon. Immense numbers of bones of Mammals and many entire skeletons have been obtained from these beds, showing that the shores of the lakes were the resort of wild beasts, some of them of elephantine size.

In Great Britain marine Eocene Tertiary beds occur in the London and Hampshire basins, and on eastern seashores a thin Pliocene stratum, but no marine Miocene is found. Over Europe and Asia the Eocene formation was widely distributed, showing that these continents, even as late as the early Tertiary, were largely under the sea. The Pyrenees, Alps, Apennines, Carpathians, and the highest mountains of Asia were partly made of them. The beds in many places contain or consist largely of coin-shaped Foraminifers, or Rhizopod shells, called *Nummulites*, varying from half an inch to one inch or more in diameter. The beds are often called *Nummulitic limestones.* The limestone of which some of the Egyptian pyramids are built is made up chiefly of Nummulites. One of them is represented in Fig. 273; the exterior is partly removed to show the cells of the interior, that were once occupied by the minute Rhizopods. Some species of a related genus occur in modern coral seas. They must have been exceedingly abundant over the great Continental seas of the Tertiary.

Fig. 273.



Nummulite.

Miocene beds have a thickness of several thousand feet in Switzerland (constituting the Rigi and some other summits), and occur in many other parts of Europe; but they are limited in area compared with the Eocene. Marine

Pliocene beds are of still less extent, yet have a thickness in Sicily of 3000 feet.

The rocks of the marine Tertiary are very various in kind. The larger part are soft sand-beds, clay-beds, and shell deposits, the shells often looking nearly as fresh as those of a modern beach. Other beds consist of moderately firm sandstone. There are also loose and firm limestones. The greensand called "marl," used as a fertilizer, which is so characteristic of the Cretaceous, also constitutes beds in the Tertiary of New Jersey.

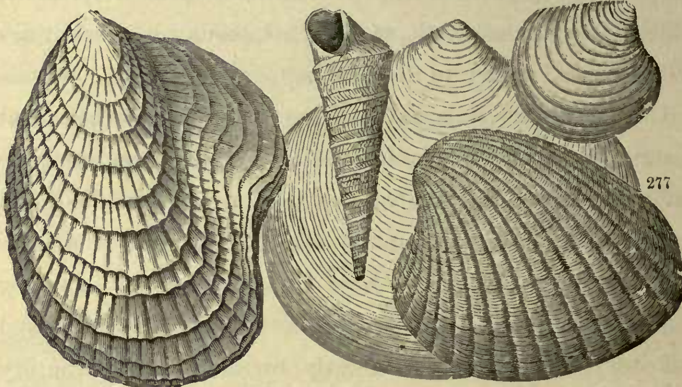
The freshwater beds are like the softer marine beds, but contain, of course, no marine shells. Part of them are quite firm; but others are easily worn by the rains. Some great areas in the Rocky Mountain region, both over the summit and the eastern slope, have been reduced by denuding waters to areas of isolated ridges, towers, pinnacles, and table-topped hills, that are mostly barren, owing to the dry climate, and which are therefore called "Bad Lands," or in French (in which language the expression was first applied), "Mauvaises Terres."

Life.

The life of the Tertiary shows in all its tribes an approximation to that of the present time. The Mammals, and probably the Birds, are all of extinct species. But among the plants and the lower orders of animals there were many species that still exist: in the Eocene, a small percentage; in the Miocene, 25 to 40 per cent; and in the Pliocene, a much larger proportion. The common Oyster was living in the Pliocene, and the Clam as far back as the Miocene period, along with a large number of species of shells that are now extinct. Progress through the Tertiary era was gradual in all departments.

Figs. 274–278.

274 278 275 276



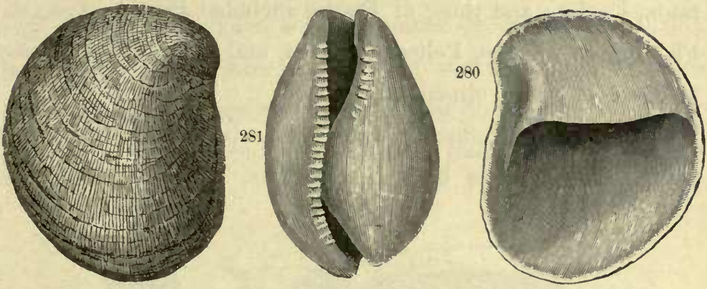
Eocene of Alabama.

Fig. 274, Ostrea sellæformis; 275, Crassatella alta; 276, Pteropsis Conradi; 277, Venericardia planicosta; 278, Turritella carinata.

The forests of North America and Europe were much like the modern, but with a larger proportion of warm-climate forms, especially in the Early Tertiary. Through the Eocene, Palms flourished over Europe and England. In the Miocene the European species were still those of a warmer climate than the present, and included some Australian species. Even in the Arctic zone there were in the Miocene great forests of Beech, Oak, Poplar, Walnut, and

Redwood (or Sequoia, the genus to which the "great trees" of California belong), with Magnolias, Alders, and others.

Figs. 279–281.

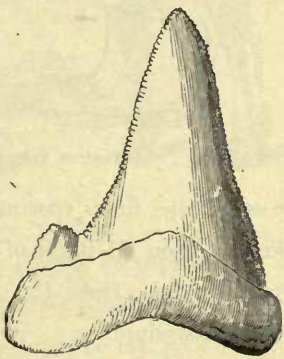


Miocene of Virginia.

Figs. 279, 280, Crepidula costata; 281, Cypræa Carolinensis.

The modern aspect of the marine shells is shown in the accompanying figures: Figs. 274–278 represent American Eocene species, and 279–281, Miocene from the Atlantic border.

Fig. 282.



Shark's Tooth.
Carcharodon angustidens.

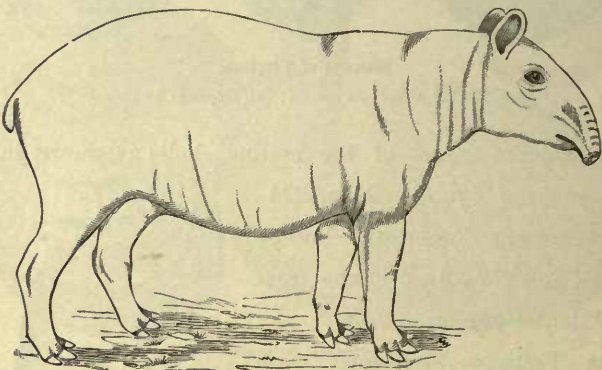
The Tertiary *Vertebrates* were less like the modern than the Invertebrates. Among Fishes, Sharks were exceedingly abundant, and their teeth, the most enduring part of the skeleton, are very common in some of the beds. Those of one kind, pointed, triangular in form, were nearly as large as a man's hand. One of the smaller of these teeth is represented in Fig. 282.

The true *Reptiles* were Crocodiles, Lizards, Turtles, some of gigantic size, and Snakes.

Among the *Birds* there were Owls, Woodpeckers, Cormorants, Eagles; and those of France included Parrots, Trogons, Flamingoes, Cranes, Pelicans, Ibises, and other kinds related to those of warm climates.

The common *Mammals* were the ordinary non-Marsupial kinds. The Eocene beds about Paris, France, afforded to

FIG. 283.



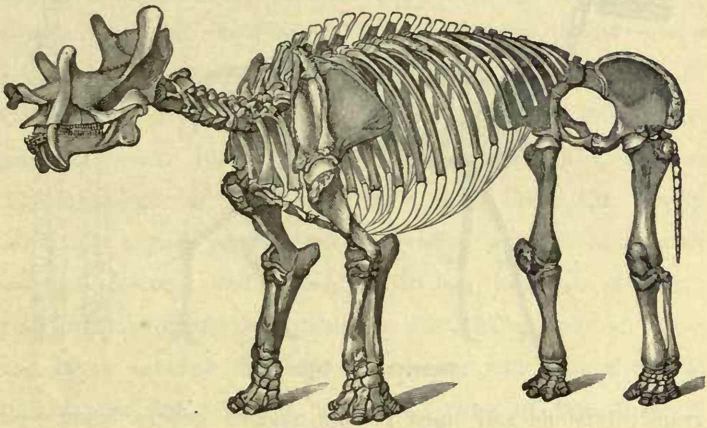
Tapirus Indicus, the Modern Tapir of India.

Cuvier the first specimens described; and now they are known from all parts of the world, and from none in greater variety than from the freshwater Tertiary region west of the Mississippi.

Some of the Eocene kinds were related to the modern Tapir (Fig. 283), Hog, Rhinoceros, and Hippopotamus.

The earliest species appear to have had the full number of toes, *five*, to both the fore and hind feet, typical of Mammals, and also the full number of teeth, *forty-four;* while most of the later species have a less number of teeth, and most of the hoofed, or ungulate, species, and some of the clawed, or unguiculate, species, have a less number of toes. The Tapir, here figured, has three toes behind and four in front; and the Hog and Hippopotamus, each four to all the feet; Camels, Cattle, and Sheep, two to each foot; and the modern Horse, but one.

FIG. 284.



Tinoceras ingens.

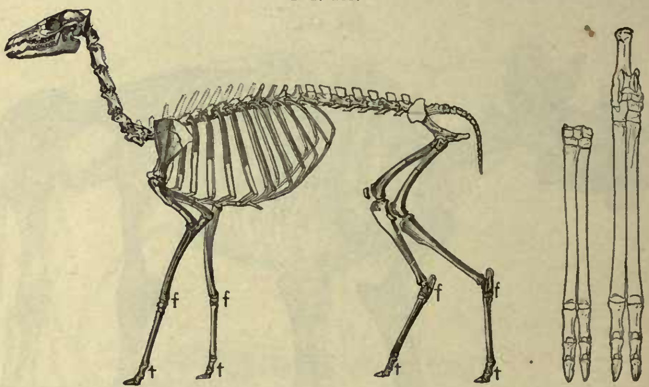
One of the strange beasts of the Eocene is represented in Fig. 284. It had three pairs of horns, feet somewhat like those of an Elephant, and a length, exclusive of the tail, of 12 feet.

The Miocene beds of North America have afforded remains of 3-toed Horses, of extinct species related to the Tiger, Wolf, Rhinoceros, Camel or Llama (Fig. 285), Deer, Mastodon, Squirrel and Beaver.

In the Pliocene beds of North America occur remains of true one-toed Horses, Camels, Mastodons, and various other species — all of them extinct, like those of the Miocene and Eocene. In the Pliocene of other lands occur species of Elephant, Bear, Horse, Antelope, Stag, Sheep, Ox, etc. Cattle related to the Ox do not occur earlier than the Pliocene.

The Mammalian type was at last very fully displayed, its

Fig. 285.



Poebrotherium labiatum.

grand divisions and most of the modern genera being well represented. But the maximum display of the brute races took place *still later*, in the early or middle Quaternary, after Man had appeared.

Mountain-making during the Tertiary.

During the later part of the Tertiary, the loftiest mountains of the world received the greater part of their present elevation.

In North America, the amount of actual upturning was small compared with that at the close of the Cretaceous period. There were low mountains made after the Miocene on the coast region of the Pacific; and some of the Miocene lacustrine areas were upturned. But besides these local events, a lifting of the Rocky Mountains as a whole from the far North to Central America was begun, which continued on through the Tertiary and ended in raising the great area from near the sea level — where it was, as fossils prove, at the close of the Cretaceous period — to a height of 10,000 feet above it in Mexico, 16,000 feet in Colorado (nearly 2000 feet of this height since lost by denudation), and 10,000 to 4000 feet in British Columbia. The existence of vast freshwater lakes over the Rocky Mountain region proves that the rising went forward with extreme slowness, and probably with long intervals of delay; that little progress was made in the Eocene period, when the lakes covered the summit region; and that the final height was not attained before the close of the Pliocene, the last period of the Tertiary. During the same time the Andes received an addition to their height of 20,000 feet in Ecuador and of many thousands in less elevated portions.

In Europe the Pyrenees experienced extensive upturnings near the close of the Eocene, and the Alps and Juras after the Miocene; and now the rocks before submerged are 10,000 and 12,000 feet above sea level. In Asia, upturning began in the Himalayas, after the Miocene, and a rise followed of 20,000 feet.

During Tertiary time, moreover, and especially in the Miocene period, great eruptions of igneous rocks took place over the western slope of the Rocky Mountains, covering thousands of square miles. The deep fractures were probably then opened which gave origin to the volcanoes Mount Shasta, Mount Hood, and other summits in the Cascade range. So also along the coast of Ireland and of Scotland, and the Inner Hebrides to the Faroe Islands, the eruptions were of great extent. Fingal's Cave and the Giant's Causeway date from this period.

This epoch of great eruptions in the Rocky Mountains appears to have begun before the close of the Cretaceous period, and to have had a climax during the making of the Laramide Mountain system. At this time also the rich silver and lead veins of the Rocky Mountains, from Wyoming to central Mexico, were probably made; and probably also those of like character and richness along the Andes. The eruptions of the Miocene period, however, seem to have been on a still larger scale. The great Continental uplifting of the closing Tertiary was a prelude to the grand events of the opening Quaternary.

Climate.

During Mesozoic time the Arctic zone was warm enough for great Reptiles, — warm-climate species; and the British seas, for coral-reefs.

The Eocene era also was one of warm climate over Great Britain, — for England was then a land of Palms; and Palms continued to flourish over middle and southern Europe during the Miocene. Through both the Eocene and Miocene the Arctic lands were covered with forests, and hence the Arctic climate must have been comparatively warm, — not colder at least than the present climate of the middle United States and northern Prussia. There was a cooling off with the progress of the Miocene, and by the close of the Tertiary the earth had probably its frigid, temperate, and torrid zones, nearly as now.

2. *Quaternary Era.*

The geological work of the Quaternary was widely different from all that had preceded it in the earth's progress. With the close of the Tertiary, the continent which was begun in the nucleal **V** of Archæan time (map, page 139, Fig. 124) was finished out very nearly to its present limits; and at its close the Tertiary formation of the sea-border was added to the dry land.

This accomplished, the Quaternary opened. Agencies were now at work over the broad surface of the continent — its dry land, and not its Continental seas, as formerly, — transporting southward gravel and earth from regions to the north, in order to cover the hills with gravel and soil and fill the valleys with alluvial plains. Over large areas in both Europe and America transportation went forward from the high latitudes southward, except where there were mountains sufficiently lofty to be sources of independent movements. Hills and valleys were no impediment to the great agent engaged in this immense continental system of transportation. The aid of the ocean was not needed in these movements, and was not given except to a small extent along its borders.

After these great results were attained, the more quiet work of the rivers went forward; and finally, through this and other agencies, in connection with some change of continental level, the earth assumed slowly its present perfected condition of surface and climate.

The age is divided into three periods: (1) the Glacial period; (2) the Champlain period; (3) the Recent or Terrace period. The Glacial and Champlain periods are also called together, the Pleistocene period.

1. **Glacial Period.** — The general facts are these: —

1. *Glacial Phenomena.* — In America and Europe, over the northern latitudes, sand, gravel, stones, and masses of rock hundreds of tons in weight are found, from a few miles to a hundred and more, south of the region whence they were derived. This transported material is called *drift*, and the stones or rocks, *bowlders*.

In North America, the region over which the transportation took place embraced the whole surface of the more northern latitudes from Labrador or Newfoundland to the eastern part of Nebraska; and it extended southward to the parallel of 40° north latitude, and beyond this in Illinois, Kansas, and Missouri.

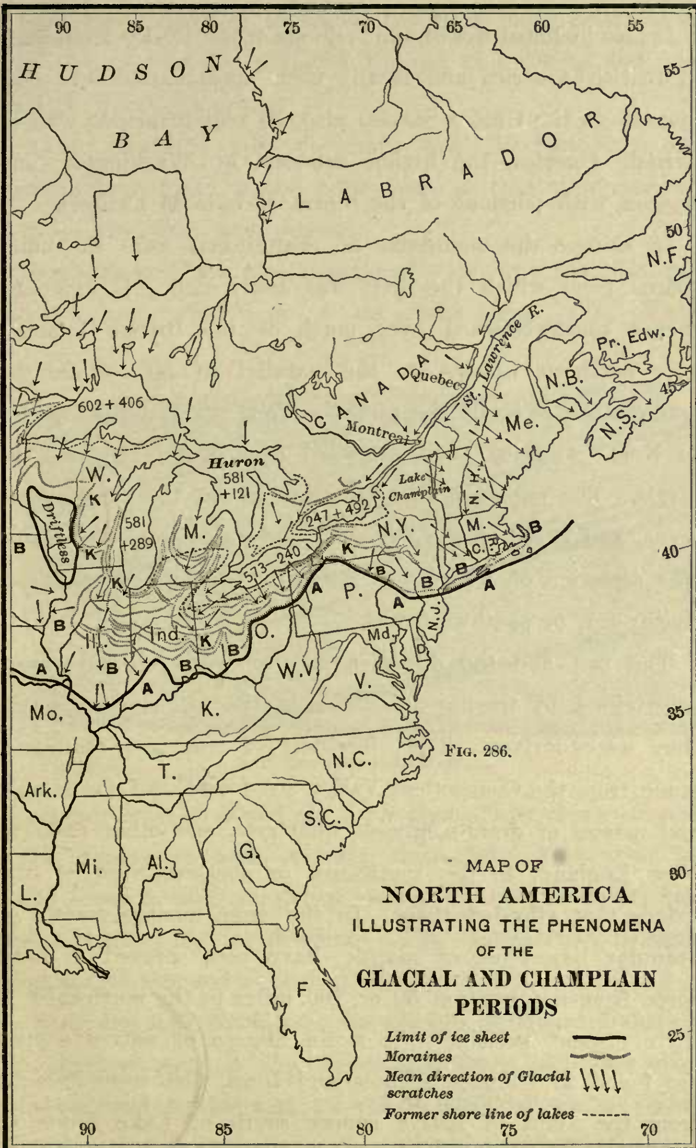

MAP OF
NORTH AMERICA
ILLUSTRATING THE PHENOMENA
OF THE
GLACIAL AND CHAMPLAIN
PERIODS
Limit of ice sheet
Moraines
Mean direction of Glacial scratches
Former shore line of lakes
HUDSON
BAY
LABRADOR
CANADA
N.F.
Pr. Edw.
N.B.
N.S.
Me.
St. Lawrence R.
Quebec
Montreal
Lake Champlain
Huron
581 +121
602 + 406
581 +289
247 + 492
573 - 240
Driftless
W.
M.
N.Y.
P.
O.
Ind.
Ill.
Mo.
K.
W.V.
V.
Md.
N.J.
D.
N.C.
S.C.
T.
G.
Al.
Mi.
Ark.
L.
F

Fig. 286.

It also included the summit regions of the Rocky Mountains in British America and locally their continuation for some distance in the United States; also the region farther west in British America, the higher summits of Washington and Oregon, with portions of the Sierra Nevada in California.

In Europe the mountains of Scandinavia were the chief source from which the drift was distributed. It extended thence southwestward over much of the British Islands; over northern Europe, to the parallel of 50°, where the temperature is about the same as along the parallel of 40° in North America; and eastward over Russia beyond the Urals. The region of the Alps was one of the local glacial areas, and those of the Pyrenees and Caucasus were others. The direction of travel was generally to the southeastward, southward, or southwestward.

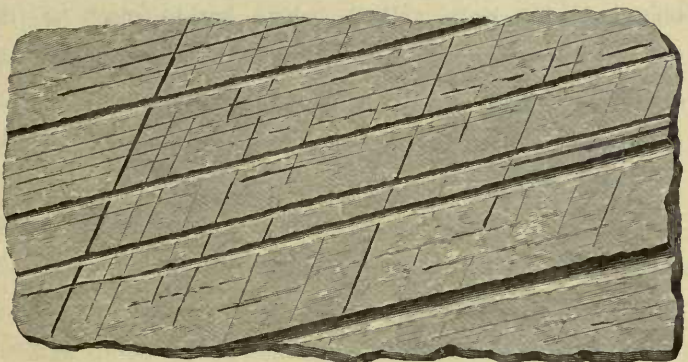
The fact and the direction of transportation have been ascertained by tracing the stones to the ledges from which they were derived. Thus bowlders of trap and red sandstone from the Connecticut Valley are found on Long Island, and masses of granite, gneiss, quartzyte, and other rocks in New England, to the southward or southeastward of the ledges that afforded them. In the same manner masses of granular limestone, or marble, have been proved to have come from a formation 50 or 100 miles to the northward of their present position. So again masses of native copper are found in Indiana, Illinois, and Iowa, that were brought from the veins of native copper south of Lake Superior.

The greatest distance to which bowlders have been traced has been 400 or 500 miles in Europe, and 200 to 400 over eastern North America.

These bowlders are sometimes over 50 feet long, and contain more than 20,000 cubic feet, so that they compare well in size with large houses.

Drift regions are also regions of extensive planings, polishings, and scratchings of the rocks (Fig. 287). These

FIG. 287.



Drift Scratches and Planings.

scratches may be found in them almost anywhere on hard rocks that have been recently uncovered. Vast areas are thus scoured and scratched over, and the scratches have great uniformity in direction. The transported bowlders and stones also are scratched.

Scratches and bowlders occur on top of Mount Mansfield, the highest point in the Green Mountains, 4430 feet above the sea, and bowlders at a level of 6290 feet on the White

Mountains in New Hampshire; and the direction of the scratches as well as of the bowlder-travel shows that the transporting agent moved over both of these summits without finding in them any serious impediment, and thence continued on its way southeastward.

The drift covers the mountains and hills of drift regions, and makes also a large part of the formations in the valleys. Over the hills it is *unstratified drift*, called also *till*, the sands, gravel, and stones having gone down pell-mell together; in river valleys, where within reach of the waters, it is *stratified drift*,—stratified because there the sands and gravel were deposited in flowing water, which assorted somewhat the material and spread it out in beds. In drift-covered regions the excavations for the cellars of houses are often made in the stratified drift, and the sands usually show a succession of beds which is evidence of the action of water.

2. *Cause of the Glacial Phenomena.*—No known agent is adequate for transportation on so vast a scale except *moving ice;* and, as Agassiz was the first to appreciate, it was *glacier* ice. The size of the blocks transported is no greater than of those now borne along on the backs of glaciers; and the planing and scratching is just what the Alps everywhere exemplify. The moraines of the glaciers, as explained on page 82, are derived in the Alps from the cliffs either side of the ice-stream, and a small part only is taken up by the abrading surface at the bottom. In the Continental

glacier of the Glacial period, the stones, gravel, and sand were gathered from the hills *over which* the ice moved, for there were no cliffs or peaks projecting above the surface even in hilly New England and rarely any in other northern states. The White Mountains, as before remarked, have bowlders at a height of 6290 feet, or almost at the very summit point, and therefore they were buried in the great glacier. Taking the height at the White Mountains as a guide, the upper surface of the glacier at that point was at least 6500 feet above the sea level. From this region the ice-surface sloped away over southern and southeastern New England to its place of discharge in the Atlantic. Over the Adirondacks, the height was even greater; for it was sufficient for the transportation of drift and bowlders across the Green Mountains, southeastward.

A thickness of even 2000 feet, which is over four times that of the largest Alpine glacier, would have given great abrading power to the heavy mass. All soft or decomposed rocks over which it moved would have been deeply worn down by it, and hard rocks with open joints or planes of fracture would have been torn to pieces. The heavily pressing, slowly moving mass would have taken the loose and loosened rock-material that lay over the hills beneath into itself, as additional freight for transportation.

Masses of trap 500 to 1200 tons in weight lie along the elevated western border of the plain of New Haven in Connecticut, which were gathered up from the trap hills between Meriden and Mount Tom in Massachusetts. The highest of these hills are about 1000 feet high above sea level, and their tops, when the masses were taken up, were 300 to 1000 feet above the level of the adjoining valleys.

A glacier moves in the direction of *the slope of its upper surface,* in spite of the slope of the surface beneath it. It is like thick pitch, as well as water, in this respect. If pitch were dropped indefinitely over a spot *in a plain,* it would spread away indefinitely; and if the surface around the spot even had a rising slope, it would fill up the basin and then take a course outward. So it is with the ice of a glacier. In order to have a southeastward course, a glacier must have its surface highest to the northwestward, with slope southeastward; and if the snows were more abundant to the north in the Glacial era, and the melting less abundant there than to the south, an accumulation to the north might have gone on that would have produced movement southward. If the plane beneath the pitch had deep channels obliquely crossing it, the pitch *in these channels* would follow their direction, while the overlying pitch kept on its main course. So with the glacier,—its lower part within the large valleys followed the directions of the valleys, as the scratches and bowlders show; while the upper portion had its usual course, the course which is indicated by the scratches elsewhere over the higher parts of the country.

The cold of the era may have been mainly due to an elevation and extension of Arctic lands, increasing the area of

Arctic land-ice; and to a partial closing, through this elevation, of the Arctic region against the warm current of the Atlantic Ocean, — the Gulf Stream which is now a source of warmth to all of northeastern Europe, and even Iceland, Nova Zembla, and the polar seas and lands. But it is probable that the land of the higher latitudes of America and Europe was higher than now; and that the Antarctic region was an area of high land; and that this was a prominent cause of the cold. Other reasons for cold have been suggested, references to which will be found in large works on the subject.

South America has in its southern portion a great glacial region, bearing evidences of transportation toward the equator; and farther north there were glaciers about the higher summits of the Andes. The phenomena described were therefore not confined to one hemisphere. Some writers suppose them to have occurred alternately in the northern and the southern hemisphere. But no direct evidence of this has been obtained.

The moving glacier of New England appears to have had its head in the height of land between the St. Lawrence Valley and the Great Lakes on the south, and Hudson Bay; for the scratches diverge from this region over eastern Maine, New Hampshire, Vermont, and New York, being in western New York and Pennsylvania southwest in direction. Over this region the ice appears to have reached its highest elevation. This ice-plateau, called the Laurentide plateau, extended westward, and also northward by the west side of Hudson Bay, and from it the ice descended with its freight of stones and gravel southwestward over Michigan, Wisconsin, Illinois, and Iowa, reaching even into Kansas and Missouri; and westward crossing the Winnipeg region to where the ice met that of the

Fig. 288.

View on Roche-Moutonnée Creek, Colorado.

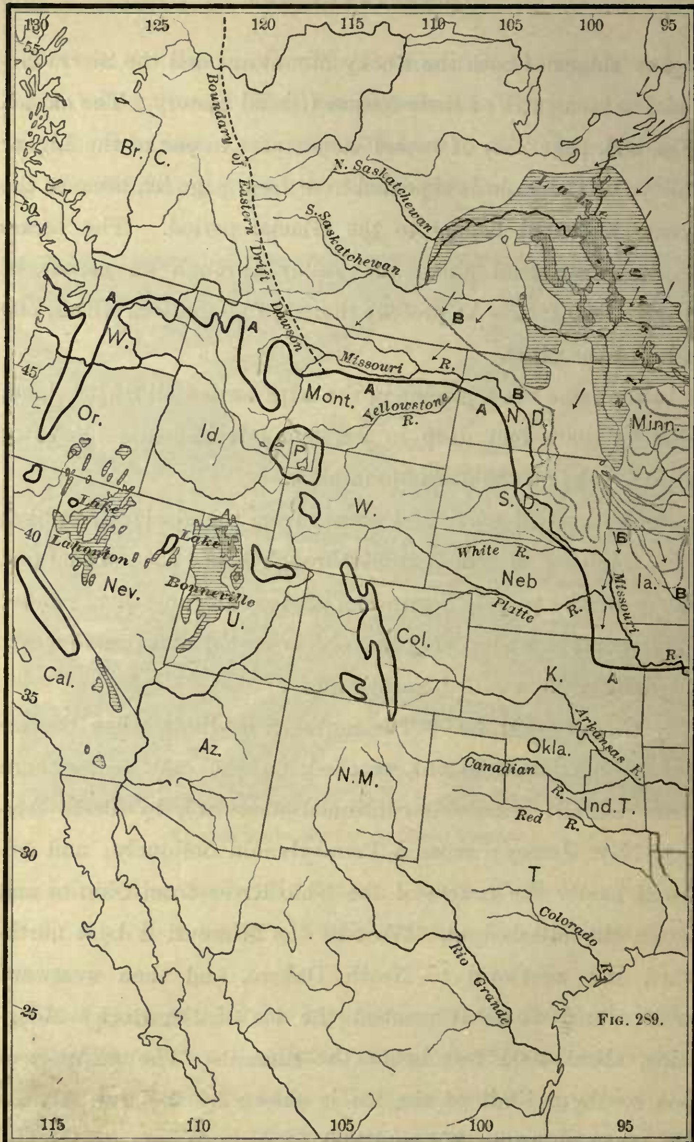
summit of the Rocky Mountains. North of Hudson Bay and of 60° to 65° in western North America, the flow was northward.

Local glaciers of great magnitude existed about the higher parts of the Rocky Mountains, within the United States, and also on the Sierra Nevada. Moraines, scratches, *roches moutonnées*, on a grand scale occur in many valleys of the higher ridges of both the Rocky Mountains and the Sierra Nevada, as mementos of their former Glacial history. The sketch (Fig. 288, page 258) of *roches moutonnées* in one of the higher valleys of Colorado is repeated here from page 82, because the events indicated belong to the Glacial period. The *roches moutonnées* extend along the valley through an ascent of nearly 2000 feet. At present there are no glaciers within 500 miles of the place.

In the same era a glacier in the Alps buried all Switzerland, 2000 to 4000 feet deep in ice, and left immense blocks of Alpine rocks on the Jura Mountains.

Depositions of earth and stones from the glacier must have been going on to some extent through the whole Glacial era. Moreover, the perpetual grinding of stones against stones under a glacier often made a very fine clayey earth; and consequently the drift is often called *bowlder-clay.*

3. *Retreat of the Ice.* — The southern ice-limit, when the ice was of maximum extent, reached, on the east, to southern Long Island; thence it continued westward, by Perth Amboy, New Jersey; crossed Pennsylvania obliquely; and followed nearly the course of the Ohio River from Ohio to and across the Mississippi. West of the Missouri it bent northward and westward to North Dakota, and then westward to Montana, where it reached the ice of the Rocky Mountains, about 4000 feet below the summit. The position of this southern limit of the ice is shown by the line AA on the maps on pages 251 and 260.



For explanation of the map see page 251.

At the melting, the retreat first showed progress in the Continental Interior, over Illinois, Kansas, and Iowa, where the land was laid bare by the melting, in Illinois and Iowa, for 250 miles northward from the southern limit, before there was much appreciable change in Pennsylvania and to the eastward. This difference in rate of melting was owing to the fact that the east was a region of great precipitation, where, therefore, snows were freely supplied to keep the ice up to its limit; while the Interior was dry, and the small amount of snow of the year was easily melted.

From Kansas over eastern Nebraska, in or near the Missouri Valley, the first retreat extended northward for 1000 miles or more, reaching far into British America. As a consequence of the melting along this 1000 miles, the Missouri was at this epoch the great river of the continent, with the lower Mississippi as its seaward continuation.

After a long halt, the melting again became so great that the retreat began anew. Over the northern part of the Continental Interior, the margin was moved *eastward* to and across Lake Winnipeg; and from Minnesota, Wisconsin, and Michigan, it was moved *northward* into British America. Then the Mississippi became the greatest of rivers; for the elevation of the land to the north was such that the Winnipeg waters poured down the Red River of the North and the Minnesota River in great volumes to fill up and flood the Mississippi.

Finally, New York and New England lost their ice, excepting what lingered about the higher mountains.

The melting is evidence of a slow change of climate. It may have begun in consequence of changes outside of the continent. But before it was completed there was a subsidence of the land over the higher latitudes, which made the climate still warmer, and so hastened the disappearance of the ice.

With this subsidence a new period opens in the earth's history — characterized by a mild climate, even milder than that now existing; and by a reforesting and repopulating of the previously glaciated regions.

2. **Champlain Period.** — The warm Champlain period, in strong contrast with the period of slow-moving ice, was the time of great floods along the river valleys, as a consequence (1) of the waters let loose by the lingering ice of the hills, and also (2) of excessive rains from the continued moist climate.

In further contrast with the Glacial period, it was, as has been stated, a time of lower level than now over the higher latitudes; and hence the action of the rivers became changed to a large extent from excavating streams, deepening thereby their channels, to streams that deposited sediment along their banks, and thereby made great fluvial formations. As a consequence, moreover, of the genial climate, the banished forests and animal life rapidly regained possession of the plains and hills.

The fact that the land of the more northern latitudes was at a lower level than now is proved by the existence of many Champlain sea-beaches or marine beds at high levels, in the form of terraces, along the existing borders of the ocean, lakes, and rivers. The beds have a height of 80 feet on Nantucket; 150 to 300 along the coast of Maine; 300 to 600 along the St. Lawrence Valley, — the greatest height up-stream, namely, 200 feet at its mouth, 520 feet at Montreal, and 600 not far from Lake Ontario, so that the St. Lawrence River was then a vast St. Lawrence Gulf, 500 to 600 feet deep. Even Lake Champlain was an arm of this St. Lawrence Gulf, for beaches containing sea shells occur on its borders to a height of 450 feet, and at a little lower level remains of a whale have been found. It had the great depth of from 700 to 900 feet. Moreover, Labrador has similar beaches at a height of 500 to 800 feet, and some Arctic land at 1000 feet. Similar facts are reported from the Pacific coast.

The subsidence was greatest to the north, it having been probably not over twenty feet on Long Island Sound, and seventy at New York Bay, while it was 500 feet at Montreal and 335 feet at Albany, New York. This increase to the northward was the cause of the diminished pitch in most of the rivers; for it affected directly all southward-flowing streams.

The deposits from the flooded waters along the valleys and about the lakes became hundreds of feet thick in many places. The upper flat surface, now the "upper terrace" of the valley, is a mark approximately of flood height. The valleys of the Hudson and the Connecticut are examples.

The waters gathered their detritus from the drift-covered hills through their numerous tributaries; for the amount of sand, gravel, and clay which had been dropped by the ice was immense, and it lay loose, easy to be taken up by streams the rains might make.

The Mississippi Valley was the outlet for the waters of the great region it now drains; and its floods during the whole Glacial period must have been great, and floating ice laden with northern stones must have often been hurried off down stream to the Gulf. During the melting it made thick deposits on the way to the Gulf, as observed by Hilgard, and in Mississippi, bowlders as large as a bushel basket are found in the beds.

In Europe and Great Britain the Champlain period was one of subsidence over the higher latitudes, as in America, and the subsidence was greatest to the north. In France and Belgium the depression below the present level was 50 to 100 feet; in southern England 100 to 200 feet. In Sweden it was 200 at the south to 400 or 500 to the northeast, — so great that an ocean channel then connected the Baltic with the White Sea.

Between the Champlain and Recent periods, Europe passed through a second, but less severe Glacial epoch. Marks of it have been pointed out in glacial deposits in the Alps and other places, but especially in southern France, through the occurrence in great quantities of remains of the Reindeer, a cold-latitude animal. With the bones of the Reindeer there are also those of other cold-climate species. This epoch is called the *Reindeer* epoch. After it comes the *Recent* period in geological history.

Life of the Pleistocene, or the Glacial and Champlain Periods.

1. *General Observations.* — The plants and the lower tribes of the Animal kingdom in the early part of the Quaternary were essentially the same as now. The species of Corals making coral-reefs in the tropics were probably in existence and at work before the close of the Tertiary age; and the same is true of most of the Invertebrates of the modern world, and also of the plants.

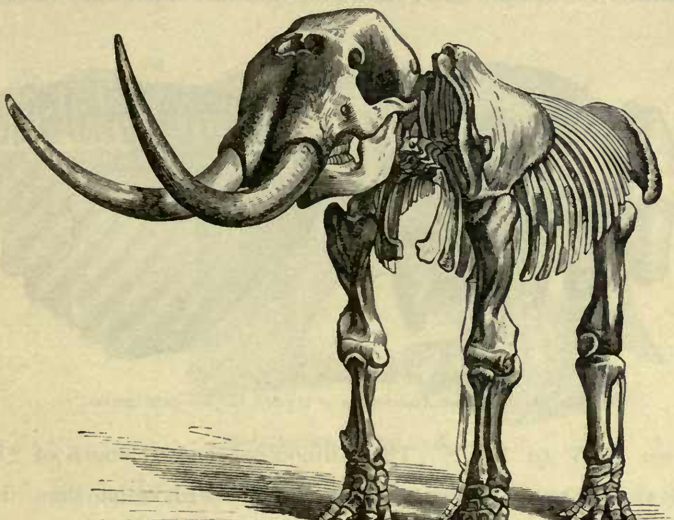
There must have been some exterminations as a consequence of the cold of the Glacial period, and of the ice of high-latitude regions. Many plants were driven south by the coming on of the cold, and thus escaped destruction; and some of these now live on Mount Washington and other high summits of temperate North America. Birds must have shortened their migrations northward and lengthened them southward, and for the most part they may have escaped catastrophe. The beasts of prey, cattle, and other large Mammals of Drift latitudes must also to a great extent have moved toward the tropics as the rigors of the approaching ice-period began to be felt. Certain it is, that after the ice had gone, a large population of brute Mammals moved in from the warm southern latitudes over Europe and the other continents; and facts seem to prove that they hung about the southern limit of the ice, and often moved northward with the lulls in the intensity of the climate or the shortening in at intervals of the ice-field.

2. *Brute Mammals.* — The brute Mammals appear to have reached their maximum in numbers and size during the warm Champlain period. Those of Europe, Great Britain, and America were largely warm-climate species, such as now are confined to warm-temperate and tropical regions. Only in a warm period like the Champlain could they have there thrived and attained their gigantic size. The great abundance of the remains and their condition show that the climate and food were all the animals could have desired. They were masters of their own wanderings and had their choice of the best. But the colder conditions of the Recent period which followed were less favorable, and many of the species are now extinct.

Remains of these Mammals have been found in deposits along the margins of rivers and lakes; in marshes, where they became mired; in caves, buried in the stalagmite (page 40) that was deposited over their deserted skeletons. In Great Britain and Europe the caves were the haunts of Bears, Hyenas, and Lions, much larger than any of the kinds now living; these beasts of prey dragged into their caves the bodies of the animals they fed upon. The Cave Bear resembled much the Grizzly Bear of western North America; and the Cave Hyena and Cave Lion are regarded as the same in species with the African Hyena and Lion, although these modern kinds are dwarfs in comparison.

With these there were in Great Britain and Europe species of

FIG. 290.



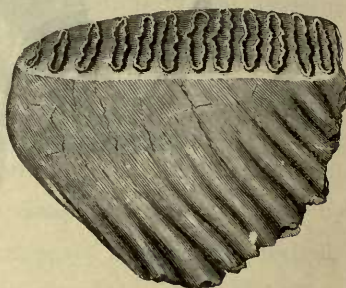
Skeleton of Mastodon Americanus.

Rhinoceros, a Hippopotamus, the Siberian Elephant or Mammoth, the Brown Bear, Wolf, Wild Cat, Lynx, Leopard, Fox, Elk, Deer, and others. The modern species of Horse was among them. The Irish Deer (*Cervus megaceros*), skeletons of which have been found in Irish bogs, had a height to the tip of the antlers of 10 to 11 feet, and the span of the antlers was sometimes 12 feet. The Elephant (*Elephas primigenius*) and the most common Rhinoceros (*R. tichorinus*) had a hairy covering, which fitted them to roam over regions in the far north. The remains, especially those of the Elephant, show that they lived in great herds over northern Siberia, where now the mean temperature of the

Figs. 291, 292.

291

292



Teeth of Mastodon and Elephant.
Fig. 291, Mastodon Americanus (× $\frac{1}{4}$); 292, Elephas primigenius.

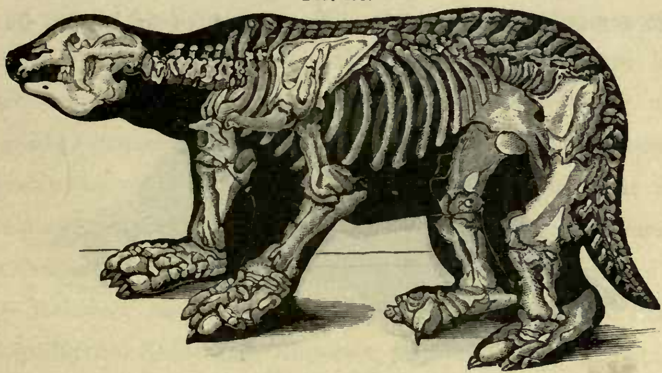
year is 5° to 10° F. The Rhinoceros had a length of 11$\frac{1}{2}$ feet, and the Elephant was nearly a third taller than the largest of modern Elephants.

In North America also there were large Lions and Bears, but none of them, so far as known, made caves their dens. The largest of the species was the *Mastodon* (Fig. 290), an animal with tusks and trunk like an Elephant. When full grown it was 12 to 13 feet in height, and to the extremities of the tusks 25 feet long. The teeth had a crown as large in area as this page, and of the form shown in Fig.

291. Skeletons have been found in marshes where the heavy beasts were mired; and portions of their undigested food — the small branches of spruces and other trees — have been taken from between their ribs, where the stomach was once trying to digest them.

There were also American Elephants of great size, of the same species as the Siberian. Fig. 292 represents a tooth

Fig. 293.

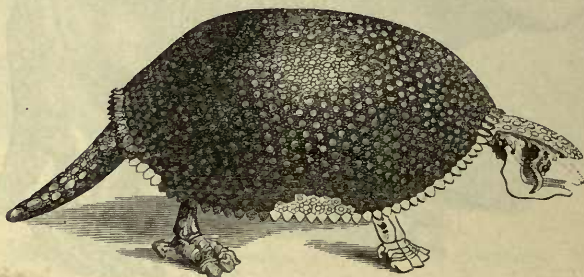


Megatherium Cuvieri (× $\frac{1}{78}$).

of one found in Ohio; it is a little larger than that of the Mastodon. There were also Horses of large size, Tapirs, Oxen, Beavers, and various gigantic species of the tribe of Sloths.

The Sloth tribe was especially characteristic of South America. The modern Sloth is as large as a dog of medium size. The species of the Champlain period included a *Megatherium* (Fig. 293), which was larger than the largest of existing Rhinoceroses. As the figure shows, it was a lazy beast; the bones of the hind legs are much like logs, and those of the fore feet are furnished with hands a yard long for pulling down trees after the animal raised itself erect for the purpose on its hind legs and enormous tail, — a third support. This is one of many kinds of gigantic Sloth-like animals that lived in South America during the era. Other related species had a shell somewhat like the modern Armadillo; and these also were gigantic, one of them (Fig. 294) measuring 5 feet across its shell, and having a length of at least 9 feet.

FIG. 294.



Glyptodon clavipes ($\times \frac{1}{30}$).

In Australia the Mammals are now, with few exceptions, *Marsupials*, the Kangaroo being one of them. They were also Marsupials then; but the ancient kinds partook of the peculiar feature of the era, — great magnitude, some of the species being as large as a Hippopotamus, one having a skull a yard long, and many of them being far larger than any modern Marsupial.

Thus the brute races of the Middle Quaternary on all the continents greatly exceeded the modern races in magnitude. Why they did so, no one has explained, beyond saying that the climate was favorable to great size.

The genial climate of the Champlain period was *abruptly* terminated; for carcasses of the Siberian Elephants were frozen so suddenly and so completely at the change, that the flesh has remained till these modern times untainted. Near the close of the last century, one huge carcass dropped out of the ice-cliff at the mouth of the Lena, and for a while made food for dogs. The existence of a hairy covering was then first ascertained. A hairy Rhinoceros has also been found in the ice. This change of climate was probably connected with the commencing of the Reindeer epoch, closing the Champlain period; it was then that the Reindeer and some other species migrated to southern France, to live there until the cold epoch had passed. The remains of the Reindeer are accompanied by those of the Cave Bear, Cave Hyena, Rhinoceros, Elephant, and other Champlain species, showing that all lived together there at that time.

3. *Man.* — Man was in existence during the Champlain period; and probably in its earlier part before the ice had disappeared. Relics, indicating that he was a contemporary of the gigantic Champlain Mammals, occur in various caverns and in river and lacustrine deposits, in Great Britain, Europe, Syria, and in other regions.

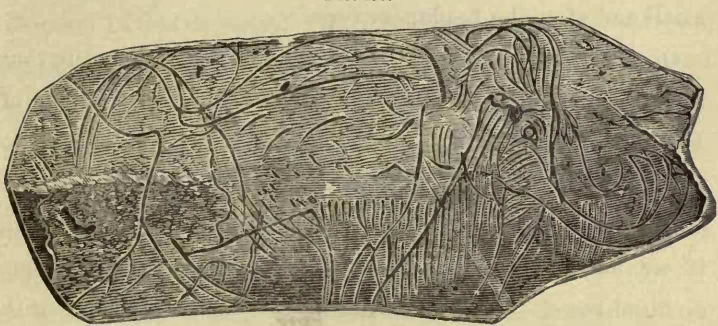
The relics of Man are stone implements, such as arrowheads, hatchets, pestles, and stone chips made in the manufacture of the implements; beads, shells, and other materials having upon them his markings and carvings; his pottery; the charcoal left from his fires; the bones of animals broken lengthwise to get out the marrow; his own bones, skulls, and skeletons.

In Europe and western Asia the stone implements of the earlier part of what is sometimes called the *Stone age* are of rude make and unpolished. This part of the age has been called the *Paleolithic* epoch in human history, or that of the *oldest stone* implements, — the word, from the Greek, signifying *old* and *stone.* The stone implements occur along with bones of the Cave Bear, Cave Hyena, Mammoth, Rhinoceros, and several other Champlain species, and also with the bones of Man; and these human relics are so associated with those of extinct Mammals that there is no reason to doubt that they were contemporaries.

Next came the Reindeer epoch. Its stone implements are unpolished, but better made than those of the preceding era. Besides these there are examples of bones, shells, horn, and stone engraved with the forms of animals; others that are variously carved, or made into spear-heads and other forms; and also perfect human skeletons. Fig. 295 represents a drawing, on ivory, of the hairy Elephant; it was found in the cave of La Madelaine, in Périgord, southern France, and shows that the Elephant was well known to the men of the period. These human relics are associated with remains of the same Champlain Mammals that occur in the earlier deposits, and also with great numbers of the bones of the Reindeer, and many of the Aurochs, Elk, Deer, and other species of later time.

The bones and skeletons of Man of the Stone age, thus far found, in no case indicate a race much inferior to the lowest of

FIG. 295.



Elephas primigenius; engraved on ivory (× ⅜).

existing races, or intermediate between Man and the Man Apes, — the species among the brutes which approach him most nearly. But still they are those of uncivilized Man, and in part of Man of a low order of faculties.

The skull of Neanderthal (a part of the valley of the Düssel, near Düsseldorf) is the worst, but it is probably not older than others having better skulls and higher foreheads. The capacity of the cranium was 75 cubic inches, which is greater than in some existing men. A jaw-bone of low type, found in the oldest Belgian deposits, had little height and great thickness, as if for powerful use, and the posterior of the molar teeth was the largest, — a brutal feature.

The human skeletons of the Reindeer era in southern France are in part those of men of unusual height, — 5 feet 9 inches to over 6 feet; and the skulls are large and well shaped, with the foreheads high and capacious. They are of better size and shape than many of the Reindeer era in Belgium, which are small and after the Laplander type.

One of the most perfect was found in the stalagmite that formed the floor of the cave of Mentone, near the borders of France and Italy, on the Mediterranean. Eight feet above it in the stalagmite there were remains of the extinct Rhinoceros and other Champlain species. The man would compare well, if we may judge from the skeleton, with the best among civilized races, — his forehead broad and high, and rising with a facial angle of 85°, his height 6 feet; and yet he was a European savage of the Reindeer epoch; for about him lay his flint implements and weapons, his chaplet of stag's canines, and shells that he had gathered for food or ornament from the shores near by. The tibia or shin-bone was somewhat flattened, a peculiarity often observed in the skeleton of the American Indian.

The brain-cavity of a skull found in the cave of Cro-Magnon, in southern France, had a capacity of 97 cubic inches, which is very much above that of ordinary Man, and nearly three times that of the highest Man Ape.

In North America cases of the occurrence of ancient human bones or skeletons in Quaternary deposits are not so well authenticated as those in Europe. Admitting the facts that have been published, they do not give Man greater antiquity than those above mentioned.

No case of the presence of human relics in deposits of the Tertiary age on any continent is yet well established. Mr. W. Boyd Dawkins, an excellent British geologist and original observer in this department of the science, states, in his recent work on Cave Hunting (1874), that the evidence obtained proves that "Man lived in Germany and Britain after the maximum Glacial cold had passed away," and that no human remains "have been discovered up to the present time in any part of Europe which can be referred to a higher antiquity than the Pleistocene (Quaternary) age."

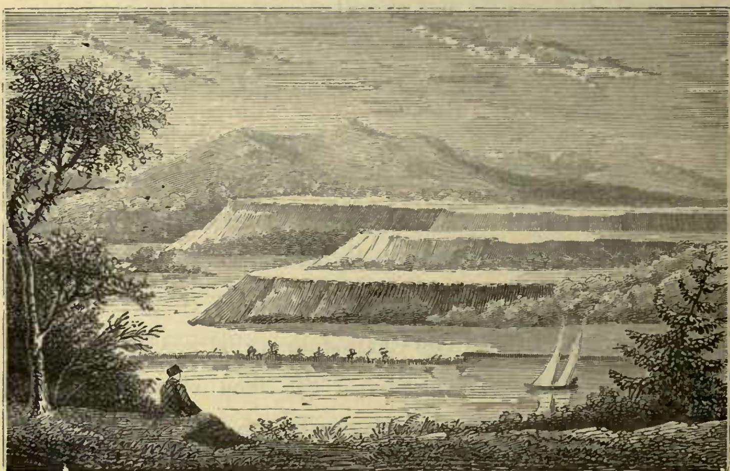
The second Glacial or Reindeer epoch in Europe (which there is reason to believe produced effects also in North America) appears to have finally brought to a close the era of giant beasts, leaving the world for Man.

3. **Recent Period.** — The Champlain period was brought to a close by a moderate elevation of the land over the higher latitudes, bringing the continent up to its present level. This elevation placed the old sea-beaches of the Champlain period at their present level high above the sea, that is, over 500 feet near Montreal, over 200 feet on the coast of Maine, and so on, the height of the shell beaches being a measure of the amount of elevation. River-valleys, after the rise, had a steeper slope than in the Champlain period, and hence their flow was increased in rate. They consequently went on cutting down their beds through the Champlain deposits

of the valley to a lower level; and at the time of their annual floods they wore away the deposits on either side of the channel, making thereby an alluvial flat or flood-ground; for every river has a flood-ground which it covers in its times of flood, as well as a channel for dry times.

This sinking of the river-beds left the old flood-grounds as a high terrace far above the level of the stream; and the great

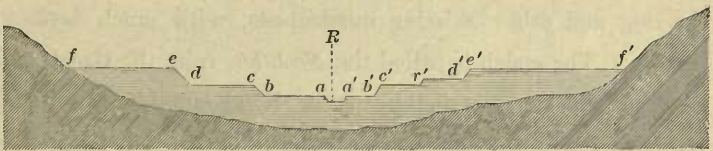
FIG. 296.



Terraces on the Connecticut River, south of Hanover, N. H.

elevated plains still remain to attest the vastness of the floods from the melting glacier. In the course of the elevation a series of terraces was often made along the valleys, as illustrated in Fig. 296. A section of a valley thus terraced is represented in Fig. 297. The formation terraced is, as is shown, the Champlain; in the Champlain period it filled, in general, the valley across (from f to f'), excepting a narrow channel for the stream, the whole breadth having been the flood-ground of the Champlain River. But after the elevation of the land that closed the Champlain period began, the river commenced to cut down through the formation, making one or more terraces in it, on either side of the stream. In Fig. 297, R is the position of the river-channel after the terracing;

FIG. 297.



Section of a Valley with its Terraces Completed.

and on either side of it there are terraces at the levels ff', dd', bb', and also another on the right side, at $c'r'$. These terrace-plains are usually the sites of villages. They add greatly to the beauty of the scenery along water courses. The terraces usually fail where the valley is narrow and rocky.

Rock-making has not yet ceased, for the old agencies — the waters, the winds, and life — are still at work with unimpaired energies. Sand-beds, pebble-beds, and mud-beds are accumulating along seashores and in shallow waters, precisely like those that were hardened into ancient sandstones, conglomerates, and shales; and limestones are forming from shells and corals similar to ancient limestones.

Further changes of level are still going on. A large part of Sweden is rising at the slow rate of four feet or so a century, and as slowly a portion of Greenland is subsiding. The Atlantic coast from New Jersey to Labrador is supposed to be sinking, and, along New Jersey, at the rate of two feet a century.

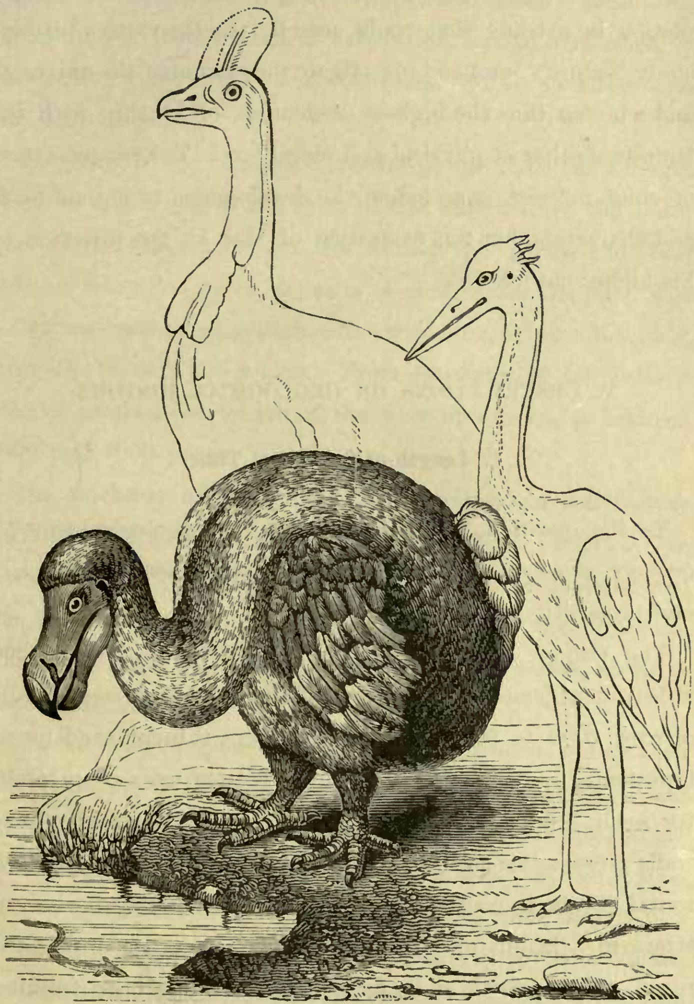
Man, in the Recent period, passed the last part of his Stone age, styled the Neolithic epoch. In Europe, the stone implements of the epoch include polished implements, as well as those which are merely chipped; and the animal remains found in the same beds are portions of skeletons of the domestic Dog and other existing quadrupeds, with much broken pottery. The epoch is called the *Neolithic*, from the Greek for *new* and *stone*. The shell-heaps or Kitchenmiddens, of the Danish Isles in the Baltic, are part of the Neolithic localities. Among the North American Indians, the Stone age was continued to within a century or two.

Besides human remains, modern fossils include corals, shells, and relics of all the various tribes of the passing period.

Moreover, species are becoming extinct; at least through Man, if not in other ways. The Dodo, an extinct bird of 50 pounds' weight (Fig. 298), was living on Mauritius in the seventeenth century. The Moa, larger than an Ostrich, and other birds with it, have recently disappeared from New Zealand. The Aurochs (*Bison priscus*) of Europe is nearly extinct. Thus wild animals have begun to disappear before advancing Man. The same is true of plants.

The age of Man now has as its fossils, not only flint implements and human bones, but also buried cities, temples, statues, and manuscripts.

FIG. 298.



Extinct Species. Dodo, with the Solitaire and an Extinct Species of Night Heron in Outline.

From a painting, at Vienna, made by Roland Savery, in 1628.

The system of life, long in progress, finally reached its completion in a being that could search into the earth's history, study Nature's laws and investigate the system of the universe; and who has thus the highest credentials of kinship with the Infinite Author of physical and moral law. The progress now of chief interest is no longer the development of animal races and characters, but the exaltation of Man in the direction of his higher nature.

V. OBSERVATIONS ON GEOLOGICAL HISTORY.

1. Length of Geological Time.

To the question, "what is the length of geological time?" geology gives no definite reply. It establishes only the general proposition that *time is long.*

The Cañon of the Colorado (page 103) is a gorge 200 miles long, bounded the most of the way by steep walls of rock 3000 to 5000 feet in height, cut through sandstones, limestones, and other rocks; and at bottom over parts of it, for several hundred feet, into granite; and above the lofty walls a few miles back from the stream the pile of nearly horizontal strata is continued in mountains of nearly horizontal strata to a height of 7000 to 8500 feet above the bed of the river. All the facts, as its describers testify, point to running water as the agent that made the great channel. The region was under the sea until the close of the Cretaceous period, for marine Cretaceous strata are the uppermost rocks. It follows, then, that all this extensive excavation was accomplished by slow-acting water during Cenozoic time. Surely Cenozoic time was very long.

The gorge of the Niagara River below the Falls has a length of seven miles. It is the work of the waters since the latter part of the Glacial period; for during this period the older channel was filled up by deposits of drift from the ice. The water has consequently made this excavation, seven miles long, since the ice left the region. From estimates of the present rate of erosion, the length of the time of erosion is between 6000 and 7000 years.

The thickness of a sedimentary deposit is no satisfactory basis for determining the length of time it took to form. In a sea 100 feet deep, 100 feet of sediment may accumulate; and the thickness could not exceed this (except a little through wave-action and the winds) if a million of years were given to the work.

Let the same region be undergoing a subsidence of an inch a century, and the thickness might increase at that rate; and much faster, if a yard a century; and with either rate, giving time enough, any thickness might be attained. Hence a stratum of sandstone 100 feet thick may have been formed in a thousandth part of the time of a thin intervening bed of shale.

Nevertheless, the aggregate maximum thickness which the strata attained during the several ages may be used for an approximate estimate of the comparative lengths of those ages.

On such data, it is deduced that the time ratio for Paleozoic, Mesozoic, and Cenozoic time was not far from 12 : 3 : 1. Consequently, if we suppose the length of time since the Paleozoic began to be 16 millions of years, Paleozoic time will include 12 millions, Mesozoic 3 millions, and Cenozoic 1 million. Most geologists would make the whole interval several times 16 millions.

2. Progress in Development of the Earth's Features.

The earth through the ages made progress: —

1. **In its Surface Features:** from the condition of a melted sphere as featureless as a germ, to that of an almost universal ocean with small lands, — enough of land to mark out the feature-lines of the future continents; and at last — after slow expansion southward, a lifting of mountain ranges at long intervals, and a retreating of the waters — to the existence of great continents having high mountain borders and well-watered interior plains.

2. **In its River-systems:** from the existence of only little streamlets draining small lands in the Archæan and Silurian eras, and making no permanent geological record beyond a rain-drop impression, to a condition of vast freshwater lakes and marshes when beds of vegetable material accumulated for the making of coal-beds; and finally to that of the completed continent, when a single river (with its tributaries) drains, waters, and contributes fertility to hundreds of thousands of square miles of surface, and the work of fresh waters in rock-making exceeds that of the ocean.

3. **In its Climate:** from a condition of general uniformity of temperature, to, at last (though with interrupted progress) that of the present diversity, when the polar regions have a permanent capping of ice, and only the equatorial regions perpetual verdure.

4. **In its Living Adornments:** from an era when the small rocky lands were bare, or gray and drear with lichens, and all other life was of the simplest kind and below the water level, to a time of flowerless forests and jungles over immense plains, yet with no sound from living Nature more musical than the Amphibian's croak; and onward to the better time when the earth abounds in flowers and fruits and birds, and is covered with the homes of Man.

3. The System of Nature of the Earth had a Beginning and will have an End.

A system of progress or development in the earth as much implies that it had a beginning, as that in any plant or animal. Man, Mammals, Fishes, Mollusks, Rhizopods, Plants, all had, according to geological history, their beginning; so also mountains, valleys, rivers, continents, rocks; and so also the earth; and therefore the system of nature, whose development went forward in and through it, had its beginning.

If this is true of one sphere in space, we may rightly take another step and assert that *the universe had its beginning.*

It also admits of demonstration that the earth will have its end. A finished state is always the state before decline and death. The earth is dependent for all the beauty in its living adornments, and even for the existence of its life, on the heat and light of the sun. The sun is annually losing its heat; and however infinitesimal the amount of loss, it is sure to end in a cooled and dark sun; and hence, even long before the sun is cold, the earth, supposing it to have met with no earlier catastrophe, will have become dark and lifeless, literally a dead earth.

4. Progress in Life.

1. **From the Simple to the Complex.** — The progress in life was in general from the simpler forms to the more complex, or from the low to the high. This truth has been illustrated in each chapter of the preceding geological history.

2. **By Gradual Steps.** — Species appeared and disappeared, not only at the beginning of ages, or of the subdivisions of ages called periods, but also during the progress of periods, each of the successive strata containing some fossils not found below, and failing of others that are abundant in underlying beds. There were at times epochs of wide-spread catastrophe, ending periods; and two of them, those closing Paleozoic and Mesozoic time, were nearly or quite universal for the Continental seas. But these must have left unharmed the life of the deep ocean; and they could not have exterminated all the life of the emerged land, or even of the whole area of Continental seas.

3. **According to System.** — The first animal life was probably the Protozoan, or Rhizopods, Radiolarians, and the like, — kinds that are minute and destitute of members. But later, the grander divisions of animals were defined; and the species which appeared afterward in the long succession were constructed according to one or another of the systems of structure thus established. Each division became displayed in higher and more diversified forms by the new species that came into existence as time moved on. The first of the Vertebrates were the Fishes, — the simplest of the principal Vertebrate classes. Even in these aquatic species the arms and legs of the higher Vertebrates were present, though only in the state of fins; and the lung, though only as a cellular air-bladder; and the ear, though only as a closed cavity containing a loose bone; and so with other parts. Thus the earliest of Vertebrates possessed in an incipient stage many of the organs that became fully developed in the later and higher Vertebrates. And in the succession of species that existed, all were made on the fish-structure as its basis, even the species of the highest class, — those of Mammals and Man. A zoölogist, in order to understand the fundamental elements in the human structure, goes to the fish and the frog for instruction; and Nature is so true to her fundamental principles, that he finds there what he looks for.

4. **A System of Development or Evolution.** — With every step there was an unfolding of a plan, and not merely an

adaptation to external conditions. There was a working forward according to preëstablished methods and lines up to the final species, Man, and according to an order so perfect and so harmonious in its parts, that the progress is rightly pronounced a development or evolution. Creation by a divine method, that is, by the creative acts of a Being of infinite wisdom, whether through one fiat or many, could be no other than perfect in system, and exact in its relations to all external conditions,—no other, indeed, than the very system of evolution that geological history makes known.

5. **Culmination and Decline of Tribes.**—As has been brought out in the history, Trilobites, Brachiopods, and Crinoids, besides other groups of Animals, reached their maximum, or culminated, in Paleozoic time; Amphibians, in the first period of the Mesozoic era; Reptiles among Vertebrates, and Cephalopods, the highest of Mollusks, in the later Mesozoic; brute Mammals, in the Champlain period of Cenozoic time. So, again, in the kingdom of plants, the highest Cryptogams—the Acrogens—culminated in the Carboniferous period; Cycads, in the middle Mesozoic; while Palms and Angiosperms have the present era as their time of greatest display and perfection. These are a few examples, showing that progress did not go on regularly upward; but that the old, not only in species, but also in tribes and orders, were culminating and then passing away, as new and higher tribes were introduced, in the progressing evolution of the kingdoms of life.

6. **Parallelism between the Progress of the System of Life and the Progress of Individual Life.** — An animal, in its growth from the germ — or, as it is called, its embryonic development — passes through a succession of forms before reaching the adult state. In Mammals the changes after birth are small, the larger part of them having taken place before birth. But in the lower animals the successive forms are often widely diverse, and they frequently mark successive stages in the life of the animal. Thus, in Insects, there is the caterpillar or grub stage before the adult; and in many Crustaceans, Mollusks, Worms, and Radiates there are several such stages.

Now species have existed, and many now exist, which have the general characters of the forms in these lower stages; and, in accordance with the above proposition, the order of their appearance in the geological series is, in general, as announced by Agassiz, that of their development in the embryonic series. Thus, as the worm-like grub precedes the adult Insect, so Worms, in geological history, preceded Insects. As a fish-like condition of an Amphibian precedes the adult form in which the fish-like features are lost, so Fishes preceded Amphibians. The examples of the principle are numerous. Some authors have so great faith in it, that they are ready to decide as to the form of the earliest species of a tribe from the earlier stages in individual development. But this is unsafe, since such forms may have come late into the system of life as well as early; inasmuch as progress was not in all cases upward progress.

Where the parallelism above mentioned is not apparent in the general form or structure, it is still manifested in certain comprehensive laws common to both kinds of progress, the geological and embryonic. The following are some of these laws:

1. *The low before the relatively high.*

2. *The simple before the complex.* A germ has little distinction of parts; the animal it is to evolve is there in a very general condition; that is, without any special organs. As development of a Mammal goes on, the defining of the head begins, and this is one of the first steps in the evolving of special parts, or in the specialization of the structure. Protuberances also form and commence the defining of the limbs; and then finally, the parts of the limb become distinct, or are specialized. Thus it is throughout the structure, until the specialization of the parts peculiar to the particular animal is completed.

This law of *the general before the special* is a law also in the geological progress of the system of life. In a Fish, the earliest of Vertebrates, the vertebrate structure is exhibited in a very generalized condition. The vertebral column consists of one single uniform range of vertebræ without a neck portion, and without a pelvis to divide the body from a tail and afford support to hind limbs; the limbs are fins, and hence only rudiments of limbs; the vertebræ have great simplicity of form; the teeth are all of the simplest kind; the lung is merely an air-bladder, and so on. Thus, all through the structure, a Fish is an exhibition of the vertebrate type in a generalized state. The Vertebrates which succeeded to Fishes — the Amphibians

—have the grand divisions of the body well brought out, and are specialized also as to limbs even to the toes, and in other ways. Passing onward in time, the new Vertebrates appearing exhibited successively a more and more complete specialization of organs and functions up to Man.

This law of progress from simple to complex has its exceptions; for Snakes, which are limbless, succeeded to higher Reptiles which had limbs. But such cases only exemplify another fact, already illustrated,—that, while upward progress was the rule, there was also progress downward, and especially after the time of culmination of a tribe had passed.

3. *Stationary forms sometimes before the locomotive.* Thus, Crinoids, part of the earliest life of the globe, were *stationary* species living attached by a stem; and, after these, there were *free* Asterioids. So the young of the modern Crinoid has a stem for attachment, and loses it, in many species, as it becomes an adult (a Comatulid).

7. **Origin of Man.**—The interval between the Monkey and Man is one of the greatest. The capacity of the brain in the lowest of men is 68 cubic inches, while that in the highest Man Ape is but 34. Man is erect in posture, and has this erectness marked in the form and position of all his bones, while the Man Ape has his inclined posture forced on him by every bone of his skeleton. The highest of Man Apes cannot walk, except for a few steps, without holding on by his fore limbs; and, instead of having a double curvature in his back like Man, which well-balanced erectness requires, he

has but one. The connecting links between Man and any Man Ape of past geological time have not been found, although earnestly looked for. No specimen of the Stone age that has yet been discovered is inferior, as already remarked, to the lowest of existing men; and none is intermediate in essential characters between Man and the Man Ape.

The present teaching of geology very strongly confirms the belief that Man is not of Nature's making. Independently of such evidence, Man's high reason, his unsatisfied aspirations, his free will, all afford the fullest assurance that he owes his existence to the special act of the Infinite Being whose image he bears.

8. **Man the Highest Species.**—It is sometimes queried whether the future may not have its various new species of life, and, among them, some higher than existing Man; whether the era now passing is not to be followed, as was true of the Carbonic, or the Reptilian, by another still more glorious in its living species; whether, if one of the great Dinosaurs of the Mesozoic age could have thought about his own and other times, he would not have imagined his era the last and the best possible; and whether Man is not playing as foolish a part in styling himself the "lord of creation."

Against the introduction of new species in coming time science has little to urge. But there is strong reason for holding that, whatever the changes in the lower tribes, existing Man will always remain the highest in the series.

(1) Science has made known that the highest of species

next to Man, that is, the brute Mammals, have already passed their maximum (page 266); hence, the rest of time remains for the culmination of the only higher type, that of Man. And, as this type includes now but one species, we have reason for expecting no new species in the future.

(2) From geological history we learn also that the type of Vertebrates commenced in kinds that were *horizontal* in attitude,—the Fishes; and that from the horizontal there was, in the Reptiles and Mammals, a raising of the head above the line of the body, up to the Ape, in which the attitude is nearly vertical; and, finally, to perfect verticality in Man, a being having the head placed directly over the body and hind limbs. Thus, as Agassiz observed, the last term in the series of Mammals has been reached; there can be nothing beyond. This is true as to the general type of structure; but it leaves it an open question whether there may not be another species of Man, or erect beings, of still higher grade.

(3) But a different species of Man higher than existing Man is not a possibility. We can conceive of other species of Man distinguished by having some of the external features of the Man Apes. But these are marks of inferiority, and, if possible in a type of so high grade, could belong only to inferior species.

The increasing erectness and breadth of forehead in Man, and the shortening of the jaws, giving a nearly vertical line to the front, which are a known result of culture, indicate the course which *upward* progress must take. And in these points and some others closely related, the limits of perfection have been nearly reached by some among the present race. Further improvement can give physically only larger capacity to the brain and greater beauty of form to the whole structure, and make these qualities more general. No wide divergence from existing Man can be conceived of. When all possible change in these directions has been accomplished, Man will still be Man, and no more the head of the system of life than he is at present.

(4) Beyond all this we may say, that since no other species but Man has ever been capable of reviewing the past or contemplating the future; and since Man not only has all time and all Nature within the range of his thought and study, but can even yoke Nature for service, and in fact has her already at work for him in numberless ways, the system with such a head must be complete.

Nature, through Man, has attained to the possession of a living soul capable of putting her once wasted energies into strong and combined movement for social, intellectual, and moral purposes, and this is the consummation that the past has ever had in prospect.

The Man of the future is Man triumphant over dying Nature, exulting in the freedom and privileges of spiritual life.

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