section 5) has been ground down and almost polished by glacial action. The stones or bowlders dragged along by the ice over the ledges are also smoothed and striated, as witness the glaciated bowlder of slate from East Boston on the right hand side of the stairs. It is probable, however, that the erosive action of glaciers has been over-estimated, and that the principal effects are due to the streams of water which run under the ice and roll along stones and sand in the usual manner. That the great ice-sheet moved for hundreds of miles from north to south across the country is proved by the occasional occurrence in the glacial detritus or drift of bowlders which are very far removed from their nearest outcrops to the northward. This evidence is especially conclusive when the rock is of a unique character and its outcrop limited. Thus the red jasper conglomerate represented by the bowlder near the stairs is found in place only in a small area north of Lake Huron, but bowlders precisely similar to this are scattered in the drift as far south as the Ohio River, nearly six hundred miles from their point of origin.

The bowlder of granite from the top of Mt. Washington is wholly unlike any rock *in situ* on that mountain; but twelve miles to the north-northwest, on Cherry Mountain, we find precisely the same kind of granite, at a level 3,000 feet lower, showing that the ice-sheet passed from Cherry Mountain up over the summit of Mt. Washington, the highest point in New England.

In the polar regions, glaciers are developed on a far grander scale; for they are not limited to elevated mountain valleys but cover the whole face of the country to a depth of hundreds or thousands of feet. The Antarctic Continent appears to be almost completely buried under a thick sheet of ice, and recent explorations have shown that Greenland is a vast *mer de glace*, from which enormous glaciers descend on every side through great

fiords to the sea. The photograph (**49**) shows one of the great Greenland glaciers entering the sea, where the ice is breaking off and forming icebergs.

During the comparatively recent geological period known as the glacial epoch or great ice age the conditions which are now limited to Alpine districts and high latitudes, appear to have extended much nearer the equator, nearly all of eastern North America down to latitude 40° having been covered by a continuous sheet of ice thousands of feet thick Its existence and the direction of its movement are plainly indicated everywhere in this region by the polishing and grooving of the ledges and the great masses of drift or moraine material of different kinds, which we find now almost as they were left by the ice-sheet. The principal phenomena of the continental glacier or ice-sheet in its slow progress over a comparatively level country and gradual retreat as the climate became milder toward the end of the glacial epoch are illustrated by the series of four models (**22–25**). The necessary explanations are given on the labels.

We have already noticed incidentally the powerful disintegrating action of water where it freezes in the joints and pores of the rocks; and it is probable that it thus facilitates the destruction of the rocks in cold countries nearly as much as the higher temperature and greater rainfall do in warm countries.

Air, especially as an agent of transportation, acts to a limited extent independently of water. The dunes or sand-hills north of Cape Ann and on Cape Cod and other parts of our coast are excellent illustrations of the extent to which the dry sand on the upper edge of the beaches may be carried inland and piled up by the wind. While the windows of houses in such districts, and the sand-blast used for etching glass, show that the wind-borne sand has considerable erosive power. Finer material or dust, especially of volcanic origin, is carried for long distances by the air currents, and spread over large areas of the earth's surface. But the principal office of the wind is to impart its energy to the water, which is the great and efficient agent of erosion; and a summary of this section can be given in a few words:—

The heat of the sun lifts the water from the ocean in the form of invisible vapor, and it also warms the air unequally, creating currents or winds. The winds cause waves and currents which are ever gnawing at the coast-lines of the globe and wearing away the land; and they also bear the aqueous vapor over the land, where it descends in the form of rain and snow. The rain-water, as soon as it falls, begins to flow towards lower levels and the sea, in streams which by their confluence become ever larger and fewer, giving in each hydrographic basin an insensible gradation from a myriad tiny rivulets to one large river. At the river's mouth the cycle of the circulation is completed. The rain-water flows through as well as over the rocks of the land, and, aided to a certain extent by the air, it acts both mechanically and chemically upon the rocks, disintegrating and decomposing them, and forming loose material or soil. To a limited extent this detritus is formed and transported by ice in the forms of glaciers and icebergs, and by the air alone; but running water is throughout the chief agent. Of the detritus swept along by streams, a small portion may be temporarily or permanently deposited in quiet portions of their channels, but the greater part ultimately reaches the sea. Thus the land is wasted away and valleys are formed which are a measure of the erosion.

Our observations up to this point show us, then, that *erosion*, by which we mean the breaking up by chemical

and mechanical action of the rocks of the land and the transportation of the debris into the sea, is one great result accomplished by the inorganic aqueous agencies.

The products of erosion carried into the sea from the land include two distinct portions: gravel, sand, and clay, which are held in suspension by the streams and waves; and carbonate of lime and other salts, which are held in solution.

MECHANICAL DEPOSITION.

We have next to consider what becomes of all this vast amount of clay, sand, and gravel, or matter in suspension, after it is washed into the ocean; although, unfortunately, this subject is one that does not admit of satisfactory illustrations within the narrow limits of the collection.

By taking up a glass of turbid water from any roadside rill, after a heavy rain, and observing that as soon as the water is undisturbed the sand and clay begin to settle, we learn that the solid matter is not held in suspension long after being washed into the sea, for the water otherwise would, in the course of time, become turbid for long distances from shore; and it is a well-known fact that the sea-water is usually clear and free from sensible turbidity close along the shore, and even near the mouths of large rivers, while at a distance of only 50 or 100 miles we find the transparency of the central ocean.

Putting these facts together, we see that the ocean, notwithstanding the ceaseless and often violent undulations of its surface, must be as a whole a vast body of still water; and to the reflecting mind the almost perfect tranquillity of the ocean is one of its most impressive features; for it is in striking contrast, in this respect, with the more mobile aerial ocean above it.

The rapid and complete precipitation of the finest mechanical detritus or clay in the sea is made still clearer by a simple experiment. Into each of two bottles put a small amount of fine clay; fill one bottle with fresh water and the other with salt water; bring the clay in each bottle into perfect suspension by violent agitation; and then allow the bottles to remain undisturbed for several hours or days. The salt water will become quite clear by the complete settling of the clay, while the fresh water remains distinctly turbid, showing that the salt favors the rapid deposition of the clay. The fact is, the clay is not held in suspension wholly by the *motion* of the water; but, just as in the case of dust in the atmosphere, a small portion of the medium is condensed around or adheres to each solid particle, *i. e.*, each clay particle in this experiment has an atmosphere of water which moves with it and buoys it up. Now the effect of the salt is to diminish their atmospheres, and consequently their buoyancy. The diminished adhesion of the salt water is well shown by the smaller drops which it forms on a glass rod.

The geological importance of this principle is very great; for it is undoubtedly largely to the saltness of the sea that we owe its transparency, and the fact that the fine, clayey sediment from the land, like the coarse, is deposited near the shore.

We have got hold, now, of two facts of great geological importance: (1) The debris washed off the land by waves and rivers into the still waters of the ocean very soon settles to the bottom; and (2) it nearly all settles on that part of the ocean-floor near the land. And now

we have in view the second great office of the inorganic aqueous agencies,—deposition, the counterpart or complement of erosion. The land is the theater of erosion and the sea of deposition; the rocks which are constantly wasting away on the former are as constantly renewed in the latter. We will now examine the process of deposition a little more closely. If a mixture of gravel, coarse sand, fine sand, and clay is thrown into quiet water, they will be deposited in the following order: the gravel falls to the bottom almost instantly, followed quickly by the coarse sand and very soon afterward by the fine sand, and then there appears to be a pause, the fine particles of clay all remain in suspension; but finally, when the water is quite motionless, they begin to settle; they fall very slowly, however, and the water does not become clear for hours.

We should, however, imitate the natural conditions much more closely by strewing the detritus in a current of water of varying velocity. The gravel would then be dropped at points where the current was still very strong, and then as the velocity of the current diminished, the coarse and fine sands would be deposited in succession in different places, while the clay would remain in suspension until the water became perfectly quiet, as when a stream enters a lake or the sea, and then it would be slowly deposited.

These are very instructive experiments. We learn from them:—

First, that the power of the water to hold particles in suspension is inversely proportional to the size of the particles.

Second, that all materials deposited in water are assorted according to size, as shown by the specimens of gravel, sand, and clay (**41**) from the shore near Boston.

Third, and this is one of the most important facts in geology, all water-deposited sediments are arranged in horizontal layers, *i.e.*, are stratified, as shown more clearly in the specimens of conglomerate, sandstone, and slate (**42**).

We have now traced to its conclusion, though very briefly, the process of the formation of one great division of *stratified* rocks, — the *mechanically-formed* or *fragmental* rocks. These are so-called because the clay, sand, and gravel are, in every instance, fragments of pre-existing rocks; and because the formation, transportation, and especially the *deposition*, of these fragments, are the work chiefly or entirely of mechanical forces.

All the fragmental rocks are, at the time of their deposition, more or less carefully assorted gravel, sand, or clay; the coarser kinds, like gravel, containing, usually, only enough of the finer material — sand or clay — to fill the interstices between the fragments. After their deposition, the gravel, sand, and clay are usually slowly consolidated or hardened to form conglomerate, sandstone, and slate; but the causes of the consolidation may be most conveniently explained in the guide to the Lithological Collection in Room B.

CHEMICAL DEPOSITION.

It is a well-known fact that the sea holds in solution vast amounts of common salt as well as many other substances; and, as already pointed out, analyses of river-

waters show that dissolved minerals derived from the chemical decomposition of the rocks of the land are being constantly carried into the sea.

Portions of the sea which are cut off from the main body, and which are gradually drying up, like the Great Salt Lake and Dead Sea, become saturated solutions of the various dissolved minerals, and these are slowly deposited. This process is very clearly illustrated along our shores in summer, where, during storms, salt-water spray is thrown above the reach of the tides, and, collecting in hollows in the rocks, gradually dries up, leaving behind a crust of salt.

When water lays down matter which it held in *suspension*, we call the process *mechanical* deposition, and the result is *mechanically*-formed rocks. But when it lays down matter which it held in *solution*, we call the process *chemical* deposition, and the result is *chemically-formed* rocks.

The principal substances which water deposits chemically are common salt, forming beds of rock-salt (**43**); sulphate of calcium, forming beds of gypsum (**44**); carbonate of calcium, forming beds of limestone (**46-47**); and the double carbonate of calcium and magnesium, forming beds of dolomite (**45**). Inorganic deposition, like inorganic erosion, is thus both chemical and mechanical.

ANIMALS AND PLANTS, OR ORGANIC AGENCIES.

As regards the *destruction* of rocks — *erosion* — plants and animals are almost powerless; and a single illustration (**61**) will suffice. This is a fragment of limestone which has been perforated, and thus partly worn away, by a bivalve mollusk. In the role of *rock-makers*, on the other hand, organisms play a very important part, being very efficient agents of *deposition*.

FORMATION OF COALS AND BITUMENS.

The general physical conditions under which peat (**62**) is formed are familiar facts. We require simply low, level land, covered with a thin sheet of water and abundant vegetation; in other words, a marsh or swamp. If plants decay on the dry land, the decomposition is complete; they are burned up by the oxygen of the air to *carbon dioxide* and *water* just as surely as if they had been thrown into a furnace, though less rapidly, and nothing is returned to the soil but what had been taken from it by the plants during their growth. But if the plants decay under water, as in a peat-marsh or bog, the decay is incomplete, and most of the carbon of the wood is left behind. Now, if this incomplete combustion of vegetable tissues takes place in a charcoal-pit, where the wood is out of contact with air from being covered with earth, we call the carbonaceous product charcoal; but if under the water of a marsh, in nature's laboratory, we call the product peat. Peat is simply a natural charcoal; and, just as in ordinary charcoal, its vegetable origin is always perfectly evident. But when the deposit becomes thicker, and especially when it is buried under thick formations of other rocks, like sand and clay, the great pressure consolidates the peat; it becomes gradually more mineralized and shining, shows the vegetable structure less distinctly, becomes more nearly pure carbon, and we call it in succession lignite (**63**), bituminous coal (**64**), and anthracite (**65**).

This is, briefly, the way in which all varieties of coal, and some of the more solid kinds of bitumen, like asphaltum, are formed. But the lighter forms of bitumen, such as petroleum and naphtha, appear to be derived mainly, if not entirely, from the partial decomposition of animal tissues. These, it is well-known, decay much more readily than vegetable tissues; and the water of an ordinary marsh or lake contains sufficient oxygen for their complete and rapid decomposition. In the deeper parts of the ocean, however, the conditions are very different, for recent researches have shown, contrary to the old idea, that the deep sea holds an abundant fauna.

All grades of animal life, from the highest to the lowest, have need of a constant supply of oxygen. On the land vegetation is constantly returning to the air the oxygen consumed by animals, but in the abysses of the ocean vegetable life is scarce or wanting; and hence it must result that over these greater than conti nental areas countless myriads of animals are living habitually on short rations of oxygen, and in water well charged with carbon dioxide, the product of animal respiration. As a consequence, when these animals die their tissues do not find the oxygen essential for their perfect decomposition, and in the course of time become buried, in a half-decayed state, in the ever-increasing sediments of the ocean-floor.

It is important to observe that an abundance of organic matter decaying under water is not the only condition essential to the formation of beds of coal and bitumen; for this condition is realized in the luxuriant growth of sea-weeds fringing the coast in every quarter of the globe; and yet coals and bitumens are rarely of sea-shore origin. These organic products, even under the most favorable circumstances, accumulate with extreme slowness; far more slowly, as a rule, than the ordinary mechanical sediments, like sand and clay, with which they are mixed, and in which they are often completely lost. Consequently, although the deposition of the carbonized remains of plants and animals is taking place in nearly all seas, lakes, and marshes, it is only in those places where there is little or no mechanical sediment that they can predominate so as to build up beds pure enough to be called coal or bitumen. In all other cases we get merely more or less carbonaceous sand or clay. Now these especially favorable localities will manifestly not be often found along the sea-shore, where we have strewn the sand and clay brought down by rivers or washed off the land directly by the ever-active surf; but they must exist in the central portions of the ocean, where there is almost no mechanical sediment and yet an abundance of life, and in swamps and marshes, where there is scarcely sufficient water to cover the vegetation, and no waves or currents to wash down the soil from the surrounding hills.

FORMATION OF IRON ORES.

The iron ores are another class of rocks which are formed through the agency of organic matter. All rocks and soils contain iron, but it is mainly in the form of the insoluble peroxide, and hence cannot be soaked out of the soil by the rain-water and concentrated by the evaporation of the water at lower levels in ponds and marshes, as a soluble substance like salt would be. If carried off with the sand and clay, by the mechanical action of water, it remains uniformly mixed with them, and there is but little tendency to its separation and concentration so as to form a true ore of iron.

But what water cannot do alone is accomplished very readily when the water is aided by decaying organic matter, which is always hungry for oxygen, being, in

the language of the chemist, a powerful reducing agent. The soil, in most places, has a superficial stratum of vegetable mould or half-decayed vegetation. The rain-water percolates through this and dissolves more or less of the organic matter, which is thus carried down into the sand and clay beneath and brought in contact with the ferric oxide, from which it takes a certain proportion of oxygen, reducing the ferric to the ferrous oxide. At the same time the vegetation is burned up by the oxygen thus obtained, forming carbon dioxide, which immediately combines with the ferrous oxide, forming carbonate of iron, which, being soluble under these conditions, is carried along by the water as it gradually finds its way by subterranean drainage to the bottom of the valley and emerges in a swamp or marsh.

Here one or two things will happen: if the marsh contains but little decaying vegetation, then as soon as the ferrous carbonate brought down from the hills is exposed to the air it is decomposed, the carbon dioxide escapes, and the iron, taking on oxygen from the air, returns to its original ferric condition; and being then quite insoluble, it is deposited as a loose, porous, earthy mass, commonly known as bog-iron ore (**66**), which becomes gradually more solid and finally even crystalline through the subsequent action of heat and pressure. When first deposited, the ferric oxide is combined with water or hydrated, and is then known as limonite; at a later period the water is expelled, and we call the ore hematite (**67**); and at a still later age it loses part of its oxygen, becomes magnetic and more crystalline and is then known as magnetite (**68**). Thus it is seen that the iron ores, as we pass from bog limonite to magnetite, form a natural series similar to and parallel with that afforded by the coals as we pass from peat to anthracite.

If the drainage from the hills is into a marsh containing an abundance of decaying vegetation, *i.e.*, if peat is forming there, the ferrous carbonate, in the presence of the more greedy organic matter, will be unable to obtain oxygen from the air; and as the evaporation of the water goes on, it will sooner or later become saturated with this salt, and the latter will be deposited (**69**). Here we find an explanation of a fact often observed by geologists, viz., that the carbonate iron ores are usually associated with beds of coal.

The formation of the iron ores, like that of the coals and bitumens, is a slow process; and the ores, like the coals, etc., will be pure only where there is a complete absence of mechanical sediment, a condition that is realized most nearly in marshes.

FORMATION OF LIMESTONE, DIATOMACEOUS EARTH, ETC.

Aquatic organisms take from the water certain mineral substances, especially silica and carbonate of calcium, to form their skeletons. Silica is used only by the lowest organisms, such as Radiolaria, Sponges, and the minute unicellular plants, Diatoms. The principal animals secreting carbonate of calcium are Corals and Mollusks. These hard parts of the organisms remain undissolved after death; and over areas where there is but little of other kinds of sediment they form the main part of the deposits, and in the course of ages build up

very extensive formations which we call diatomaceous earth or tripolite if the organisms are siliceous, or limestone if they are calcareous.

The specimen of diatomaceous earth or tripolite (**83**) represents that which is now forming in ponds and marshes near Boston; and deep-sea dredging has proved that a similar impalpable siliceous ooze or earth is now accumulating over very extensive areas of the ocean-floor.

The next two specimens (**82, 84**) show very clearly how limestones are formed by the accumulation of shells. At first the shells are loose or unconsolidated (**82**); but they are soon firmly cemented together by the deposition of carbonate of calcium between them (**84**). This newly formed limestone or coquina is a very porous, friable rock; but in the course of time the interstices between the shells become filled with finer fragments and clay, and the coquina is gradually changed to the dense, solid, fossiliferous limestone (**85**) found in the older formations.

Limestones are also made in a similar manner from corals (**86**). The pure coralline limestones, however, are formed chiefly on coral islands and reefs, since the rock-building corals, unlike mollusks, do not flourish in all parts of the sea. They are, in general, limited to regions where the temperature of the sea-water does not fall below 68° Fahr. and the depth does not exceed 120 feet, *i.e.*, to shallow water in the tropics or warmer regions of the globe.

Coral polyps extract carbonate of calcium from sea-water and deposit it within their own bodies. The radiated structure of each polyp is perfectly reproduced in its coralline axis. This is a purely vital function, having no more connection with volition than the secretion of the shell of an oyster or the bones of the higher animals. The carbonate of lime thus deposited within the animal constitutes 90 to 95 per cent. of its whole weight. A single coral polyp is very small, but, like many of the lower animals, it has the power of multiplying indefinitely by buds and branches. Thus are formed compound corals (**87**). These may branch profusely, forming coral trees, or grow in hemispherical masses, called coral heads.

Coral polyps also reproduce by eggs: and thus from one coral tree other coral trees spring up all around and form a coral forest. Finally, the limestone accumulation of thousands of generations of the coral-forest growing and dying on the same spot, together with the shells of mollusks and the bones of fishes, the whole, of course, crowned with the living forest of the present generation, constitute the coral reef. It is evident, then, that a reef is formed somewhat after the manner of a peat bog. As a peat bog represents so much matter taken from the air, so a coral reef represents so much matter taken from the sea-water. As each generation adds itself to the ancestral funeral pile, the reef steadily rises until it becomes elevated far above the surrounding sea-bottom.

The models (**88–89**) illustrate the principal phases of the growth of coral reefs around oceanic islands. The first model shows fringing reefs only. The land is in a state of rest, as regards movements of elevation and subsidence, and the reef-building corals have formed a fringe around the islands, extending out as far as the depth will allow and building nearly straight up from that line to the surface of the water. The fringing reef, represented by the white band following the shore-lines of the islands, is essentially a coral terrace or platform with a breadth inversely proportional to the angle of slope on which it is built, and terminating outwards in a steep, straight wall of coral extending down to the maximum depth of twenty fathoms. When the fringing reef reaches the surface of the water, its growth must stop, unless the water is made deeper by a gradual subsidence of the sea-bottom. This gradual subsidence has occurred in the case of nearly all extensive reefs. As the original island slowly sinks beneath the waves, the outer, most rapidly growing, edge of the reef keeps pace with the downward movement, leaving a shallow, circular channel of water between it and the shore, as shown in the second model. This outer ring of coral is called a barrier reef; and the channel inside of it owes its existence to the fact that the coral grows most rapidly on the outer edge of the reef, where the water is freshest and purest.

The piece of phosphate rock (**81**) represents, in a general way, the accumulation of the bones and excrement of the higher animals, in which phosphate of lime is the chief mineral constituent.

The rocks here considered may be, and, as we have already seen, sometimes are, deposited in a purely chemical way, without the aid of life; and it is important to observe that in no case do the organisms make the silica and carbonate of calcium of their skeletons, but they simply appropriate and reduce to the solid state what exists ready-made in solution in the sea-water. These minerals, and others, as we know, are produced by the decomposition of the rocks of the land, and are being constantly carried into the sea by rivers; and, if there were no animals in the sea, these processes would still go on until the sea-water became saturated with these substances, when their precipitation as limestone, etc., would necessarily follow. Hence it is clear that the animals simply effect the precipitation of certain minerals somewhat sooner than it would otherwise occur; so that from a geological standpoint the differences between chemical and organic deposition are not great.

This section of our subject may be summarized as follows: Animals and plants contribute to the formation of rocks in three distinct ways:—

1. During their growth they deoxidize carbon dioxide and water, and reduce to the solid state in their tissues, carbon and the permanent gases oxygen, hydrogen, and nitrogen; and after death, through the accumulation of the half-decayed tissues in favorable localities, — marshes, etc., — these elements are added to the solid crust of the earth in the forms of coal and bitumen.

2. During the decomposition, *i. e.*, oxidation, of the organic tissues, the iron existing everywhere in the soil is partially deoxidized, and, being thus rendered soluble, is removed by rain-water and concentrated in low places, forming beds of iron ore.

3. Through the agency of aquatic organisms, certain mineral substances are being constantly removed from the water and deposited upon the ocean-floor, forming various calcareous and siliceous rocks.

We now bring the review of the aqueous or superficial agencies to a conclusion by noting once more that the great geological results accomplished by *air*, *water*, and *organic matter* or *life* are: (1) *Erosion*, or the wearing away of the surface of the land; and (2) *Deposition*, or the formation from the debris of the eroded land of two great classes of stratified rocks, — the mechanically-formed or fragmental rocks, and the chemically and organically-formed rocks.

STRUCTURAL GEOLOGY.

Structural Geology treats of the different kinds of minerals and rocks, and rock-structures; and, in its broadest aspect, takes account of the constitution and contours of the entire crust of the earth. This department of geology embraces two distinct sciences: Mineralogy, which treats of the composition, structure, and physical properties of homogeneous chemical compounds or minerals: and Petrography, which treats of the composition, structure, and distribution of rocks, or the massive, impure aggregates of minerals.

The mineralogical collections are in Room A and the Petrographical collections in Room B. The Guide to Mineralogy has been published as a separate volume, and this volume embraces the second division, only, of Structural Geology, — Petrography.

Petrography, the science of rocks, is conveniently divided into two subordinate sciences, Lithology and Petrology. Lithology is an in-door science; we use the microscope largely, and work with hand specimens or thin sections of the rocks, observing the composition and those small structural features which go under the general name of texture. In Petrology, on the other hand, we consider the larger kinds of rock-structure, such as stratification, jointing, folds, faults, cleavage, etc.; and it is essentially an out-door science, since to study it to the