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WALKS AND TALKS IN THE GEOLOGICAL FIELD

WINCHELL

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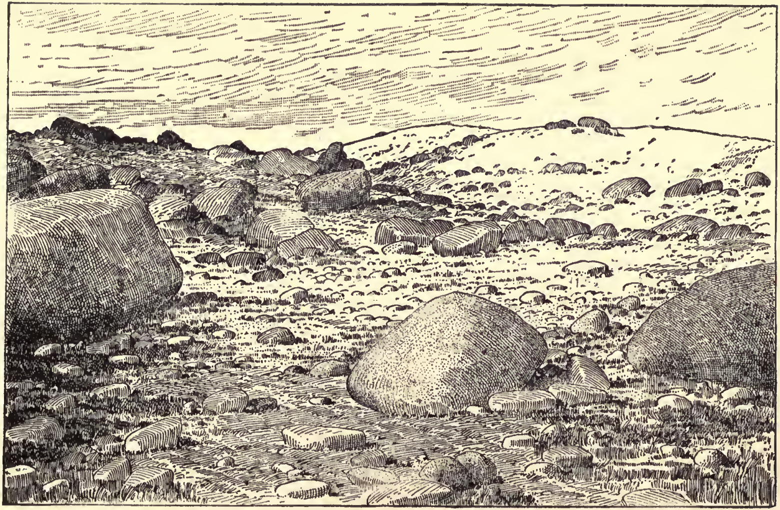

SURFACE OF SOUTH SLOPE OF FRONTAL MORAINE, CHILMARK, MARTHA'S VINEYARD.

Chautauqua Reading Circle Literature

WALKS AND TALKS

IN THE

GEOLOGICAL FIELD

BY

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REVISED AND EDITED BY FREDERICK STARR,

Of the University of Chicago.

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The required books of the C. L. S. C. are recommended by a Council of six. It must, however, be understood that recommendation does not involve an approval by the Council, or by any member of it, of every principle or doctrine contained in the book recommended.

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PREFACE.

In writing this book for Chautauqua readers, Dr. Winchell desired that it should hold a position between text-books and books of light reading. No one was better qualified than he to prepare such a volume. In revising the work, the editor has left it as entirely Prof. Winchell's work as possible. Although a number of pages have been cut out, it is believed that the geological material is all retained and in the author's own words. Marginal comment has been introduced as a convenience to the reader and a few footnotes have been added.

The illustrations used in the work, with two exceptions, have been furnished through the kindness of Major J. W. Powell, Director of the U. S. Geological Survey.

The reader is advised to read the book in sections of related chapters, as follows:

I.-VII.—Surface Geology: The Drift and its origin.

VIII.-XIII.—Strata: Their origin, contents, and position.

XIV.-XX.—Igneous Agencies. Elevatory forces.

XXI.-XXVI.—Economic Geology: The wealth of the hills.

XXVII.-XXXIV.—Fossils.

XXXV.–XXXVIII.—Beginnings of the Earth.

XXXIX.–XLIX.—History of life and the growth of the continent.

Those who knew and loved the author will delight in re-reading his work; to those who did not know him these Walks and Talks will be in some degree a revelation of a true and noble man.

THE EDITOR.

Chicago, Illinois, December 2, 1893.

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WALKS AND TALKS IN THE GEOLOGICAL FIELD.

I. The Geology at our Doors.

SURFACE MATERIALS.

Geology is the story of the earth and of earth's populations. It is more than a story told by some narrator to whom we must listen. We ourselves shall weave the story. We will ask the world to tell its own story. The scope of our study.

We shall travel all over the world. We shall climb over mountain-cliffs and descend into deep mines. We shall go down under the sea, and make the acquaintance of creatures that dwell in the dark and slimy abysses. We shall split the solid rocks and find where the gold, the silver, and the iron are hidden. We shall open the stony tombs of the world's mute populations. We shall plunge through thousands of ages into the past, and shall sit on a pinnacle and see this planet bathed in the primitive ocean; boiled in the seething water; roasted in ancient fires; distorted, upheaved, moulded, and reshaped again and again, in a long process of preparation to become fit for us to dwell upon it. We shall see a long procession of strange creatures coming into view and disappearing—such a menagerie of curious beasts and crawling and creeping and flying things as never yet marched through the streets of any town. And what is most wonderful of all, we shall plunge through thousands of ages of coming events, and sit on our pinnacle and see the world grow old—all its human populations vanished—its oceans dried up—its sun darkened, and silence and midnight and Winter reigning through the entire province in which a sisterhood of planets at present basks in the warmth and light of a central and paternal sun.

Material is all around us.

We must begin at the beginning. Those who go on long and pleasant journeys have to start from their own doorsteps. Geology tells all about this world. The world is *here*—under our feet. It is in the garden and along the roadside, and in the field, and on the shore where the summer ripples sing lullabies to the sleepy crags, and winter storms tear them from their resting-places. No summer ripples or wintry storms are here ; but the solid land is here. Let us walk up this hill-slope and sit where we may get an outlook over a little piece of the world's surface.

Scenery is a geological problem.

What is there, now, within reach of our vision that we can distinguish and describe and say that it belongs to the world—is a part of the world? Whatever it may be, it is a geological fact. It is a part of the science of geology. Now, here is this hill-slope, and the soil and stones which make it. Back of us the hill rises to a higher level. Perhaps brown cliffs frown near its summit; and there are huge, heavy trees upborne five hundred feet above the town. But, in the opposite direction, there is the landscape. That is a geological fact. With all its scenic beauty, that is geology, at foundation. The houses and the herds, the wheat-fields and the gardens—these are accessories. But the dark, beetle-browed ridge which skirts the horizon—that is nature's. The green forest which glides down to the field borders ; the stream which winds across the landscape, and rises and falls with the rains ; the low swells and the valleys between ; the outcropping ledge in the field, and the loose stone by the roadside—these belong to nature. There, in the distance, flies the train of steam-cars, its iron-bound way has been cut through hill and rock-mass, and opens to our view something of the hidden material which goes to form the world. There is the meadow, with its green turf, and deep, dark soil. The gully scored in the hillside by the summer storm, and the train of stones and sand at its foot—which the water tore from their hiding-places beneath the soil. Up the stream we see the tamarac swamp or the open marsh, through which the head-waters flow—the head-waters of the main stream or of some small tributary. There, just beyond, is the little lake or pond, sleeping in its green-fringed nest, and looking out on the grass-covered slopes and the blue sky.

This is all geology. We are in the midst of it. We have been enchanted by it before we knew its name. We have admired the forms fashioned in beauty by the hands of the geological forces before we knew that it had a geological origin, or possessed any geological significance, or had passed through long ages of preparation. We have been like children born in the parental dwelling, reared in the midst of its comforts and adornments, without once thinking that, before we were born, some mind planned the dwelling, some hands reared its walls, laid its floors, and fashioned every doorway and casing. The green slope was made; the pretty lake was scooped out; the swelling hill was shaped; the dark mountain was upbuilt, its foundations were laid, its vast weight has been sustained and is to-day sustained by some support, with strength proportioned to the requirement. It is time for us to come to a realization of these facts.

We may begin in this very spot to inquire how this terrestrial home was fashioned. It was made without hands, but not without the use of the same forces of nature and properties of matter as were employed in the building of our paternal dwelling. Its plan was not drafted on paper and carried out under the direction of a builder, who issued his orders in audible tones; but our terrestrial abode is built under a plan just as real and just as intelligible, and is just as truly a fit subject for study. There is this difference, that we may arrive at a complete understanding of the plan and purposes and modes of construction of the paternal home; but of the terrestrial home we can only arrive at an incomplete understanding.

Its materials, our first study. If we decide to interest ourselves in the inquiry, how the world was made and what it has become, we must first give attention to the *materials* of which it is composed. It is a stone dwelling; it is imperishable—at least as imperishable as granite foundations and massive courses of masonry can render a structure. Here are, indeed, beds of gravel and sand, overspreading the greater part of the country. These are not firmly consolidated, and are easily moved out of place. But they are like the gravel used on the roofs of some buildings—a very insignificant part of the whole. Underneath these loose materials we shall find the solid and enduring foundations. But the study of the loose surface materials is full of interest, because their presence renders the earth habitable. What sort of a home for man or beast would this planet be, if all the loose surface beds were cleared off down to the rocky floor on which they rest? Did you ever hear that question asked before? We must, by all means, begin with the stones, and sands, and clays, which lie upon the surface, or near the surface, and try to ascertain what they are and how they are arranged, and of what use they are to man.

II. Lost Rocks.

BOWLDERS.

Who cares for a cobble-stone? It is a kind of nuisance anywhere—so most people think. The farmer would be glad to have every one of them carted from his fields. I have seen land so thickly covered by them as to be almost impossible to cultivate. You will notice that cobble-stones are of various sizes. In fact, it is difficult to state where a cobble-stone is small enough to be called a "pebble," and just where it is too large to be a cobble-stone. Pebbles differ from them only in size. Pebbles are hard and rounded, and seem formed of the same kinds of rocks; and the large, rounded, loose stones, which lie scattered over the earth's surface, are in every respect

Bowlders.

only a larger style of cobble-stones. It is plain that these are all *one class of rocks.* So it has been decided; and geologists call them *bowlders.* This is an old name used by common people before the science of geology existed, because these stones are rounded like balls or *bolls*; and, being loose on the surface, are apt to be *bowled* about. Even grains of gravel and sand appear to be of the same nature as bowlders. You will also notice, especially, that these rocks are all separate and detached, as well as rounded, and they are of various colors and mixtures of colors. They are apparently different kinds of rocks, which by some means have been brought promiscuously together. Ledges of rock, which you must have noticed many times, are generally all one kind of rock. They extend long distances, and continue under the earth. Should a ledge of rocks become broken up, and the fragments, large and small, have their angles rounded off, and the whole then be scattered over a township, far from the ledge, the result would be much like what we see in our actual bowlders. From all we know of rocks we are constrained to believe that our bowlders are rounded fragments of broken up ledges. But where are the ledges? Not in the next township or county. Perhaps not in the next state or province. They have strayed far away from their native ledges. They are "lost rocks." Now, it would be very interesting to know where the parent ledges are; and it is curious how these fragments have been transported so far, and how they became so rounded, instead of remaining angular, like the stones blasted from a quarry.

The origin of bowlders.

Indeed, the more we think about this, the more astonishing the facts appear; for we call to mind that just such bowlders are scattered all over our northern states, and they lie buried beneath the surface in countless numbers. And the very sand and gravel, to the depth of many feet, is only the same kind of material in a finer state. What an incalculable amount of work has been accomplished in transporting all these materials so far that the places from which they came have been lost, and can not be found. Suppose it were necessary to cart all the loose stuff on a township to a distance only one mile further, on what terms do you think the contract would be taken? But all that stuff has been moved—not one mile alone, but many miles. And not alone the stuff on a township, but the stuff on ten thousand townships. The work was not done, you say, by the slow process of hauling in carts. No, indeed; but it was done somehow, and it is the same job whether performed by Nature's method or by human muscle.

"Lost rocks" are travelers.

What do you imagine was Nature's method? Would it not be a grand discovery if we could find out? It was Agassiz that ascertained this, and the discovery gained him great fame. Suppose we could stand by and see Nature in the midst of the job—carting and dumping on the bare surface of the rocks, the gravel and sand and clay so indispensable to render the surface of the earth habitable for man or beast or plant. I think we should consider it a grand revelation of the method and mind of the Author of nature. I am happy to assure you that we have found out pretty precisely how this immense and beneficent work was done.

Many bowlders attain to dimensions which are

Some great bowlders.

truly enormous. The largest are found in northern New England and Canada. As we proceed southward, the average size diminishes, and south of the parallel of Cincinnati, bowlders are entirely wanting, except along the Appalachians. In New Hampshire are many immense bowlders, which have excited the wonder of all who have seen them. Several of these have been described and figured by Professor C. H. Hitchcock in his Report on the Geology of New Hampshire. The Churchill Rock of Nottingham is 62 feet long, 40 feet wide and 40 feet high. It contains 75,000 cubic feet, and weighs 6,000 tons. Close by is Chase Rock, 40 feet long, 40 feet high and 30 feet wide. Vessel Rock, in Gilsum, now split by frost, weighed 2,286 tons. The Green Mountain Giant, in Whittingham, Vermont, weighs 3,000 tons; and a bowlder formerly existing at Fall River, Massachusetts, weighed 5,400 tons. At St. Ignace, in the Upper Peninsula of Michigan, lies a porphyry bowlder 25 feet in height. Mr. G. M. Dawson, in his Report on the Geology of the Northwest Territory, describes a quartzite bowlder 42 feet long, 40 feet wide and 20 feet high, and another nearly as large. It appears that the greater part of North America, down to the latitude of Cincinnati, is overstrewn by incoherent materials containing bowlders. The situation is similar in Europe; and there, also, certain "lost rocks" or "erratics" attain vast dimensions. The "Pierre à bot" (or Toad-stone), on the Jura Mountains, about two miles west of Neufchâtel, contains 40,000 cubic feet, and weighs 3,000 tons. As far south as the Lake of Como, bowlders of large size are very frequently encountered.

Often these lost rocks lie perched on the summits of sharp cliffs; and sometimes we find them so nicely poised that the strength of a man suffices to give them a tilt. They are then called "rocking stones." In Hanover, New Hampshire, half a mile east of Dartmouth College, is a rocking stone 12 feet long, 10 feet wide, 5½ feet thick, containing 480 cubic feet. In Goffstown is one 8 feet high and 42 feet in circumference. In Barre, Massachusetts, is one having a smaller bowlder on its back, which, when in motion, suggests the idea of a child's rocking-horse. One in Fall River, poised on granite, weighs 160 tons. **Rocking-stones.**

We find bowdlers at various altitudes, from the level of the sea, to the height of perhaps six thousand feet; but above this, though rock fragments are extremely numerous, they are mostly angular, and appear to be derived from rocky ledges close by. They are not "lost rocks." The summit of Mt. Washington is covered by a bed of angular fragments, and such fragments are common for two thousand feet below the summit. Lower than this, rounded bowlders are abundant. Professor C. H. Hitchcock, however, thinks he finds real transported rocks to the very summit. The great quartzite bowlder in the Northwest Territory, Canada, is 3,250 feet above sea-level. Many others in that part of the continent are up to 4,400 feet in elevation; and in one region, attain 5,280 feet. Some erratics on the flanks of the Sweet Grass Hills lie at an elevation of 4,660 feet. The Pierre à bot, in Switzerland, is 800 feet above Lake Neufchâtel, which lies itself 1,427 feet above sea-level. **Bowlders of high elevations.**

We observe, in passing over the country, that the

The sources of bowlders.

larger bowlders are northward; while toward the south, their average size diminishes to cobble-stones, and finally, all indications of transported rocks disappear. Since we have concluded that all these lost rocks have been removed from extensive ledges somewhere, it seems probable that the direction of these ledges is to the north. We notice also, that bowlders of any particular kind become more numerous, as well as larger, as we proceed northward. In fact, in some cases, by following up a train of bowlders of a particular kind, we trace them to their origin. That origin is often sixty or one hundred miles, or even two hundred miles away. It is not always possible to trace bowlders to their source by following back a train. But we can always consider where is the nearest locality of bed-rocks of the same kind as any particular bowlders. For instance, in Connecticut, we can find these bed-rocks sometimes, in the near vicinity, but at other times, not farther away than Massachusetts. In Ontario, the nearest sources of the bowlders are in the regions east and north of Georgian Bay. At Chautauqua, the nearest bed-rock for the hard bowlders is beyond Lake Ontario and Lake Simcoe. In Michigan, the nearest source is north of Lake Huron and south of Lake Superior. So in Indiana, Illinois, and the northwest generally, we must go northward to find rocks in place which are of the same sorts as the bowlders. This is plainly demonstrated in the case of bowlders of *native copper*, which are frequently found in Wisconsin, Illinois, Indiana, Michigan, and Ohio. There is no other credible source than the native copper region south of Lake Superior. So, in the case of the Pierre à bot, near Neufchâtel, the nearest credible source is the Mont Blanc chain of Alps, seventy miles distant, and separated by the valley of Switzerland and the Lake of Geneva.

Generally from the north. We seem authorized to conclude, therefore, that the bowlders have been transported generally from the north; that many of them have been moved one or two hundred miles; that they have sometimes been borne over regions which are now lake basins; that they have been carried, at times, to higher levels than their origin, and much higher than valleys over which they passed; that a vast mass of sand, gravel, and clay was moved with them, since they lie imbedded in these accumulations, to the depth, sometimes, of one or two hundred feet.

III.—The Gravel Pit.

ARRANGEMENT OF THE DRIFT.

Drift. This subject has its alphabet, like most others; and every child can testify that there is little inspiration in the alphabet. A few more letters of our alphabet will be found in the *arrangement* of the loose materials which cover the surface of the northern states. These materials are called *Drift.* The bowlders are a part of the Drift. We wish to know more about the internal constitution of this deposit. Let us visit a gravel pit, or some deep railroad cut through a pile of these incoherent materials.

Do you find these loose sands and gravels arranged in regular courses? Yes, you say; and then you hes-

Structure of the Drift.

itate; and well you may; for the semblance of courses is exceedingly interrupted. Here is, indeed, a layer or bed, or stratum of sand, but it thins out in one direction, and in the other loses its upper and lower boundaries, and merges in a general mass of sand. Here is a bed of gravel, but it lies at a different inclination from the last, and in one direction it changes to sand, while in the other, it becomes split up into a number of subordinate layers which bend down and lose themselves. This bed also is composed of many oblique laminæ, coarser and finer in alternation, which are cut off completely by the upper and lower surfaces of the bed or stratum. What is singular, the very next bed below this, which is also obliquely laminated, has its laminæ tilted in the opposite direction. And then next to this is a long straight course of cobble-stones and pebbles.

Variety of Drift material.

In some places are large beds of fine sand, which are taken out and used for mortar-making. In others we find extensive deposits of gravel and pebbles, which are used for paths and streets. Mixed in the sands are some cobble-stones and large bowlders. Here and there, too, are some beds containing much clay; and these are impervious to water. Now, all this is not a regular nor a perfect bedding or stratification. We may say the Drift here is semi-stratified. You can all recall some locality where this arrangement of materials occurs.

Upper and lower Drift.

This cut or exposure, however, extends only fifteen or twenty feet down. How is the arrangement below? There are places where the bed-rock is not reached in less than a hundred or two hundred feet.

There are wells fifty to eighty feet deep, without reaching bed-rock. Those who have seen such wells have observed the deeper structure of the Drift; and they report it much like what we see in the gravel-pit. I will tell you how we shall ascertain the arrangement to the depth of perhaps two hundred feet. Go to the lake-shore, or the sea-shore. Of course it must be a place where the shore is not formed of bed-rocks. Here the whole thickness of the Drift may be cut through, exposing at the bottom the solid foundation on which the Drift reposes. Well, here we find two kinds of Drift. The semi-stratified Drift passes down into a sheet of Drift quite unstratified. It consists of blue clay and a large quantity of imbedded bowlders. These are rounded like those at the surface. They are in every respect the same thing—made, apparently, by the same agency; transported in the same company. This is the Bowlder Clay or *Till*.

Till or Bowlder Clay.

We must state, however, that in some situations the semi-stratified Drift rests directly on the bed-rock. Perhaps in these places the Bowlder Clay was washed off before the semi-stratified Drift was laid down. Again, there are many places where the semi-stratified Drift does not rest on the Bowlder Clay—perhaps because it was never laid down; but more probably because it has been removed. In such places the stiff, blue clay is exposed over the surface, and the soil is full of bowlders. Can you not call to mind such a place?

Both members of the Drift not always present.

The sheets of sand and gravel, often obliquely laminated, which we saw in the gravel-pit, were there cut through in a vertical section presented edgewise.

You must think of these sheets as extending into the earth a certain distance, but very irregular in extent as well as in form and position. Some of them are flat; some are concave upwards, and some are convex. Now and then one is nearly horizontal, but most are considerably inclined.

Stratified Drift structure due to moving water.

Did you ever see a huge mound of rock-rubbish at the foot of a torrent rushing down a steep ravine to the open, level land—a torrent sometimes suddenly swollen to a terrific and maddened volume, which tears stones and trees from their fastenings? And have you ever seen such mound cut through for a highway or other purpose? If you have, you have witnessed a semi-stratified order of deposition somewhat like that in the Drift. Those who have thought on this resemblance have reached the conclusion that the semi-stratified Drift must have been moved and laid down by some kind of *torrential action.*

Unstratified Drift structure not due to water.

But however this was, the origin of the bed of Bowlder Clay must have been very different. Here is no sort of bedding. The whole is in a state of uniform confusion. Evidently, then, Nature employed two kinds of action successively in transporting and dispersing the Drift. In the semi-stratified Drift, water in tumultuous movement may have been the chief agent. In the Bowlder Drift water was *not* the chief agent, since here is none of the assortment and stratification due to water, and here also are rock-masses moved scores or hundreds of miles, and these results are not ascribable to water.

Let us take another glance over the general distribution of the Drift. We have seen the bowlders increasing in bulk and abundance northward. We have seen the whole Drift formation terminating southward on about the parallel of Cincinnati. We find incoherent surface deposits in Kentucky and southward; but they contain no bowlders; and they have mostly resulted from the disintegration and decay of the bed-rocks in place. The Drift, then, is a *northern* phenomenon.

The Drift a northern phenomenon.

If we notice more carefully the detailed distribution of bowlders, we find that, while they have generally moved southward, there has also been a radial distribution from high mountains. In New Hampshire the bowlders move east and west from the White Mountains, as well as south. In Switzerland, the *Pierre à bot* and thousands of other bowlders moved north-westward from the Mont Blanc range—though on the opposite sides of Mont Blanc the movement was in the opposite direction. In the Rocky Mountains and the Sierra Nevada, the movement of the bowlders was east and west from the mountain axis. So, too, the southward distribution of bowlders was greatest along mountain elevations.

Bowlders have traveled southward.

Thus the distribution of Drift materials sustains a relation to altitude similar to that which it sustains to latitude. What factor, or force, or agency exists in altitude which exists identically in latitude? Temperature, certainly. To ascend a high mountain range is the same as to ascend to a high latitude. All high mountains support animals and plants related to species farther north. Ascending the Andes, you have tropical products at the foot, temperate products at ten thousand feet, and arctic conditions at the summit. The distribution of the

The relation of temperature to the distribution of Drift.

Drift, then, has relation to heat and cold. Greater cold has been accompanied by larger results.

Now, how does cold act to effect transportation of rock-fragments? Our thoughts run over the world to scrutinize the modes of action of cold. Much cold implies much snow and ice, if moisture and water are abundant. Most far northern regions and high mountain summits are covered much of the year, or the whole of it, by a sheet of snow. Winter snow, under the action of thawing and freezing temperatures in alternation, becomes granular, as we often observe in old snow, especially in early spring. With a more advanced stage of granulation, the icy grains coalesce into larger grains, and finally merge completely into a solid mass of ice. This, also, we have often noticed in the last lingering patches of last winter's snow.

Glacier formation.

We have many observations of this kind on a large scale. On high mountains broad fields of granular snow come into existence, and at a certain elevation the average annual temperature is not sufficient to dissolve it before autumnal snows begin to increase the amount. The old snow becomes a permanent granular sheet on the high slopes. In the Alps the Germans designate it *Firn*, and the French, *Névé*. When the firn-masses are accumulated in valleys, the amount of snow is so great that it may reach to a much lower altitude before finding a temperature which will suffice to melt it all away before the next winter. So tongues of granular snow stretch down the mountain valleys, and being, like our late spring snow, exposed to increased action of warmth, these valley prolongations of the upper firn become completely changed into solid ice. This is now a *glacier.*

Movement of glaciers.

All substances expand with increase of temperature, and contract with reduction of temperature. The glacier is certainly at a lower temperature in winter than in summer — though it can never be warmed above thirty-two degrees Fahrenheit, which is the thawing temperature. The surface of the glacier is also at a lower temperature during the night than during the day. The glacier, therefore, must sometimes expand and sometimes contract. Now, when it expands, the whole expansion will be developed at the free lower border, since the upper border is frozen to the earth, and pressed also, by the snows beyond. Also, if both were free, *most* of the expansion would be developed below, because gravity aids motion downwards. Next, when the glacier contracts, the lower border does *not* retreat, because the ice is not strong enough to bear the pull of the mass up the slope. The ice breaks in innumerable little cracks. These are soon filled with water, which freezes, and thus restores the complete solidity of the glacier. Thus, when the next expansion takes place, the glacier takes another slide down the valley. So the glacier travels. So, if a whole state should become glacier-covered, the ice-sheet would have a motion from higher to lower, and from colder to warmer. Every thing on its surface would be transported; every loose object beneath it or in front of it would be pushed forward.

Now, here are some hints toward an explanation of the method of transportation of our millions of bowlders. If we go to the Alps we find exactly such

The glacier is the agent of bowlder transportation.

glaciers, on a small scale, performing precisely such work. Thus our theory receives confirmation. We can not pretend that glacier action explains all the phenomena of the Drift. The action which arranged the semi-stratified Drift must have been exerted by water rather than ice. But we leave the subject now to your thoughts. By and by we shall come upon this subject again from another direction. (Talk XLVII.)

IV. Among the Glaciers.

GEOLOGICAL ACTION OF GLACIERS.

Perhaps it is best to pause at once and contemplate a fuller sketch of some living glaciers. We indulged in a little speculation about the cause of the Drift. We argued that glaciers must perform a work pretty nearly such as the Drift required ; and I cited you to Alpine glaciers as actually exemplifying this kind of work. But come, now, let us take a closer look at Alpine glaciers.

The vale of Chamonix and its glaciers.

About fifty miles from Geneva lies the "vale of Chamonix" — the classic valley of classic glaciers. Its axis lies nearly east and west, and the Arve, taking its rise from the east, flows through the length of the valley, and bends north to the Lake of Geneva. On the north, the valley is bounded by the sharp pinnacled Aiguilles Rouges (A-ghee-Roosj) ; on the south rises the stupendous mass of the Mont Blanc (Blahnc) range, nearly sixteen thousand feet above sea level. The rounded summit of the monarch mountain is silver white with perpetual snow. On one shoulder rises the Dome du Goûter, and beyond this, the Aiguille de Goûter, (A-ghee-du-goó-tay). For three thousand feet below the summit, compact snow covers the surface to an unknown depth. In one region below the Aiguille de Goûter, may be seen a long perpendicular cliff of snow left by a slide. It looks like a vast entablature to the glittering dome. This is said to be fifteen hundred feet in height. At the foot of the final dome stretches a fathomless crevasse, in which a number of persons have been lost. This is the "Grande Crevasse," and for a long time it prevented all successful approach to the mountain's summit. Sometimes a temporary bridge is stretched across by drifting snow. Occasionally it becomes sufficiently solid to serve for a passage over, but it is always treacherous.

Features of glaciers.

From the Grande Crevasse stretches a gentle slope called the Grand Plateau at an elevation of thirteen thousand feet. This is covered with granular *névé*. Along its lower limit the snow-mass is broken into tumultuous confusion, and the passage over it is difficult and dangerous. Below this is the Little Plateau, ten thousand feet above sea-level; and then come other broken belts of snowy precipices. Now, the upper limits of two glaciers are reached in the downward flow of the ice. This common ice-field is a scene of grand confusion. The mountain slope beneath the ice-sheet presents many irregularities of pitch, and many projecting bosses. Over all these the ice-stream flows toward the lower level. In one place, nine thousand feet above sea-level, a vast pinnacled mass of rock rises some hundreds of feet above the ice. This divides the wide stream, but the parts completely coalesce again around the lower side. In other places, the underlying inequalities break the sheet by fractures large and small. Some of these crevasses extend up the general slope, and others are transverse. The ice-mass is therefore broken into innumerable prismatic fragments. The tremendous mashing together which they experience through the movements of the flow, squeeze numbers of them out of their places; and they stand as huge pyramids and columns ten, twenty, and forty feet above the general surface. The columnar forms are called *séracs.* The afternoon sun acts on them, and some are sharpened to a point; others are worked out at the sides, and stand with broad flat caps. Finally they tumble down or waste away, while new ones rise in other places. Though the ice is continually shattered by crevassing, the fissures are continually closing together, when changes in underlying configuration permit. Two fractured surfaces pressed tightly unite again as one mass; and a patch shivered into ten thousand fragments becomes solid and transparent under the lateral squeezing to which it may become subjected. So, to whatever extent the ice-sheet may be shattered, it is continually healing, and tends to return to the condition of a sound and solid mass. Thus the tourist, picking his way among the séracs, and jumping the bottomless chasms, hears frequently the detonation of some new split, which is echoed back from the red pinnacles of Mont Maudit, which rises on his left. These themselves hurl down rocky fragments to keep alive the watchfulness of the traveler, and place material on the back of the glacier to be borne gradually but steadily down toward the valley.

The common glacier-field just mentioned strikes the sharp upper limit of a mountain salience, which slopes down to the valley of Chamonix, and separates two mountain valleys. This prominent dividing point is the Aiguille de la Tour. As the common ice-mass impinges against it, the ice parts to the right and left like a river. Down the western valley flows the ice-stream known as the Glacier de Taconnay. Down the eastern valley flows the greater stream known as the Glacier des Bossons, having the little village of Bossons at its foot. Another valley lies still farther west, and the common ice-field of Mont Blanc fills it with a stream known as Glacier de la Gria.

These three glaciers descend to the valley on the west of the pretty village of Chamonix. On the east are three others. The nearest is the celebrated Mer de Glace, the lower part of which is called the Glacier des Bois, with the little village of Bois at its foot. The snowy eastern slope of Mont Blanc and Mont Maudit (Mo-deé) feeds an enormous glacier which, to an observer from the valley of Chamonix, lies behind the pinnacled summits of Charmoz and Midi. This is the Glacier du Géant, and it forms the western tributary of the Mer de Glace. Into the head of the Mer de Glace comes the Glacier de Léchaud (La-shó), fed by the snow-fields of the Grandes Jorasses. On the east, the Léchaud is reinforced by the broad triangular Glacier de Talèfre (Tah-lefr') in the midst of which, at an elevation of 9,143 feet, is the Jardin, an island of land-surface, walled in on all sides by lofty mountains, and adorned in August with a display of several species of Alpine flowers. Beyond the Mer de Glace is the Glacier of Argentière—a fine long river of ice, almost equal to the Mer de Glace itself. The bright village of Argentière lies at its foot. At the very head of the valley of Chamonix comes down from the same direction, the Glacier du Tour.

The scenery of the vale of Chamonix.

Thus six glaciers descend into the valley, and each contributes its torrent of muddy water to create and swell the Arve. This grand series of ice-rivers and the more majestic mass of the mountains, with their swelling domes and sky-piercing pinnacles, may be contemplated as a panorama from the summits which overlook the valley from the north, and put the spectator face to face before the stupendous Mont Blanc range. No person can gaze on this spectacle from the Flégère, which faces the Mer de Glace, or from the Brévent, which faces directly the Glacier des Bossons and Mont Blanc, without feeling a sympathy with Coleridge in his "Hymn in the Vale of Chamonix":

Coleridge's hymn.

"Ye ice-falls! ye that from the mountain's brow
Adown enormous ravines slope amain,
Torrents, methinks, that heard a mighty voice,
And stopped at once amid their maddened plunge!
Motionless torrents! silent cataracts!
Who made you glorious as the gates of heaven
Beneath the keen full moon? Who bade the sun
Clothe you with rainbow? Who with living flowers
Of loveliest blue spread garlands at your feet?
God! Let the torrents like a shout of nations
Answer, and let the ice-plains echo, God!"

The conception of a glacier as a frozen cataract is suggestive and truthful. When, from the Montanvert, overlooking the Mer de Glace, De Saussure contemplated the sea of ice, he received an impression thus recorded: "Its surface resembles that of a sea which has become suddenly frozen—not during a tempest, but at the instant when the wind has subsided, and the waves, although very high, have become blunted and rounded. These great waves are nearly parallel to the length of the glacier, and intersected by transverse crevasses, the interior of which appears blue, while the ice is white on its external surface." Farther down, in the narrow Glacier des Bois, the séracs and needles bristle over the surface in mighty uplifts and fearful confusion.

De Saussure's description.

The crevasses really run in any direction, according to the nature of the underlying surface. In length they vary from twenty feet to a mile. The downward direction is originally vertical, but as the surface of the glacier moves more rapidly than the deeper portions, the transverse crevasse assumes, after a while, an inclination which gives it a dip up the valley. Its depth may be ten or a hundred, or two hundred feet; and its width, which is a few inches at first, may grow to fathoms. Forbes measured a crevasse at the base of the Glacier du Géant, which had a breadth of not less than 1,214 feet. The two walls generally approach each other downward, and we may sometimes safely descend to the bottom. The wall-ice is absolutely immaculate, with a greenish blue transparency. Down in the crevasse we hear the rills coursing through the substance of the glacier, and sometimes the central torrent rumbling along the bottom. The surface of the glacier is white and granular, from the action of the sun. Pools of

Crevasses.

water rest here and there—pure, cool, and refreshing—and numerous rills flow over the surface, discharging themselves through crevasses and perforations in the ice-mass, into some subglacial stream.

Lateral moraines.

Each of these great glaciers is bordered by a *moraine*, or long ridge of material thrown off the surface in the course of ages, and pushed up by the movements of the ice. It consists of clay and rounded bowlders. It is completely unstratified, and resembles precisely, the till at the bottom of the Drift. These lateral moraines at the present epoch, tower fifty to eighty feet above their glaciers. The ice, for centuries, has been in process of shrinkage. Such masses of *débris* could never have been raised by the existing glaciers. Other attestation of a former higher stage of the glaciers is seen in the smoothed and striated rock-slopes which bound the glacier valleys. These surfaces remind us of the smoothed and striated rocks underneath the till in America. The records of the glaciers may be traced on these smooth slopes, two or three hundred feet above the present ice-surfaces.

Terminal moraines.

At the foot of each glacier is a terminal moraine, which is continuous with the two lateral moraines. Among the Chamonix glaciers, this moraine is half a mile or more below the termination of the ice, showing to what extent the glaciers have diminished in length. These remote moraines were left in 1817 and 1826. The "chief of guides" at Chamonix remembers the occasion, and narrated to me a number of memorable incidents. The plain between the moraine and the foot of the glacier is strewn with bowlders. Many descend on the surface of the ice or imbedded in its mass. One sees them frequently precipitated from the foot of the Glacier des Bois to the plain below. The diminution of the glaciers appears to be a persistent phenomenon, and not dependent on climatic fluctuations of short period. There must be either a continuous diminution of cold or of precipitation.

All parts of the glacier mass move continually downward. In the Glacier des Bossons the amount of the movement has been determined by means of a catastrophe. In 1820, eight persons were buried in the Grande Crevasse at the foot of the dome of Mont Blanc. In 1861, their remains began to appear in the ice near the termination of the glacier. In forty years they had traveled 26,000 to 29,000 feet, or 680 feet a year. As they were buried 200 feet beneath the surface, it appears that 200 feet had been melted from the top of the glacier in the same interval. The Mer de Glace, as shown by Forbes, moves past Montanvert at the rate of 822 feet per annum. Near the foot of the Glacier des Bois the motion is 209 feet a year. The lower Glacier of the Aar, which was the scene of Agassiz's observations, moves downward at an average rate of 250 feet per annum. Hugi's hut, according to Agassiz, had been carried 5,900 feet in thirteen years. A record bottled up by Hugi, stated that it had traveled 197 feet in three years and 2,345 feet in nine years. The great continental glacier would not have traveled at rates so rapid; but if it moved 200 feet a year, the time required to transport a bowlder 250 miles would be 6,600 years. **Glacial movement.**

These interesting Chamonix glaciers are but the stumps of what they have been. Once they were

Alpine glaciers are remnants only.

noble tributaries of a greater glacier which filled the valley of Chamonix. Out of this valley it passed along the valley of the Arve, all the way to Geneva. As we ride along the highway, the rocky bounding walls rise on either hand, smoothed and scored after the same fashion as the rock-walls of the valley of the Mer de Glace. Evidently, the Chamonix glaciers have long been in process of shrinkage. Evidently, they once existed under an enormous development. When that period was passing, we may well believe our northern states were extensively glaciated, and a work was in progress very nearly like that which we have already reasoned out.

V. The Hillside Spring and its Work.

SUBTERRANEAN WATERS AND THEIR DEPOSITS.

Where goes the rain which falls upon the earth? If the surface were completely level, and all the water should stand which comes from the clouds in the form of rain and snow in one year, it would be everywhere about forty inches deep. Such an amount of water would be 34,480 barrels on every acre. What becomes of all that water?

Rain water in soaking into ground dissolves parts of its material.

Part of it runs off, you say; and part of it soaks in the ground. True, and part of it evaporates, and is afterward condensed and rained down again. Also, part of that which soaks in the ground returns when the surface becomes dry, and is evaporated. But, let us attempt to follow the water which soaks in. First of all, it must have dissolved some substances with which it came in contact at the surface. These substances must be, to a limited extent, certain mineral constituents of the Drift; but the Drift has been so many thousand years exposed to rains, that all its readily soluble constituents have been dissolved away from the surface. The chief agencies which supply soluble matters to the surface are man and animals. The underground waters, therefore, carry with them a certain amount of solutions of organic and inorganic origin, and are not absolutely pure, like carefully distilled water. They may even be poisonous and unsanitary.

Clay beds arrest descending water.

Following these waters in thought, beneath the surface, we see them percolating through the sands and gravels, which we have found to make up the principal part of the upper Drift. Through layer after layer they continue to descend. If any obstruction is encountered, they are quickly deflected around it, and so continue to settle toward the impervious Bowlder Clay at the botton of the Drift; or, if that is absent, the waters settle to the bed-rock. We will not attempt, at present, to follow them in the rocks.

Now, we know that the Drift contains sheets of impervious clay. Of course, then, these intercept the descending water. The water arrested by a clay-bed saturates the overlying sand, and gradually flows along the surface of the clay to a lower level. But we have seen that all these Drift beds are of quite limited extent. The water, therefore, soon reaches the edge of the clay-bed and escapes down to a lower level. Probably it is again intercepted by a deeper clay-bed. Along this it flows in a similar way, and so continues—always approaching nearer and nearer to the lower limit of the Drift. Some of the clay-beds are concave upward, and thus form real dishes or cisterns, which remain full.

Conditions for wells.

Suppose we dig a well. While passing through the sandy strata, from which the water drains away, no supply will be struck. As soon, however, as we reach one of the subterranean basins or cisterns, a supply is found. Should we dig a hole through the bottom of the cistern, we would, of course, lose much if not all of the water. But we might continue down to the next water-basin.

Let us suppose another well is needed, a few rods away. We must not be too sanguine in the expectation of getting water at the same depth. Perhaps the new well is beyond the limits of the higher water basin ; we must then dig to some lower one. Perhaps the new well is on higher ground ; it does not follow that we must dig to the level of the basin in the first well. In the higher ground may be a higher water-basin ; and so the second well, though several feet higher than the first, may not require to be so deep.

Do not suppose these water-beds are everywhere of such limited extent. There are districts where the same bed may be traced one or two miles. The bed, in such cases, is nearly horizontal ; and that condition of the underground structure is indicated by a level condition of the surface.

Hillside springs.

Now, how are springs produced? Suppose a river valley has cut through a deep mass of the Drift, must it not cut the water-bearing sheets with the rest? And when that is done, will not the water flow out? Certainly. The water in escaping from the cut edge of the sheet finds some spot where least resistance is experienced, and there it escapes in largest quantity. It forms a sort of stream, and by degrees wears a little channel, which extends back into the bank, opening at its mouth in a little arch under which the water finally escapes. Of course, all the work was accomplished before we ever saw the spring. A well is an artificial spring.

Generally, the water of a hillside spring is allowed to flow off to a brook or rivulet. In the course of a number of miles, scores or hundreds of springs may discharge their contributions into the stream. In fact, the greater part of the water in the stream is supplied by springs. It gets directly from rains only so much as flows from the surface of the basin which the river drains. Most of the rain falling within the basin, however, sinks into the ground, and finds its way into the stream only in the form of spring water. But when a stream flows over a drift-formed bed, much water wastes away. Besides this, many deep water-basins convey their contents under the river. So the river never contains the whole amount of water which falls within the basin which it drains.

Value of springs.

Suppose all the water-basins under a township or a county should cease to exist, what would become of wells and springs? You understand at once that they would dry up. Therefore the streams would dry up. The water would settle to the Bowlder Clay or the bed-rock, and there would be the only accumulation. Every well must then be sunk to that depth—even if it were two hundred feet. And wells would be the only resort, for of springs there would be none; of brooks there would be none; of ponds and lakelets there would be none. Then, again, the Drift sands being so dry, little evaporation would take place from the earth's surface. The air would be dry ; no dew would condense ; no clouds would form, and so the rains would stop descending, unless some other region could supply us with clouds. How beneficent, then, are the clay-beds ! Literally, they are all which saves many a fertile region from becoming a desert and an uninhabitable waste.

In regions of deep Drift and abundant water-basins, the supplies of spring-water are sometimes sufficient to meet the demands of towns and cities. The city of Ann Arbor, with its ten thousand of population, is thus supplied with nearly five hundred thousand gallons daily. This is obtained from two groups of springs, and distributed through the city in the usual way. Five times this amount could be had, if needed.

Solution of limestone.

Now let us consider springs in another light. We have already reflected that the percolating water takes some substances in solution from the surface. It must take up much more in leaching through the sands. This is the reason why most sands are composed chiefly of insoluble constituents. Their soluble constituents have been leached out. But there remain still, in many regions, some soluble limestone pebbles or larger masses which have not yet been dissolved, and the water is continually diminishing the amount of these.

Water that has dissolved much limestone is "hard." Hence, many spring and river waters are hard. The water of a pond may be softer, because a large proportion of it has been directly rained in, or

KONWAKITON GLACIER, MOUNT SHASTA, CALIFORNIA.

supplied by surface drainage from the surrounding land. Of course, the hardness of underground water depends upon the amount of limestone pebbles and grains with which it has come in contact. Aside from any supply of limestone from neighboring ledges, the amount of limestone in the Drift depends on the amount transported from the northern regions which supplied the material of the Drift at each particular place. Some northern regions supplied much limestone, and others little. Hence, in Michigan, Ohio, and Indiana, well and spring waters are hard, while in New England and Pennsylvania they are comparatively soft.

Deposits from springs.

Underground water often experiences great pressure. In this state it dissolves more limestone than it can hold in solution after the pressure is relieved. Hence many springs throw down a calcareous deposit which in the open air hardens into *tufa* and *travertine.* It often incrusts mosses and forms what is called "petrified moss." The vegetable matter perishes and disappears by degrees, but the form of the moss remains. Calcareous springs flowing into ponds cause a deposit of chalky matter on the bottom, which is called *marl.* It is generally mixed with earthy substances washed in from the surrounding slopes. In precisely the same way certain springs deposit peroxide of iron, which is yellowish or red. Iron is also often transported to bogs and ponds, and there undergoes deposition. Thus *bog iron ore* is formed.

VI. Introduction to the Rocks.

KINDS OF MINERALS AND STONES.

It is not entirely satisfactory to roam over the fields, with bowlders lying on the right and left, but without any knowledge of their names or natures. True, we shall experience much satisfaction in feeling that we know something of their origin and their history. We may walk up to the side of one of these ancient and way-worn travelers and say: "Old Hard Head, when did you arrive in this country, and where did you emigrate from?" Old Hard Head will lie sullenly and answer never a word. But he is written all over with inscriptions which we can already begin to decipher. So we look on the rounded and weather-beaten form, and say to ourselves: "This immigrant rock came from a northern country. He left his mother-rock, and most of his kindred, in the woods of northern Maine, or New Hampshire, or on the shore of Lake Superior. A large number of his kindred came with him. He rode part of the way on the back of a glacier. By and by he fell off, or got into a hole; and after that he had a severe squeezing. He got crushed and rubbed and rolled and pushed for some thousands of years. But every year he made some progress. By and by there was a great change of weather. The ice-carriage melted away from him, and fine weather returned, and lo! he found himself, one spring, in this field."

To complete our introduction to old Hard Head we must know his name. To call him old Hard Head is like calling a man "Old Russian" or "Old Englishman." He has, besides, his personal name. Now, there is a way of finding out the particular name of each rock. Like a dog with his name on his collar, each mute rock displays a name written on its exterior. Let us look into this subject a few minutes.

Minerals compose rocks.

Do you see that nearly all these bowlders appear to be mixtures of different colors and kinds of materials? See one rock with round pebbles—white, red, black—imbedded in a mass of smaller grains. See another rock, less coarse, with grains white, pink, and black. See still another with grains all nearly alike. See one rock nearly a uniform white; another, bluish; another, reddish; another, nearly black. See one rock with numerous black shining scales; another, with smoky scales; another, with silvery scales. Now, all these differently colored constituents of the rocks are so many different *minerals.* Rocks are composed of minerals. Some rocks have two minerals; some, three; some, four; and some, only one. The particular name of a rock depends on the minerals in it. As soon as we know the minerals, we can call the name of the rock. Now, sit down and take a lesson in minerals.

Quartz and quartzites.

Do you see this white flint rock, composed throughout of one kind of mineral? That mineral is *Quartz.* It is the hardest of all the common minerals. Try to scratch it. You see the point of steel makes no impression on it. But it leaves a black mark. The quartz wears away the steel. When one of these bowlders is thus composed entirely of quartz, its name is *Quartzite.* There are many quartzites. Let us learn the other part of the name. Look at these uniformly colored quartzites—white and gray. You see one is composed of distinct grains; this is a *Granular Quartzite.* One has the grains almost completely melted together or confluent; this is a *Vitreous Quartzite.* One contains pebbles; this is a *Conglomeritic Quartzite*, or simply a *Conglomerate.* Another has some of its pebbles red; this is a *Jaspery Conglomerate.* You will find quartzites exceedingly abundant; and you will find grains of quartz in many other rocks than quartzites. In fact, quartz is most abundant of all minerals.

Conglomerates. Conglomerates always excite curiosity—especially if the pebbles are of different bright colors. Two large masses of conglomerates of different sorts lie on the campus of the University of Michigan—souvenirs of two graduating classes. One is a jaspery conglomerate from the north shore of Lake Huron. It weighs six tons. The plum pudding, as big as the State House dome, demolished by the giant's wife and her screaming boys, refers to a conglomerate.

> "They flung it over to Roxbury hills,
> They flung it over the plain;
> And all over Milton and Dorchester, too;
> Great lumps of pudding the giants threw;
> They tumbled as thick as rain."

Mica. Well, here is a rock with shining scale-like mineral fragments. Pick up a scale with your knife-blade. Do you see it split into laminæ or leaves of indefinite thinness? "Yes," you say; "this is the same thing as is used in the doors of our stoves to permit the light to shine through; only these are black leaves and those are transparent." Quite right. What do you call the mineral in your stove door? "Mica, though some people call it isinglass." Mica is correct. One species of mica is black, and has a particular name; another varies from dark-brown or smoky to transparent, and has a different name. There are also some other species of mica. So you know mica.

Feldspar. Examine this rock very closely—do you find any quartz? "Yes," you say, "there are two kinds of light-colored minerals here." Carefully test them both for hardness. Can you scratch them? "Well, no. One of them is hard enough for quartz—it is quartz; but the other I am uncertain about." Then you must try again. Bear on hard; can't you make a little scratch with your knife-point, or the end of a file? "I believe I do make a little impression on it." Well, then, it is *not* quartz. Now take another look at it. Compare it with the quartz grain by its side. Is its surface broken and irregular? "No," you say, "it is flat." Hold it then so as to reflect the light from the window. Is the reflection as bright and glassy as the reflection from the quartz? "I think there is a little difference." You see, too, it is an unbroken reflection, while that from the quartz is not uniform, in consequence of the uneven surface. There is also another point; this mineral appears to be a fragment of a crystal; you can detect one or more edges or angles. It is not so with the quartz. Thus, in several particulars, this mineral differs from quartz. Its name is *Feldspar*. But feldspar is not always white nor cream-colored. Very often it is pink-tinted; often almost red. But you may know it to be feldspar by the same signs, independently of color.

So we find in this bowlder three different minerals, and their names are *Quartz*, *Mica*, and *Feldspar*. These three minerals mixed together form the rock *Granite*. There are several varieties of granite, according to the species of mica; according to the colors of the quartz and feldspar; according to coarseness of the constituents; according to the relative proportions of the three ingredients. But they are all granites. If, however, the minerals are not uniformly mixed; if they are ranged in courses, the rock is *stratified*, and it is not a proper granite, though quarrymen and builders often call it granite. Properly, it is *Gneiss* (Nice). If the mica is almost or completely wanting in a granite-like rock, the rock is *Granulite*. When a gneiss-like rock contains very little feldspar, it is *Mica Schist* (Shist).

Granite, gneiss, granulite, and mica schist.

Now, let us examine another bowlder, with a similar appearance, but in which the dark mineral is *not* mica. Be sure, first of all, that we have quartz and feldspar in it. Then, if the dark mineral is not scaly, it is probably *Hornblende*. It may be nearly black, or greenish-black, or dark green. It may be in grains, or in flat-sided fragments showing an indistinct fibrous structure. It can be scratched, giving a pale bluish-green *streak*. Now, a rock with these constituent minerals—*Quartz*, *Feldspar*, and *Hornblende*—is *Syenite*, so called because the rock quarried by the ancient Egyptians at Sye′ne was of this kind. Many persons call this granite also. The "Quincy granite," near Boston, is a syenite. Often syenite contains also some mica. This is the case

Hornblende, syenite, and other hornblendic rocks.

with the "obelisk," in Central Park, New York, and the Mormon Temple, in Salt Lake City. If the constituent minerals tend to arrangement in courses, the rock is *stratified*, and we call it *Syenitic Gneiss*. If the quartz is wanting, or nearly so, the rock is *Hyposyenite* when the feldspar is of the common kind, and *Diorite* when otherwise. When Syenitic Gneiss contains very little feldspar, we call the rock *Hornblende Schist*.

Other crystalline or crypto-crystalline rocks. The names above explained embrace a majority of the rocks, and I do not by any means expect you to learn at present all of the others. But we may mention a few. Some rocks *appear* to be composed wholly of one mineral, and yet they are not quartzites. They are mostly dark-colored—slate-colored or blackish or greenish. If these are banded in different colors, or are capable of splitting into sheets, like shingles, they are *Argillites*—including most of the hard slates, like roofing slate. If a rock is very fine, blackish, and harder than slate, it may be an *Aphanite*. If it consists of a very fine, hard, uniform reddish or greenish base, having crystals of feldspar scattered through it, the rock is a *Porphyry*. But, if you feel inclined to go further into rock-details, it will be better to study some work which takes up the subject more thoroughly. (See the Author's *Geological Excursions*, and still fuller *Geological Studies*).

Sedimentary rocks. One word more. These bowlder rocks are all hard, crystalline, and generally (not always) foreign to the region where they lie. We sometimes find fragments of rocks which are not hard and crystalline, and far-fetched. They come from ledges which appear at the surface not far away. The most common uncrystalline ledges are of sandstone, limestone, and shale. *Sandstone* is composed chiefly of grains of quartz—like those in a granular quartzite, but not so brilliant or so firmly compacted together. A grindstone is a fine sandstone. *Limestone* can be easily scratched with a knife; is generally not composed of grains; and, if you apply strong acid, an effervescence takes place. Very strong vinegar will often suffice, especially if the rock is first pulverized. *Shale* is quite soft, easily cut with a knife, dark-bluish or black, splitting into thin sheets. It is exceedingly common in coal regions. It crumbles into small fragments, and finally becomes mere mud.

I think this little knowledge about rocks is better than total ignorance. We may now go amongst our bowlders, and speak many of their names.

VII. The Floods of the Great Lakes.

LACUSTRINE DEPOSITS AND TERRACES.

The Ridge Road.

Persons living along the borders of the "Great Lakes" well understand what is meant by "The Ridge Road." That road is a geological phenomenon. It is a record of high waters in the lakes.

The Ridge Road runs parallel with the lake shore for many miles at a stretch. It is almost perfectly level and serves as a ready made road-bed for country roads. It consists of gravel and sands, and presents oblique lamination or cross-bedding in its internal structure. The materials have evidently been arranged by water. It has the general characters of a beach, and like a beach retains a level nearly uniform. Generally two or more of these ancient beaches run parallel with the lake, at different altitudes. The "ridge-road" south of Lake Ontario is 190 feet above the lake. The principal terrace bordering Lake Erie is 220 feet above the lake on the south side. On the north side, near Toronto, there are terraces from 30 to 500 feet above the lake. The Davenport ridge west of Toronto is 250 to 300 feet. At the west of Lake Ontario, near Dundas, the ridge is 318 feet high. Around Lake Huron are clayey deposits up to 500 feet. North of Lake Superior the upper terrace reported is 331 feet above the lake.

Evidence of former higher level of the Great Lakes.

Evidence from Mackinac Island.

There are other indications that the Great Lakes have formerly stood much higher than at present. Mackinac Island is a monument commemorating in stone the fact of the ancient high tides of the lakes. Get into a Mackinac boat and sail around the island. On all sides a wall of limestone rises perpendicularly from the water's edge to a height of about 150 feet. Only on the south, for a narrow space, is the approach practicable. Here is the village; back of it, on the first rock-terrace, is the modern fort. The old Fort Holmes, captured by the British, is on the highest dome of the island, 350 feet above the lake. As we pass along the limestone wall which bounds the island, we see the waves breaking against the barrier. We notice the peculiar smooth concavities into which they wore the exposed surface. These are marks characteristic of wave action. Our eyes follow along the weathered buttresses to the summit. From bottom to top are the same records of warring waves. There was evidently a time when the lake acted at the height of 150 feet precisely as it acts to-day at the lake-level, before our eyes. We ascend to the main plateau of the island. On this rises a striking monument-like remnant of a formation which once covered the whole of this plateau to an altitude at least 134 feet greater. This is "Sugar Loaf." But notice the fashion of its sides. Here, too, are the same smooth conchoidal depressions as the lake is still carving in the wall at the water's edge. The waves have certainly been there. The time was when Lakes Huron and Michigan stood at least 200 feet higher than at present.

Great Lakes at time of high level.

Think of that condition of things. Picture the lakes filled up till the water covered Sugar Loaf. At present, Lake Superior stands twenty feet higher than Lakes Michigan and Huron. These are sixteen feet higher than Lake Erie; and the descent thence to Lake Ontario is 323 feet. This is according to Gannett. Now, we find lake-terraces up to three, four and five hundred feet above the present levels of the lakes. But let us assume the principal terrace south of Lake Erie as representing the highest flood of the lakes. This 220 feet above Lake Erie, 204 feet above Lakes Huron and Michigan, and 180 feet higher than Lake Superior. We have perfectly satisfactory proof that the water of the Great Lakes has stood at least as high as this. Now let us cast our eyes over the expanse. The sites of all the busy and populous lake cities are submerged. The greater part of the peninsula of Ontario is under water. The flood stretches westward of Detroit twenty-seven miles. There, near Ypsilanti is the ancient beach which marks the limit of the flood. Mackinac Island is submerged to the pinnacle of Sugar Loaf. Passing around to the head of Lake Michigan, we find the vast inland sea stretching southward and westward over a large part of the state of Illinois.

No barriers remain.

What hemmed in this broad expanse of water on the south? This interesting question has not been completely answered. We know that in southern Illinois are the remains of an ancient barrier which crossed the Mississippi, and was worn down for the passage of the great river. The barrier is a prolongation of the Ozark range, from Missouri. The gap cut through is at Grand Tower. Perhaps here was the barrier which held the waters back at the west, until the Mississippi gradually sawed the notch which drained the inland sea. At the east, however, we know no barrier adequate to hold the lakes at the level of the 220 feet terrace of Lake Erie. The high flood of the lakes must have been 182 feet higher than the escarpment or wall of rock back of Lewiston, through which the Niagara River has cut its gorge. Undoubtedly, this escarpment, which runs east nearly parallel with the shore of Lake Ontario, was formerly much higher than at present; but we have no evidence that it stood 190 feet higher than in our time.

The Lewiston escarpment is at present 38 feet above Lake Erie, and could have dammed the lake to that height, at any time before the Niagara gorge was begun. The water, setting back to the site of Chicago, would have buried it 22 feet deep. Even this would overflow the present southern barrier of Lake Michigan, and inundate the prairie region of Illinois. Thus, the existence of a terrace, but 38 feet above Lake Erie would indicate that the Great Lakes once flooded the greater part of the state of Illinois. Now, if we examine the nature of the prairie deposit, it presents every indication of formation in the bottom of a lake. Here is the stratified arrangement; here are the clay and marls, and here are even the shells of the molluscs which dwelt in the water. These facts must be borne in mind.

Date of high level.

The high water of the Great Lakes has occurred since the Drift was deposited—since the latest semi-stratified Drift was laid down. The lake terraces rest on the Drift. All the other lacustrine deposits attending the high water, rest on the Drift. The entire broad region covered by the high water is overspread by a sheet of lacustrine clays and thin seams of sand. These deposits exhibit a regular horizontal stratification. Occasionally we find a bowlder imbedded in them. Excellent material for bricks and pottery is furnished by the clays; and in many situations, as at Milwaukee, the absence of iron prevents the production of a red color in burning. The famous "Milwaukee bricks" are of a pale lemon color, or even, in some cases, as white as chalk. This sort of clay occurs on both sides of Lake Michigan.

Lake deposits.

These lacustrine deposits rise from the shore with the general slope of the earth's surface, to the upper level reached by them. The lowest beds come to the surface at the highest elevation. Often these are sandy; and, becoming saturated with rain at the surface, they convey a sheet of fresh water under the other deposits to the lower levels. These water-bearing sheets pass under the cities which have been built in modern times on the lacustrine border. In some cases, as at Toledo, and many points on the north shore of Lake Erie, artesian borings have been carried down to the water-bearing strata, and thus artesian wells have been obtained.

River terraces.

We have been considering lake-terraces and high water in the Great Lakes. But every observer has noticed terraces also along the borders of rivers. On the lower Ohio they occur up to 160 feet above low water; at Louisville, 128 feet above low water; near Cincinnati, 120 feet. On the Connecticut, they range from 150 to 240 feet above the modern flood level. On the Missouri we find them up to 335 feet; on the Athabasca and Saskatchewan, up to 370 feet. There is no need of citing further; for these facts show that the rivers in all the northern parts of the country have been enormously flooded, as well as the lakes. These terraces, also, rest on the top of the Drift deposits. The flooded waters, therefore, in general, existed after the events which left the Drift overspreading the northern states.

Now let us reason a moment from the facts which have been brought to our notice. We have been led to speculate on the possible agency which transported the bowlders from their northern home. We have been thinking of glaciers as a satisfactory explanation. Now, suppose there really was a vast glacier covering the country as widely as the Drift at present covers it. The ice must have melted; it is not here now. Suppose it melted rapidly; what enormous floods must have been occasioned! How they moved and mixed and half assorted the sands and pebbles! May not such a flood have produced the results which we see in the semi-stratified Drift? And then may not an excess of water have remained in all the streams long after the southern portion of the glacier had disappeared, and the semi-stratified Drift had been put in place?

VIII. The Mud Flat.

SEDIMENTATION.

Transporting power of running water.

A few years ago, in ascending the valley of the Aar, in Switzerland, I enjoyed an extraordinary opportunity to observe the action of moving water. The Aar is a turbulent stream issuing from the foot of the Aar glacier of the Jura Mountains. It comes out of its ice-roofed cavern milky-white with the clay sediment which results from the scouring of the rocks by the sliding glacier. The sharp collision of transported rock-fragments accompanies the loud roaring of the impetuous stream. On this occasion, the white streamlet, always rapid, had been swollen to a furious torrent by a recent cloud-burst. The torrent, in its rage, had rent all barriers, and coursed over the adjacent lands. Stones, up to several tons in weight, had been hurled right and left, as the autumn wind disperses the light leaves of the maples along the street. Hundreds of acres lay buried beneath sand and mud, cobble-stones and massive rocks. The rough and rocky slope had received its deposits; the late goat pasture lay concealed beneath a bed of stones, and the grassy flat was hidden by a blanket of gravel and slime.

The running water sorts the material it carries.

Observe the power of assortment exerted by the moving water. The heavier rocks were left where the most precipitous hillside graduated into the sharp slope. Here was the first abatement of the force of the stream. It dropped what could no longer be moved by the diminished power of the torrent. The smaller rocks lay next in order. Where the sharp slope passed into a gentler grade, the still waning force of the maddened stream became insufficient to bear them on. Still beyond, on the lower levels, the flood was widened, its velocity slackened, and its transportative power so abated that the average sized cobble-stones had to be left. Still went on the gravel, and found pause only on the pastures where domestic animals had been grazing. But the sand was borne to the level, and spread itself out over many an arable field and fragrant meadow; while the fine alluvial mud had floated with the tired waters, which sought out sheltered nooks and depressions in which to rest. This was yesterday. This morning the lesson lay before me. Here were effects of a geological cause on whose action the startled peasant yesterday gazed despairingly.

Filling of ponds by stream-borne sediments.

Not far from the home of my boyhood was the mill-pond, dear to every school-ward trudging urchin who had to pass it, and a Saturday resort for many others who lived in the adjoining "district." Here we bathed; here we fished; here we risked our lives in shaky skiffs, and astride of unmanageable logs. The water was deep and clear. Last summer I visited the old pond. The deep, clear water was silted up, and flags were thrusting their brown noses up, in the sites where I used to swim in summer and skate in winter. Sedges fringed the borders; bulrushes, to their knees in water, were holding possession of land that was expected to be, and the encroaching marsh threatened to corner the anxious perches and sunfishes in the last lingering bowl of clear water close by the decrepit old dam. How long, I queried, before this mill-pond will be a swamp? Is this the impending fate of all our ponds and lakelets?

Examples in Michigan.

The first land-surveyors of the territory of Michigan laid down on their plats an extraordinary number of swamps and bogs. But the early settlers of Michigan found many of the swamps non-existent; some were grassy plains; some were quaking bogs, and others were part marsh and part lakelet. During sixty years, many of the quaking bogs have become solid meadows; and many of the marsh-side lakelets have totally disappeared under the encroachments of the growing marsh. These are geological changes, and the geologist's eye looks about for the causes. It is not a far-fetched solution to see in the hillside wash a source of silt, which annually diminishes the depth of water to a certain extent. And it requires but ordinary sagacity to notice each decaying crop of grasses, sedges, and rushes as the source of the dark peaty deposit which displaces the last water, when other causes have produced the requisite shallowness. We have caught the marsh-making business in the midst of its accomplishment. Short as our lives are, each life falls within the geologic age in which vast results are actually working out. All these marshes have been lakes. If we dig in them we find the bleached relics of the very shells which held animated tenants of the vanished lakelet. Thus, gathering sediments add sheet after sheet to the deposits which are filling the larger as well as the smaller bodies of water which rest on the earth's surface.

Amount of river sediment.

All great rivers are enormous mud-carriers. The Nile, the Amazons, the Ganges, the Hoang Ho, the Mississippi, are great vehicles for the transport of earthy substances from the higher to the lower levels. Like the Tiber, their waters are all "yellow." The Chinese have surpassed all other nations in making a proper name of the generic description of muddy rivers. What a potion is a glass of Mississippi water, placed by the side of one's plate in the cabin of the steamer! In thirty minutes it holds a deposit of impalpable sediment, which is simply mud. Think of the entire breadth and depth of this mighty stream charged with earthy materials to such an extent. What must be the total amount of matter carried down to the Gulf annually? The engineers of the United States have attempted to answer this question. They say that if the annual discharge of mud were brought together and dried, it would form a block a mile square and two hundred and seventy-eight feet high. Imagine that block lying on the surface of some level township. Then think another block on the top—the result of another year's transport. Recall the fact that the Mississippi has been at this business at least five or six thousand years. Put five or six thousand such blocks together; the aggregate would be a mountain range.

There are seasons when the proud river climbs over its bounds—climbs over the artificial restraints which have been imposed in the form of *levées*. Water and mud spread over hundreds of plantations. Then, as in the overflowing torrent of the Aar, the slackened motion of the water allows the fine sediment to subside. Corn lands and cotton lands receive a new contribution of fertilizing material. Such service the Nile performs for Egyptian agriculture—under the rule of the Khedives, as during the reigns of the Pharaohs. Thus the *deltas* of the great rivers are formed. Still the great preponderance of river silt passes on to the outlets. Not only the floating sediment, but a large amount of bottom mud, too thick to float and too loose to lie unmoved. This the stream *pushes* along into the sea—year by year into deeper and deeper water, as the shallower shore region becomes silted up. This is the *bar*. By the annual extension of the bar, the delta gradually protrudes a tongue of land into the sea. Look at a map of the mouth of the Mississippi, or the Nile, or the Ganges. Often the piled up bar-material so obstructs the exit through the main channel, that the water sets back up the stream during some flood, overflows its banks, and seeks a new route to the sea. This may be many times repeated. So these great rivers acquire numerous outlets. Look at the map again. The bar at the mouth of the Mississippi extends three hundred and thirty-eight feet into the Gulf annually. Deltas.

Much of the Mississippi sediment, therefore, lies somewhat permanently on the Gulf bottom, near the shore. Through this Engineer Eads has staked out a channel, to which the current of the Mississippi is confined after entering the Gulf, until deep water is Sedimentation in the sea.

reached. Its velocity is thus preserved, and its mud is carried beyond into the deeper basin. Before this improvement the water spread out fan-like, and slackened its velocity to such an extent that the mud was deposited in a region where the water was already so shallow that navigation became seriously obstructed.

Still, some of the sediment floats on beyond the bar. There is a current in the Gulf which sets eastward along the northern border, and bears Mississippi sediment as far as the straits of Florida. The fine impalpable dust finally comes to rest on the bottom of the Gulf.

A thousand rivers thus are bringing their contributions to the sea. Around ten thousand miles of coast, the sea itself is battering down the land. The coarser fragments are left along the beach. The enfeebled action of the retreating surf bears some distance seaward the smaller fragments and the pebbles—rolled and rounded on the beach. The finest sediments have no opportunity to subside till floated far from shore. Thus the same assortment is exerted which we saw effected by the torrent of the Aar. The ocean's bottom lies covered to a vast extent with sheets of sedimentary materials which, near the shore, are coarse, and remoter from shore are progressively finer, as far as the finest sediments are floated. This process goes forward before our eyes ; it has been continued during all the thousands of ages past, since the ocean first came into existence. How many layers must there be ? How many feet of sediments have been piled up ? What conditions have they assumed while the geologic æons have rolled by ?

IX. The River Gorge.

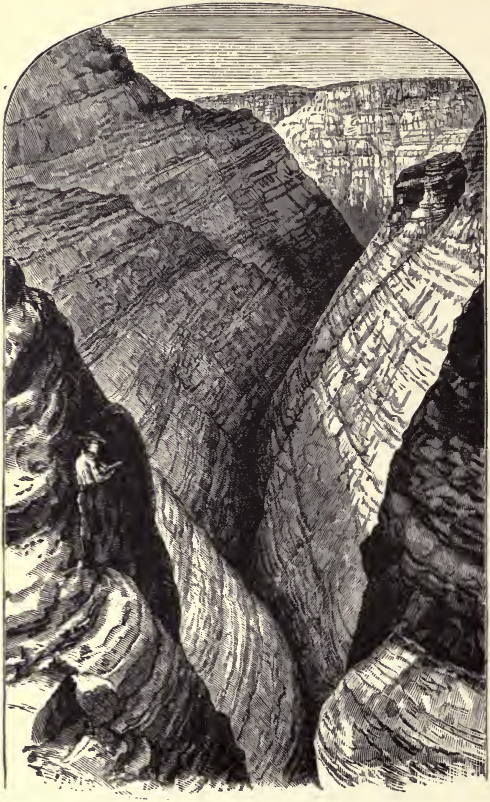
EROSION.

The source of sediments.

Whence come the sediments which muddy the rivers and fill the lakelets, and make even the oceans shallower? These sediments must all come from some source where they existed as solid, massive constituents of our planet. They are portions of the planet transported from one position to another. Their transportation changes the figure of the planet. Every film of sediment proclaims that the fashion of the planet has been worked over to some extent. The making of the planet has been merely a progressive changing of the fashion of the materials of which it is composed. If the completed planet as we see it is the product of geological forces, then the work of sedimentation proceeds by means of forces which are geological. The filling of boyhood's mill-pond was a geological work. The slime settled by the roadside is a geological phenomenon. These are results accomplished.

The sediment's journey traced.

The sediments have been brought by moving waters; we must therefore trace the waters to their sources; we must retrace their course from the higher level. Obviously, the roadside slime has descended the rill-ways from the middle of the street; from the hill-slope down which a portion of the water descended. Some water flowed down the field-slope, moved under the fences, and found its course to the roadside pool, bringing as much sediment with it as



THE WATER POCKET CAÑON, UTAH.
Illustrating the effects of water erosion.

it had power to bear. The corn-fields have been taxed; the earth built into the highway has been stolen; the form and bulk of the hill have been changed. So the farmer's fields contributed the material which lies in the bottom of the mill-pond. To some extent, the fields have been scraped down and impoverished. There lies the farmer's property spread over a surface which forms the floor of the sunfishes' home.

Over every square mile flows some stream. The smallest stream, as well as the largest, occupies a valley; and down its slopes descend the sediment-laden drainage waters which seek the stream to join in its journey to the lower levels. Follow the streamlet. Along every rod of its course we find discharged during a rain the muddy washings of the land. The streamlet grows. Many a lateral rill brings in its contribution from the fields which stretch in another direction. Our streamlet flows on, and sooner or later it discharges its burden in some larger stream, which has already grown to its present volume by the contribution of a score of streamlets higher up the valley. All are merged together; but we are sure the water and the mud from our own village—our own farms—are there with the rest. The stream moves on—it never rests—and it grows as it moves. It courses across a state; it marks a boundary between states. Men have made it a vehicle for floating logs; a highway for skiffs and barges. Now, the more pompous stream styles itself a river. It hastens to join the Ohio and share in the dignity of floating steamboats and carrying on the commerce of a populous valley. The Ohio has even surpassed the tributary by which we have been led, in taking on its cargo of mud. We stand in the middle of the suspension bridge at Cincinnati and look down on the yellow surface of the great stream. There go the contributions from half a dozen states. There goes the soil filched from our garden, or torn from our new made road, two hundred miles away. We know it is there.

Drainage areas. Look on the map and notice how many rivers are bringing their sediments to the Ohio. Trace these tributaries to their sources. From how wide a territory is the mud gathered which thus rushes down with the main river? Notice that the Ohio carries its burden to the Mississippi. Look again upon the map and see how many other great rivers bring the mud from other far-off regions to concentrate it all in the mighty Father of Waters. Here float sediments from western New York, from West Virginia, from the Ozark Mountains, from the Cumberland Table Land, from Minnesota, and the Indian Territory. Here in this resistless tide floats the identical soil which was washed from Farmer Jones's potato field.

In this view, consider the great Missouri. It pours its yellow stream into the clearer tide of the Mississippi a few miles above St. Louis. I have stood on the deck of a steamer between Alton and St. Louis and looked down on the Missouri's turbid volume pushing far into the Mississippi, and retaining for miles a distinct boundary between the waters of the two rivers. It appears that the contributions from the far northwest exceed all those from the east. Follow the whirling tide of the Missouri upward toward its sources. There stand great cities on its alluvial banks. The crumbling bluffs by spells slide into the river. Above the limits of city populations the river is already gathering in the mud destined to journey to the Gulf of Mexico—mud which has already been floated from some remoter region and deposited here at times of overflow. Here comes the Niobrara, with slime from the prairies of Nebraska; the Cheyenne, with washings from the mining camps in the Black Hills; the Little Missouri and Yellowstone, with sands worn from the Big Horn, the Wind River, and the Snow Mountains; here, on a grassy plain, unite the Jefferson, Madison, and Gallatin tributaries, which bring the dust of the continent from the high water-shed of the Red Rock Mountains, which parts the continental drainage to opposite points of the compass. It is a bewildering breadth and complexity of operations. Over every foot of this wasting expanse the land is yielding to the corrosive action of rivers and rains and frosts. The proud mountain domes and pinnacles are coming down to acknowledge the supremacy of the powers of denudation. The Rocky Mountains have begun their journey to the Gulf of Mexico. Cubic miles of their granitic substances are buried in the delta of Louisiana and the bar of the Mississippi.

Examples of river gorges.

Every river, in its search for a resting-place, has cut a way of even grade across the inequalities of the land, and the rubbish has been dumped somewhere—in alluvial border or broad delta, or seaward rolling bar. The Yampa has sawed a broad gash through the Uinta range on its way to the Green River. The Green has cut a dark chasm down through the plateaus of Colorado to the river whose colored waters, poured in from the snow-born floods of the Rocky Mountains, gave name to the river and the state. The Colorado, with augmented force, has dug a deeper and a wider cañon through the shattered terraces of the southern half of the state. The "Grand Cañon" sinks vertically six thousand feet through the rocks—a terrific gash, like a sabre-cut from some of the powers of Nature.

"It looks as if broken by bolts of thunder,
Riven and driven by turbulent time."

So a hundred rivers of the far west have scored the land. So the Cumberland, the Kentucky, the Hudson, the James, the Mississippi, by gentle worrying of the underlying rocks, have plowed out channels whose steep walls rise as high as the smoke from the steamer which utilizes the water-way. We have not seen these works begun; but we see them in progress; and we feel bound in reason to infer that the rivers have worked in the distant past as they are working before our eyes.

Mountains of circum-denudation.

There are other erosions, however, which were effected not only before human times, but by agencies which have disappeared from existence. There are the Catskill Mountains—essentially a mere wall of horizontally laid slabs of red sandstone. These mountains must be a remnant of a broad formation once stretching far east and west. The forces of erosion have worn away the formation on both sides, and the Catskills stand forth a feature of *relief* as the statue emerges from the block of stone under the chisel of the sculptor. Such, too, is the Cumberland Table Land, high upraised like a mountain, but yet not uplifted. It is a mere salience resulting from the vast erosions that have taken place along its western border. In central Tennessee, indeed, this erosive process has excavated a basin a hundred miles in diameter, bounded on all sides by the ragged edges of the formations which were left.

Outliers. So this completed work of erosive powers which have retired from action is commemorated in many a monument-like *outlier* in Wisconsin and Minnesota. A great formation which once overspread many a township has all been carried away, save here and there an isolated remnant which lies like an island in the midst of geology of a different character. It is the Potsdam Sandstone which has been thus eroded; but wide areas still remain, and underlie portions of those states. Similar are the columns in Monument Park, and the ruins in the "Garden of the gods." Like the great basin of central Tennessee are many of the excavations in the Bad Lands of the Upper Missouri and in New Mexico.

These two great processes, erosion and sedimentation, must be vividly appreciated. The whole history of the visible land has consisted chiefly of upbuilding and destruction, rebuilding and disintegration, by the action of forces which have left gigantic monuments of their former power, and are even in our times, working on a scale large enough to illustrate to us how the foundations of the land were laid, and how the face of the earth has been carved into the fashion it presents to our interested eyes.

X.. A Walk Under the Sea.

WHAT GOES ON IN THE OCEAN DEPTHS.

The sea. THE sea has always inspired the wonder—often the veneration — of mankind. Its vastness and power overwhelm the imagination. Its permanence, its antiquity, form a bewildering conception. The same "far-sounding sea" roared in the hearing of the mariners of the remotest past. The same ocean floated the ships of the Tyrians and Carthaginians. A "glorious mirror," as Byron conceived it,

> "Where the Almighty's form
> Glasses itself in tempests. . . . .
> Boundless, endless, and sublime,
> The image of eternity—the throne
> Of the invisible."

Let us stand on some bold headland and look out over the Atlantic. Let us plant ourselves on Sankaty Head, the eastern promontory of Nantucket, itself the "ultima Thule" of New England. The breakers roar along the beach. Across the billowy blue thought wanders to the European shore. Underneath the ruffled surface imagination pictures a world of curious and wonderful existences. We go down like the bathers in the sea. We pass the margin where

Down through the depths.

> "The dreary back seaweed lolls and wags."

We traverse the borders where the brown, belted kelp sways to and fro in graceful curves. We get beyond the slope of stony bottom to the smooth sand. We come to the gardens of the rosy-tinted sea-mosses—the *Dasya*, the *Grinnellia*, the *Callithamnion;* and startle the blue-fish and halibut in their safe seclusion. A moonlight gleam is here, and the water also takes on the chill of evening. We pass on, and attain a depth of half a mile. Our feet press into the finer sediments derived from the land —the dust of other "continents to be." The twilight has faded into a deep shade. The creatures of the sea swarm curiously about us, then flee in terror from our presence. We feel the gentle movement of "a river in the ocean," but the surface disturbances do not reach even to this depth. A change of climate impresses itself on our sensations. The water where we started in had a temperature of sixty degrees—here it is forty. We descend to the depth of a mile under the sea. The curiously gazing species of the shallower water appear no more. Their home is the zone which now stretches above our heads. The green and rosy sea-mosses never venture here. We are in total darkness; no chlorophyll tints the growths of the vegetable kingdom. Here are only stony, white calcareous algæ and silicious diatoms of microscopic minuteness. We feel our slimy path down to the deeper profound. Above us now float two miles of black sea. Any surface fish brought down here perishes from the effect of enormous pressure, if possessing an air-bladder. If it have none, the fish becomes torpid, and finally dies. We are here, probably miles from the shore—that varies with the steepness of the slope. The sediments which the rivers have brought to the ocean have mostly been deposited between our starting point and this. But here still are some of the finest particles contributed by the land—slime from Louisiana, from Chautauqua, from the Rocky Mountains, from our native town. Will these far-brought and commingled atoms ever see daylight again? We are standing on the border of the vast abyss which extends over half the area of the earth. It is an undulating, silent desert.

Physical condition of the deep sea.

The pressure on us in this abysmal region is four or five tons to every square inch. The water is ice-cold everywhere. The darkness absolute and palpable. A curdling revulsion of feeling and purpose seizes us. We halt and reflect. We turn our eyes upward with a painful longing for the "holy light, offspring of heaven first-born." Only the black ceiling appears. Two miles above us is the sunny sea, where all the blue of a genial sky beams down. There float the ships in summer calm upon a "painted ocean," or tossed and rent by the winter tempest which inspires the waves with madness. But no summer and winter vicissitudes are here. No sunlight ever penetrates this Cimmerian gloom. No sunrise, or noonday, or sunset is ever known. As it was when the Garden of Eden was first consecrated to man, so it has remained and must remain. Not even the crash of thunders or the roar of tempests can be heard. The huge wave, crested with elemental fury, rolls on, but makes no stir in the stillness and stagnation of the abysmal realm.

Globigerina ooze.

When we crossed the borders of this dark and silent abyss, our feet sank in a white pasty slime which has been designated "Globigerina ooze." The dredges of the *Challenger* and the *Albatross* have been down here, hung by a piano wire over the stern of the vessel, and samples of this ooze have been studied. We find it composed chiefly of microscopic dead shells called *Fo-ram-i-nif′-e-ra*, together with others called *Pter′-o-pods.* The little creatures which formed the shells do not live here; they dwell in calm zones of water far above. When the conscious animal ceases to live, its tiny house sinks down into this dark world. And thus, as the ages roll by, the fine chalky rain slowly accumulates upon the bottom. When this ooze is dried and hardened, it resembles the chalk of Europe; and when that is microscopically examined, we find in it the same little *Foraminifera.*

Clay ooze and volcanic dust.

We have groped our way down three and four miles beneath daylight. A sort of ooze still overspreads the bottom; but it is not the *Globigerina* and Pteropod ooze. It is a fine rusty clay. But the white shells are not wanting because the tiny creatures which secrete them are not overhead. They swarm there as elsewhere, far from land with other *pelagic* forms. But the fragile matter of the shell is dissolved before it reaches this great depth. Only the aluminous and insoluble constituent reaches the bottom. This clay ooze possesses other interest. Disseminated through it are minute crystals of such minerals as escape through the throats of volcanoes into the upper air. Here are the dust particles which have imparted a ruddy glow to many a past sunset. Once the source of the roseate glory of the twilight hour, they lie now, in impenetrable darkness and the repose of death. How changed the fortune of the little particle. It floated for months in the upper thin air—in the film of space which separates earth from heaven—borne hither by the simoon, thither by the anti-trades, hurled in the vortex of a cyclone and precipitated in mid-ocean by a down-falling mass of vapor. Then, perhaps, seized by the waves, and rocked and beaten at the surface till it reached a zone of calm, it began its silent descent into the dark world where it is destined to rest undisturbed for centuries.

Cosmic dust.

Here too is cosmic dust. The seeds of worlds have been sprinkled through space, and some of them have been planted in the soil of this abyss. These minute globules of magnetic iron were sparks emitted from a burning meteor. The meteor was a small mass or particle of material stuff coursing swiftly through the cold interplanetary spaces. It pierced the atmosphere of the earth ; the friction resulting ignited the meteor, and for a brief moment it painted a fiery streak in its flight, when all had been transformed to ashy particles which floated in the air like volcanic dust, until it found, at last, a resting place in the cold bed of the Atlantic. What a reversal of fortune was here! The particle might have swept on through space, as many of its companions did, until it became part of a glowing comet. Perhaps it once shone in a star—now it is dead for a cycle of ages. It is an impressive thought that here, in this rayless night, we find the black ruins of a star.

We still stand wondering over the scene which surrounds us. How oppressive is this silence. From age to age this reign of death persists. A chill which is more than icy, pierces us to the marrow. Sometimes, as we grope through the Egyptian gloom, we kick the bones of aquatic creatures which have perished in the water above us. Often their kind is still in existence; but sometimes their species are long extinct. Here are teeth of sharks and ear-bones of whales which have lain during geologic ages. Grand vicissitudes have passed by, which transformed the aspect of continents, but these relics lay here undisturbed—unburied—so slowly do the sediments accumulate.

But there is indeed life here. Sparse, quaint life; **Life.** and the species are of archaic and embryonic forms; that is, they resemble creatures which lived in the earlier ages of the world, or creatures which have undergone but a part of their development—crude, uncouth, and alien to the modern world. Here are Crinoids, or Stone Lilies, which, in most other **Crinoids.** waters, have perished from the earth. They are an antique type. But from deep waters off the coasts of Florida and Norway, comes up, with other forms, *Rhiz-oc′-ri-nus*, a genus which disappeared from shallow seas unknown millions of years ago; but here, where nothing changes, it has perpetuated its existence through half the history of the world. Between death and the changeless life which here reigns, the difference is slight.

Still more startling in their grotesqueness, are some **Fishes.** of the fishes which lie here more than half buried in the mud. Here is one fashioned like a scoop-net. The long, slender body is the handle, and the net is an enormous pouch under the chin, which would take in the whole of the body three times over. Another hangs like an open wide-mouthed meal-bag.

In this case, also, the bag hangs suspended from the part where the throat should be. The diminutive body is noticed as an appendage attached to the back side of the bag. It is known by the fins. Four of these bodies might be contained in one pouch. A different, but equally erratic form brandishes an attenuated body like a whip-lash appended to an enormous head, exposing an eye which is nearly half its own diameter. Still again, we note a shark-like form, with enormous gape and horrid teeth, having a range of spines along each side of the slender body, above and below, and, most curious of all, a long, thread-like organ depending from beneath the chin, with a tassel-like tentacle bearing structures for feeling, at the end.

But see! somebody is here with a lantern. How sleepily the light gleams in the darkness. There is no fire in it. Something it is. An animated lantern. A lantern without a flame. It is another strange fish. It is phosphorescence which gleams mildly from his shiny sides. Still another lantern-bearing fish. Here are luminous plates beneath the eyes; behind them, in a cavity, retinal tissue, as if these structures were planned for eyes; but they are not eyes. Real eyes are present. We discover, then, faint relief from the palpable darkness in which we have groped.

But our task is done; our curiosity is gratified; we have glimpsed the underworld, and have gathered observations on which we shall ponder many a day. Let us now, like the heroes of epic song, ascend to the light of the upper world.

XI. By the Rocky Wall.

STRATA AND THEIR CLASSIFICATION.

Examples of strata.

Let us walk in front of the precipice which frowns along the hillside near the village of Panama,[1] on the west. It is no more instructive than a thousand other cliffs, but it may be more convenient to reach. The cliff rises fifty or sixty feet and presents a broken and rugged front. The brown and yellowish rock is composed of fine silicious grains, with small imbedded pebbles, and thus answers the description of a conglomeritic sandstone. The face of the cliff shows several yawning fissures extending from bottom to top. The winter snow drifts into these in such abundance as to remain, sometimes, till midsummer. One of these chasms is known, therefore as the "Ice House." You observe that this precipice is composed of layers of sandstone piled one above the other. These are *strata*, and the whole formation is *stratified*. [Notice that one of these layers is a *stratum*—not "a strata"; and we must never say "stratas."] You observe, also, that some of the strata are composed of *laminæ* which run obliquely across the stratum. This is *oblique lamination*. It is of the same nature as we saw in the semi-stratified Drift. We concluded that such mode of arrangement was caused by torrential action. A similar explanation is allowable here, but the water was less turbulent; it was, perhaps, wave action along a beach.

Conglomerates.

Oblique lamination.

[1] Panama, N. Y., nine miles south of Chautauqua. F. S.

THE MU-KU'N-TU-WEAP ON THE VIRGIN RIVER, COLORADO.
Showing architectural forms resulting from erosion.

Watkins' Glen, at the south end of Seneca Lake, is a wild, deep gorge cut by a stream which rushes down from the highland on its way to the lake. It is a striking example of erosion, and the materials carried away are deposited in Seneca Lake. The rocks here are shales. They are *thin-bedded*, and soft enough to be cut with a knife. We see no oblique lamination. This is a fine example of another sort of strata. At Rochester, where the Central Railroad crosses the Genesee River, a few rods above the Falls, we look down into a gorge eroded by the river. The high walls of the gorge are distinctly stratified ; and here many of the strata are composed of limestone. No traces of oblique lamination can be found in limestones. If we go to Portland, in Connecticut, we may look down into wide and deep excavations in a sandstone rock of a brownish color, and very evenly bedded. Near Cleveland, and at Berea, Ohio, are extensive quarries in a grayish and bluish gray sort of sandstone. At Cincinnati, back of the city, we find a steep slope formed of beds of limestone, shale, and clay. Descending the Mississippi from St. Paul to St. Louis, we see high cliffs of buffish strata overlooking the river at frequent intervals—now on the west, now on the east. At St. Paul the rocks are distinctly stratified limestone. At Davenport and St. Louis we find other kinds of limestones.

Shale, Limestone, Sandstone, etc.

Now, I have directed your attention to these few examples out of hundreds for the purpose of enabling you to understand that everywhere solid rocks underlie the Drift ; and that they are, at least very generally, stratified rocks, and are composed chiefly of sandstones, limestones, and shales. Let

Strata are sediments, us consider how these solid strata have been produced. None of these have we ever seen making, but I think we have seen a process similar to rock-making in the beds of alluvial matter deposited by an overflowing stream. In traveling down the lower Mississippi, we can see from the deck of the steamer that the material of the alluvial banks is horizontally stratified. More strictly we should say that it is laminated; but the nature of the geological work is the same in either case. Now, if those alluvial banks should become firmly consolidated, they would present the appearance of some of the rocky cliffs—those in Watkins' Glen, for instance. You have also learned how large quantities of sediments borne down by rivers are carried out to sea many miles, and slowly deposited on the ocean's bottom. These deposits must necessarily be in layers, each of which is spread evenly over the bottom. You remember that the distance to which materials of a certain degree of coarseness may be carried before sinking to the bottom, depends on the velocity of the motion of the water. At a certain place in the sea the velocity is undoubtedly more rapid at one time than another. The motion is caused by winds, by tides, and by currents. Therefore, a coarser sheet of materials will be laid down at one time, and a finer sheet at another. The alternations of coarser and finer render the bedded arrangement conspicuous. Very likely the colors of the sediments will vary also; since, from one direction, they may be supplied by pulverized limestone, from another by pulverized sandstone, and from another by pulverized shale, which may be blue, red, or black. We noticed, too, in our walk under the sea, that sedimentary materials are spread over all the slope of the ocean's floor, within fifty or a hundred miles of the land—often much farther, if the shore is "shelving" or the currents are favorable.

These various indications compel us to adopt the conclusion that water has been the agent by which the materials of the stratified rocks have been spread out in broad beds or strata. But, though river overflows must leave the sediments in a bedded condition, these beds are not exactly like those seen in great formations of limestone and sandstone. River sediments never have so wide an extent as the strata which underlie a continent; nor are they generally so evenly bedded as our ordinary rock-strata. We must conclude, therefore, that the watery action which arranged the sediments from which our rock-strata have been formed, was a very widely operating action. There is no watery action known sufficiently widespread except the action of the ocean. In the ocean, sediments are now settling down in sheets a thousand miles broad. This conclusion is a somewhat startling one. It implies that, wherever rocky strata exist, there the ocean's waters have stood. Rocky strata are found hundreds of feet above the level of the ocean, and the fact seems incompatible with our conclusion. The average level of all the northern and northwestern states is from six hundred to a thousand feet above the sea. If the underlying strata were deposited by the ocean, then either the ocean has greatly subsided in later times, or regions which were once sea-bottom have been extensively uplifted.

Sordid by water,

Mainly in the ocean,

Slowly,

Now, if all the strata which underlie the land are formed from marine sediments, the time required for their accumulation must have been enormous. We have made observations along the sea-shore, and have formed some conception of the rate of sedimentation over a belt near the land. There are times when violent winds cause the waves to wear down the shore at such a rate that the sea, for a mile from shore, becomes turbid with sediments. This has been seen often at Long Branch and Coney Island. But these periods are of short duration, and the deposits at the distance of ten miles from land are no longer conspicuous. In the vicinity of coral reefs and islands the attrition of the waves imparts a milky complexion to the sea, especially during the prevalence of a storm, and the calcareous particles are floated sometimes a hundred miles and more. But it is apparent that, as a rule, the sea floats too little sediment to build up a formation in any other than a very gradual manner. We noticed, also, in our walk under the sea, that the bottom sediments grew thin with distance from the shore, and that those of continental origin ceased entirely at about two miles in depth. When now we remember that the stratified rocks are over a hundred thousand feet in thickness, we perceive immediately that the process of sedimentation has been an extremely long one.

Near shore.

Geological history must be subdivided.

We have then to consider what changes may have taken place in the conditions of the world during so long a period. Probably the nature of the sediments has been changed from time to time by these changes in the physical conditions of the planet. We do not wish to anticipate conclusions to be rested on facts which have not yet fallen under our observation; but everybody has noticed that the surface of the earth is undergoing changes; and these, in thousands of years, must aggregate amounts which transform the aspects of the planet. We have lived to see lakelets filled; new channels formed for great rivers; ocean beaches consumed by the waves; hundreds of miles of continental coasts upraised or sunken—as in Chili, Scandinavia, and Greenland; new islands bursting into view; whole provinces shattered by earthquakes. Suppose our observation extended back a million years, and the tenor of events had been the same as in modern times; is it not certain that changes must have aggregated to such an extent that, waking at times to distinct consciousness of the greatly changed conditions, we should from æon to æon have felt ready to declare a new chapter of the world's history had begun? Geologists have considered these facts, and have settled on the principle that the long history of sedimentation has been divided into æons corresponding to successive conditions of the world. Names have been assigned to these æons. Thus, the first series of sediments formed the strata which lie deepest of all. They are called *Eozoic*, and the æon during which they were accumulating is the *Eozoic Æon.* We will not pause *here* to inquire what these sediments rested on—in other words, what kind of rocks formed the bed of the sea, at the beginning of that Æon.

The great rock systems.

The Eozoic Great System of strata is at least fifty thousand feet thick. In the next æon the changed conditions gave origin to changed strata.

They constitute a Great System known as the PALÆOZOIC; and the time during which this system of strata was accumulated, is the PALÆOZOIC ÆON. Next after this came the MESOZOIC ÆON, during which the MESOZOIC GREAT SYSTEM of strata was accumulated. Lastly, followed the CÆN′-O-ZO-IC ÆON, which continues to the present. The strata formed constitute the CÆNOZOIC GREAT SYSTEM.

XII. MYSTERIOUS FORMS OF LIFE.

FOSSILS.

EVERYONE has noticed the curious forms found in the Drift, which so much resemble shells and corals, and buttons or beads. Often they lie loose in the soil; and often we see them imbedded in fragments of limestones and sandstones which are sometimes bowlders transported from a distance, and sometimes fragments derived from a neighboring ledge or *outcrop* of stratified rocks. In the cliffs at Panama are occasional traces of shells, both bivalve and univalve. The latter is a little shell three quarters of an inch in diameter, and closely coiled almost in a plane, like a watch spring. I have been amused to hear some of these forms like bivalve shells called "petrified butterflies." Through western New York, Ontario, Michigan, Ohio, and Indiana we find in the Drift innumerable masses popularly known as "petrified honeycomb," and "petrified wasp-nest." There are also quantities of little flat discs like "buttons," each with radiating striæ or other decorations, and having a hole in the middle, as if intended to be strung like beads. These have sometimes been styled "St. Cuthbert's beads."

Old theories of fossils.

These curious forms, so much like animal structures, were wondered over, hundreds of years ago. Very few persons would then entertain the suggestion that they are real relics of living things. They indeed bear the similitudes of marine creatures; but such they cannot be, it was argued, because they lie hundreds of feet above the sea. Some of the early Italian writers attributed them to the "influence of the stars"; but Leonardo da Vinci demanded "where, in the hills, are the stars now forming shells of distinct ages and species? And how can the stars explain the origin of gravel, occurring at different heights, and composed of pebbles rounded as if by the motion of running water?" Others attributed these forms to the influence of a "plastic force" in nature. Agricola, a German miner, conceived the notion that a "certain fatty matter, set into fermentation by heat, gave birth to fossil organic shapes"; Fallopio thought that petrified shells were generated by fermentation in the spots where they are found; or that they had, in some cases, acquired their form from the "tumultuous movements of terrestial exhalations." Olivi thought fossils were mere "sports of nature," and some indulged in the amusing fancy that they were "prototypes" or "models" after which the Creator subsequently fashioned the living creatures of the sea; and others held that they were "created" just as we find them. The last opinion I have heard dogmatically asserted in America; and probably it still survives.

When it became impossible to resist the evidence that these forms were relics of the sea, the theory obtained a foothold that, as the deluge of Noah had inundated the lands, these forms must be the relics of that recognized universal submergence. It required a century and a half to argue down this error; and, meantime, the geologists who did not subscribe to it, fell under the accusation of "disbelieving the whole of the Sacred writings." Thus, in our day, we stand at the outcome of a contest of three hundred years.

That the sea has covered the land, and that shore lines have greatly changed, was taught by Pythagoras, and afterward by Strabo and Pliny; but these views were almost forgotten. Many Arabian writers have left on record views and opinions on many subjects, quite in advance of their European contemporaries. On this subject we find an entertaining revelation of opinion by Mohammed Kazwini, of the seventh century of the Hegira—the close of the thirteenth century of our era. It is given as the narrative of Kidhz, an allegorical personage:

"I passed one day by a very ancient, and wonderfully populous city, and asked one of its inhabitants how long it had been founded. 'It is indeed a mighty city,' replied he, 'we know not how long it has existed, and our ancestors were, on this subject, as ignorant as ourselves.' Five centuries afterwards, as I passed by the same place, I could not perceive the slightest vestige of the city. I demanded of a peasant who was gathering herbs upon its former site, how long it had been destroyed. 'In sooth a strange question,' replied he, 'the ground here has never been different from what you now behold it.' 'Was there not of old,' said I, 'a splendid city here?' 'Never,' he answered, 'so far as we have seen, and never did our fathers speak to us of any such.' On my return there five hundred years afterwards, I found the sea in the same place, and on its shores were a party of fishermen, of whom I inquired how long the land had been covered by the waters. 'Is this a question,' said they, 'for a man like you? This spot has always been what it is now.' I again returned five hundred years afterwards, and the sea had disappeared. I inquired of a man who stood alone upon the spot, how long ago this change had taken place; and he gave me the same answer as I had received before. Lastly, on coming back again, after an equal lapse of time, I found there a flourishing city, more populous and more rich in beautiful buildings than the city I had seen the first time; and when I would fain have informed myself concerning its origin, the inhabitants answered me, 'Its rise is lost in remote antiquity; we are ignorant how long it has existed, and our fathers were on this subject as ignorant as ourselves.'"

This allegory sets forth the nature of the modern scientific conception of changes in relative positions of land and sea. It must not, however, be understood that continents ever occupied the sites of the modern oceans; though these oceans once extended over all the lands.

What fossils are.

Thus these strata of sandstone, limestone, and shale are real ancient sea-sediments, as we have already argued; and these forms of life imbedded in the strata are the relics of the animals which dwelt in the sea while the sediments were accumulating.

Life forms vary from age to age.

When we subject these relics to critical examination, we discover that their resemblance to living forms is in fundamental characters only. As to particular species we find none, save in peculiar situations, which are identical with living species.

If the relics buried in the rocks present undoubted divergences from living forms, it must be because they lived in other ages, and under different physical conditions from modern species. As there is now, so there must always have been, some co-ordination or suitability between the conditions in which species lived, and the structures, instincts, and capabilities of the species. We are witnesses of this great principle—*the adaptation of organism to environment.* The Hippopotamus and the Elephant, dwellers in warm climates, are almost naked. The White Bear and the Arctic Fox, dwellers in the frigid zone, are densely clad in fur. The Duck is impelled by its instinct to the water; so its feet are webbed to adapt it to movement in the water. These co-ordinations of structure to environment or surroundings, are everywhere seen, and possess extreme interest.

Law of adaptation to environment.

Now, during the long history of rock-accumulation, there must have taken place very great changes in the conditions of the world. This may be inferred from the fact that *some* changes are taking place before our eyes; and also from the fact, which we must admit, that the ocean was once universal, but is now interrupted by wide continental expanses which deflect the winds and the currents of the sea, and modify the climates of many regions. It might thus be inferred beforehand, that the populations of the world have shown a correspondence with the changing conditions of the world. If the physical world has improved—if it has undergone a progression from some cruder condition to the present, then the populations of the world have progressively improved; and we shall find the records of this improvement in the fossil remains of those populations, as we hunt for them in strata farther and farther from the surface—that is, farther and farther removed in their origin from the present time.

Progress of life traced.

Now, with this preparation of mind, permit me to state what has been ascertained by studying the fossils imbedded in the succession of strata. The deepest rocks of which we have any knowledge are those already named Eozoic. They are mostly hard and crystalline—such as we find in our innumerable bowlders. They were stratified originally, nevertheless; they were marine sediments, and if any marine creatures lived at the time, their relics were inclosed in the sediments. But you see how greatly the sediments have been changed to make of them granites and gneisses. If the change almost or completely obliterated the lines of bedding, it must also have destroyed most traces of the included fossils. As a fact, almost no fossil remains are found; and they belong to the very lowest grade of animal life. The ages during which they existed may be styled the REIGN OF PROTOZOANS.

The strata next above, in the lower part of the Palæozoic Great System, abound in the remains of marine animals; but no traces of fishes or other vertebrates have been found. This was the REIGN OF MARINE INVERTEBRATES. Their exclusive remains extend through two systems, *Cambrian* and *Silurian.*

In the next higher formations we detect the bones and teeth and armor-plates of fishes. There were many invertebrates also, but, as the fishes were dominant in rank and prowess, we designate this age the REIGN OF FISHES. The strata deposited during this Reign form the *Devonian System.* Next came the relics of the first air-breathers which ever lived. We find their bones resembling those of modern salamanders or amphibians, though often much more powerful. This was the REIGN OF AMPHIBIANS; and the corresponding strata are the *Carboniferous System.* The Cambrian, Silurian, Devonian, and Carboniferous systems make up the Palæozoic Great System.

Next, as stated in our last Talk, come the strata which form the Mesozoic Great System. Through this, in addition to relics of amphibians, fishes, and invertebrates, we find for the first time the bones and teeth of *reptiles.* These creatures offer extraordinary interest. Their empire is known as the REIGN OF REPTILES. Following this was the REIGN OF MAMMALS, since their bones are found distributed through the *Cœnozoic Great System* of strata. Lastly came man. His bones and works are confined to the surface of the earth. They are not found imbedded in solid rocks. This last and highest animal characterizes the REIGN OF MAN. This is a grand progression. These are fundamental conceptions in geological science.

As the reader will desire frequently to refer to this classification of formation and of organic history and geological time, I insert the facts in the following table:

TABLE OF GEOLOGICAL HISTORY.

Divisions of the history.

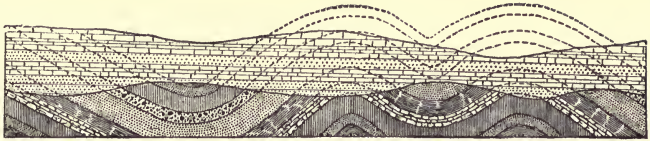
Great Systems, or Æons.	*Systems, or Ages.*	*Groups, or Periods.*	*Organic Reigns. (Highest Fossils.)*
CÆNOZOIC	QUATERNARY...	Recent........	MAN.
		Champlain.........	
		Glacial.........	
	TERTIARY	Pliocene........	MAMMALS.
		Miocene........	
		Eocene........	
MESOZOIC..	CRETACEOUS	Upper Cretaceous........	REPTILES (and Birds).
		Middle Cretaceous........	
		Lower Cretaceous........	
	JURASSIC......	Wasatch........	
		Nevada........	
	TRIASSIC	Star Peak........	
		Koipato........	
PALÆOZOIC..	UPPER CARBONIFEROUS	Permian........	AMPHIBIANS (Land Animals).
		Coal Measures...	
		Conglomerate Measures	
	LOWER CARBONIFEROUS	Carboniferous Limestone	
		Catskill (Waverly)........	
	DEVONIAN....	Chemung........	FISHES (Marine Vertebrates).
		Hamilton........	
		Corniferous........	
		Oriskany........	
	SILURIAN.....	Helderberg	MARINE INVERTEBRATES.
		Salina........	
		Niagara........	
		Trenton........	
	CAMBRIAN...	1. Potsdam	
		2. St. John.........	
		3. Georgia..........	
EOZOIC.......	HURONIAN...	(Undivided)	PROTOZOANS.
	LAURENTIAN...	(Undivided)	

XIII. Courses of the Earth's Masonry.

HOW THE FORMATIONS ARE ARRANGED.

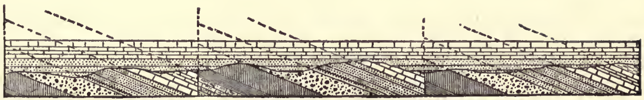
First, let me explain what is meant by a *formation*. It is the mass of rock resulting from some action continued uniformly to a conclusion or a pause. It was indicated in our last Talk that the conditions

Meanings of the term *formation.*



IDEAL SECTION OF A TRUE "UNCONFORMITY."

The series of strata represented in the lower half of the figure were, after the deposition of the entire series, bent into mountain folds and raised above the sea, after which the resulting land surface was deeply denuded, and the whole area was then depressed again beneath the sea, to receive the undisturbed strata represented in the upper half of the figure.



Theoretical diagram showing how a "discordance" sometimes results from the uplifting and "faulting" of the older strata, followed by a period of atmospheric "denudation," then a submergence and deposition of later sediments.

of the world must have changed from time to time, and that the nature of the ocean sediments must have changed correspondingly. The sediments laid down during the time in which we conclude to say no change occurred, are one formation. After this, a slight change would result in another formation. But these two formations may much resemble each other, though decidedly different from the contiguous formations above and below. These two formations together may, therefore, be said to constitute a formation in a larger sense, accumulated during a time when the main action continued the same, though in subordinate particulars it changed. Formation, therefore, is a general term, not always signifying the same amount of accumulation nor even the same range of diversity. We may employ it in various applications, and we shall find it convenient to have such a term. A system is a "formation"; a Great System is a "formation"; a coal-bed is a "formation"; a river-terrace is a "formation", and a metallic vein is a "formation." I must state, however, that the term is not employed by all geologists in this indefinite sense.

The oldest strata are unknown.

Glancing back, now, to the beginning of sedimentary formations, we recognize two principles which must be accepted. *First*, the oldest or lowest sedimentary formation must have rested on a foundation *not* sedimentary. The nature of that foundation will have some light thrown upon it after we have proceeded a little farther with our talks. *Secondly*, since the lowest rocks of which we can gain any knowledge are *not* such non-sedimentary foundation, we are unable to affirm that we have ever explored to the bottom of the sedimentary rocks. There may have been, underneath, originally, a vast additional amount of strata. We will study the oldest strata accessible to us, and observe how they lie in respect to the later strata.

Outcrops. If we travel over the surface of the country, we find it generally overspread by loose materials which in the northern states are the so-called Drift. But here and there the bed-rocks appear at the surface. That is, they *outcrop*. The nature of the outcropping rocks is various. Sometimes they are limestone, sometimes sandstone, sometimes shale, sometimes granite or some other sort of crystalline rocks. It seems at first, as if everything were in a state of confusion. But let us be patient; we shall discover order. We shall perceive that one sort of stratum passes under another, and perhaps at the distance of some miles comes to the surface again. We shall notice that a different stratum or formation passes under this, and then perhaps comes to the surface again at some point still more distant—as if they were three wooden dishes in a pile—*A*, the largest; *B*, the next in size, and *C*, the smallest. *B* goes down under *C*, and comes up beyond *C*. *A* goes down under *B*, and comes up beyond *B*, on the opposite side. Many times numerous successive strata are nested in each other precisely in this fashion. The lower peninsula of Michigan is a good example. If you refer to the Table on page 85 you will see that the Coal Measures are *underlaid* by the Conglomerate Measures, the Carboniferous Limestone, the Catskill Group, the Chemung Group, the Hamilton Group, and the Corniferous Group. Each of these formations underlies

Arrangement of strata.

Synclinal basins.

the peninsula in the form of a broad, shallow dish. The Corniferous Group is at the bottom. Its margin comes to the surface in southern Michigan. You see it in the limestone at Monroe and throughout that region. Thence it passes under the state and comes to the surface again at Old Mackinac and Cheboygan. Mackinac Island, which we have talked about, is of Corniferous Limestone. The eastern margin of this dish is at London, in Ontario, and the western is under Lake Michigan. A little nearer the center of the state we find the margin of the next overlying group—the Hamilton. So the other groups follow as the successively smaller dishes. The top dish consists of the Coal Measures. It is a pretty flat dish, however, since the middle is about as high as the margin.

Synclinal folds.

That is one kind of arrangement which we observe. More frequently, however, the arrangement is more like a pile of long, broad, thin troughs without ends. In this case you perceive that each formation goes down on one side and comes up on the opposite side. But at the ends, they may not appear at the surface. Such an arrangement of strata is called *synclinal*, and the line along the middle is the *synclinal* axis.

Anticlinal basins.

Still another arrangement is quite as common. Suppose we turn our nest of wooden dishes upside down, and suppose that is their natural position. They represent so many formations still. Then suppose we saw through the nest horizontally in such place as to saw off all the bottoms except that of the smallest dish. It is done. Now you see the edges of the formations presenting themselves in concentric outcrops. Plant yourself on the inner or middle formation. Notice that this now *underlies* all the others. This also, *dips* toward all the others, and passes under them out of sight. Then fix your attention on the outcrop of the next dish. Notice that this *dips away* from the first one—the older one, first laid down; and that it *dips toward* the newer or overlying formations. And so to the uppermost or newest—*each newer dipping away from all the older.*

This arrangement of strata is common. The city of Cincinnati stands on an upward bulge of Cambrian rocks. All around, at the distance of some miles, may be seen the outcropping edge of the Silurian System. The Silurian strata overlie the Cambrian, as shown in the Table, page 85, and dip away from them. Next, a few miles farther from Cincinnati, on all sides, we come to the Devonian strata; and next, the Lower Carboniferous.

Anticlinal folds.

Very frequently the dip is in opposite directions along a line, as if an inverted nest of troughs had had their bottoms sawed off. If you turn an open book so that it rests on the table with the back up, then the leaves are strata; their inclination to the table is the dip, and the two inclinations in opposite directions form an *anticlinal* structure. If you keep the leaves in the same position and turn the back of the book down, the structure is *synclinal.* It is rather necessary to understand these terms, because we meet with such structures so frequently, and shall have to talk about them.

Variations in arrangement.

Very commonly, the dishes and troughs of which I am speaking are irregular. A trough, whether inverted or not, may bend, and change the course of its axis. That makes it more difficult to follow, especially as nearly all the rock surfaces are concealed by Drift. Sometimes the trough is depressed at one end; sometimes at both ends; sometimes in the middle. Again, there may be an uplifting of one or both ends, or of the middle. The determination of the order of the strata is often much complicated by those erosions of which we have talked. Suppose, for instance, we have an anticlinal axis, and suppose the surface of the earth horizontal. Then if a deep broad valley were worn across and through the anticlinal series of strata, what sort of curves would be presented by the cut edges of the formations? Can you think them out? But suppose the anticlinal strata are elevated in a long ridge like a mountain, and a deep valley should be cut down one side, can you picture to your imagination the lines which the cut edges of the strata would trace? I think it would be well for the ingenious reader to contrive something to serve as a model to illustrate these complicated arrangements. A nest of wooden or paper dishes might be glued together and sawed and grooved and carved into shapes imitating the configuration of the earth's surface. Even in level and undisturbed strata erosions have created some complications. These are easily illustrated. Glue together thin board-like pieces of pine, cherry, oak, beech, mahogany, apple or other woods, to represent strata. Then cut the pile in various slopes and curves, and notice where the various sorts of wood outcrop. This represents precisely what we observe in the actual arrangements of outcrops. But the Drift covers so much that we often experience difficulties in finding where the rocky outcrops lie.

The complications in the structural arrangements of the rocks are still greater. Anticlinal dips pass off each side into level strata or synclinal arrangements. A synclinal arrangement is often along the highest region, instead of the lowest, as one would expect. On the contrary, an anticlinal arrangement is often along the bottom and sides of a valley, instead of running along the crest of a mountain, as one might expect. These things result from extensive erosions. Again, the dips sometimes become very great—even vertical—and there may be difficulty in deciding which is the upper side of a stratum. Worse than this, we sometimes find a pile of strata tilted so far as to seem to dip in the opposite direction. Then the older and lower strata in fact lie uppermost, and seem to be newer. This inversion of strata sometimes occurs along the Appalachians.

But there are some compensations for all this confusion. The Eozoic, or crystalline rocks are lowest of all in position, and when they are in sight they form a landmark from which we can estimate upward. Remember, however, that the lowest rocks—lowest in geological position—are often highest in topographical position. They are often at the summits of mountains, as in the Alps and the Rocky Mountains. The newer strata then slope down in order along each side of the mountain, and pass under the plain.

In the next place, strata are to some extent, arranged in long folds, which here rise in a ridge, and there disappear under a synclinal. Such long drawn forms are found along the Laurentian hills in Canada, and along the Appalachians. Here we catch sight of a general method in rock arrangements.

Still again, the newest strata lie along the Sea and Gulf shores, and dip down under the water. These sheets of sediments are undisturbed. Beneath these are generally older strata which have a corresponding dip. These seaward dipping strata are Cænozoic and Mesozoic. When we descend to the Palæozoic strata we often find them considerably folded and irregular.

General explanation of positions of strata

In general, the present positions of the strata may be explained as if they had been produced thus:— First, the universal ocean deposited sediments which hardened into Eozoic rocks which universally underlie. Then some portion of the bottom was uplifted to daylight, and the sediments of the next, or Palæozoic, Æon were *not* universal. Next the uplifted regions were further uplifted, and some of the Palæozoic sediments appeared along the margins of the Eozoic. Then followed Mesozoic sedimentation, another uplift of the same regions; then Cænozoic sedimentation and other uplifts. Meanwhile the destructive work of erosion was in progress, and the original shapes of the uplifted strata, already disguised by many movements, were further obscured by the wearing down of extensive formations, and the obliteration of some. But of all this we shall catch more satisfactory glimpses hereafter.

XIV. A Walk in the Yellowstone Park.

THERMAL WATERS.

In the northwestern corner of the territory of Wyoming is a tract sixty-five miles long and fifty-

GIANT GEYSER IN ACTION, YELLOWSTONE NATIONAL PARK.
(From Winchell's *Geological Studies.*)

The Yellowstone Park.

five miles broad which has been reserved by act of Congress (March 1, 1872) as a national park or reservation "dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of the people." This was done on the recommendation of the national geologist, Dr. F. V. Hayden. The tract on the north extends about two miles into the territory of Montana, and on the west, two and a half miles into Montana and Idaho. It lies on the great continental divide at a mean altitude of six thousand feet, and includes mountain summits rising to ten and twelve thousand feet—about twice the altitude of Mount Washington, and covered, of course, with perpetual snow. Within the tract is the Yellowstone Lake, which lies 7,427 feet above sea-level. Two or three miles west of this is Two Ocean Pond, lying on the water-shed. On the east, the drainage from this pond passes into the Yellowstone Lake and River, and thence into the Missouri and the Gulf of Mexico. On the west, the same pond drains into Shoshone Lake, the Snake and Columbia Rivers and the Pacific Ocean. The Yellowstone and Madison are the chief rivers of the reservation, the first flowing west to form the Missouri, and the other north to a navigable tributary of the same. The upper Madison is also known as the Firehole River. Gardiner's River is an important tributary of the Yellowstone, flowing north, and making its junction on the northern boundary of the Park. Some of the loftiest mountains of the interior overlook the Park on all sides. On the east, are the two ranges of the Shoshone Sierra; on the west, the Gallatin Range; on the south the Red Mountain Range and the Pitch-stone Plateau ; on the north, a belt of "peaks" rising ten and eleven thousand feet high. These mountains, like nearly the whole surface of the Park, are composed of volcanic rocks. The Yellowstone, after passing two falls, respectively 162 and 350 feet, flows through a cañon nine miles long, which has been thus described :

The Cañon.

"For a mile away, the sides are formed of slopes from which rise vast battlements, turrets, pinnacles, alone or in clusters, of tall conical spires ; some are of basalt, some of limestone [this is probably an error] ; they rise through slopes part clay and part broken silicates and limestone. On this mass of material nature has lavished her wealth of colors with a spendthrift hand. The taller rocks of ruddy browns or Pompeian red melt away in the *débris* from which they spring, to rich yellows, fading below, to cool grays in exquisite gradation. Here and there are rocks of a red like claret lees ; others have a basis of rich ochre, with the projections of umber brown. In places, the reds are nearly of a dark scarlet. Here the rocks are of a lovely French gray ; there, of a delicate fawn tint, rising above to saffron, and melting to snow-white below ; while in places, patches of vivid green, orange or black mark the masses of moss and lichen fed by the abundant spray, and forced into luxury of growth by the warm streams from the numberless springs issuing from the walls of the cañon."—*Lippincott's Magazine*, June, 1880, p. 699.

Hot Springs.

It is not for the scenery—not even for the geology of the Park, that I have led you hither. I wish your imaginations to be impressed by the wonderful groups of geysers and hot springs scattered through the Park. Mr. A. C. Peale, one of the United States geologists, has described in the Park 2,195 warm springs, and expresses the belief that three thousand exist. He has also named and described seventy-one geysers. A *geyser* is a spring which periodically throws up hot water to some distance above the level of the ground.

Let us take a particular geyser and note its situation and the phenomena connected with its eruptions. "Old Faithful" geyser is one of a group in the upper part of the valley of Firehole River. The external formation is a mound or table of *geyserite* or *silicious sinter*—a whitish mineral composed chiefly of silica and water, and deposited from the waters of the geysers. The mound is one hundred and forty-five feet by two hundred and fifteen at base, and twenty by fifty-four feet at top. It rises about twelve feet above the surrounding level, and is composed of layers of deposit arranged in a succession of steps that are made up of small basins. Near the top these basins are beautiful, broad, shallow pools, with pink, cream, white, brown, and gray bottoms, in which the deep azure-tinted water stands after the eruptions. The "chimney" or "crater" is the top of a "basin" five feet deep, at the bottom of which is an irregular orifice, the head of the geyser "tube." The eruption begins with some preliminary splashes or spurts—from three to a dozen or more. These grow more powerful for about four minutes when jets in rapid succession escape with a roar, and soon attain the maximum height. In a few seconds later the column subsides with occasional vigorous spurts. The water

Geysers.

Old Faithful.

eruption is followed by steam which escapes gently and soon dies away, leaving the crater empty. The water is thrown to a maximum height of one hundred and fifty feet.

General Sherman thus describes "Old Faithful": "We saw Old Faithful perform at intervals of sixty-two to eighty minutes. So regular are its periods of activity that we could foretell its movements within a few minutes. Sometimes we stood near enough to feel the hot spray, and at others, we sat at our camp, three hundred yards away. Each eruption was similar, preceded by about five minutes of sputtering, and then would arise a column of hot water, steaming and smoking, to the height of one hundred and twenty-five or one hundred and thirty feet, the steam going a hundred or more feet higher, according to the state of the wind. The whole performance lasts about five minutes, when the column of water gradually sinks, and the spring resumes its normal state of rest."

The Giantess.

The "Giantess" geyser, belonging also to a group on the upper Firehole, has an inconspicuous crater, but is characterized by magnificent eruptions. Mr. N. P. Langford writes of it: "No water could be discovered, but we could distinctly hear it gurgling and boiling at a great distance below. Suddenly it began to rise, boiling and spluttering, and sending out huge masses of steam, causing a general stampede of our company. When within about forty feet of the surface, it became stationary, and we returned to look down upon it. It was foaming and surging at a terrible rate, occasionally emitting small jets of hot water nearly to the mouth of the orifice. All at once it seemed seized with a fearful spasm, and rose with incredible rapidity, hardly affording us time to flee to a safe distance, when it burst from the orifice with terrific momentum, rising in a column the full size of this immense aperture, to the height of sixty feet; and through and out of the apex of this vast aqueous mass five or six smaller jets or round columns of water, varying from six to fifteen inches in diameter, were projected to the marvelous height of two hundred and fifty feet." This eruption continued twenty minutes; and two eruptions occurred during twenty-four hours.

Geyserite and travertine cones.

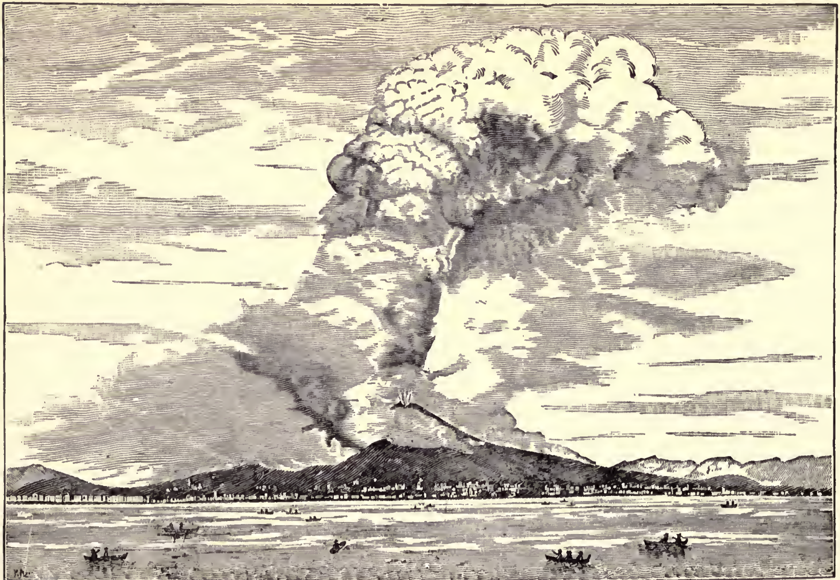
The numerous other geysers in their action present phenomena essentially similar to these. The mineral deposit generally forms a mound, cone, or nozzle, through which the water escapes. This varies greatly in diameter and height. In the White Dome and White Pyramid geysers it is twenty-five feet high. In the Giant geyser the cone is ten feet high and rests on a platform four feet high and over three hundred feet in diameter. The material is generally geyserite; but a few geysers and springs exist in which it is *travertine* or calcareous tufa, consisting of calcium carbonate. The Soda Butte, on the east of the Yellowstone, is a conical mound twenty feet high, which, though now closed at the top, was formerly an active geyser. It is composed of travertine, and *Soda* Butte is a misnomer.

Terraced basins.

The thermal springs of the Park have built up mineral deposits of extremely curious and interesting character. The Mammoth Hot Springs, on Gardiner's River, three miles from its mouth, situated on a series of terraces, present a fine development of a style of formation characteristic of hot springs in various parts of the world. The waters issue at many different levels along a slope, and the calcareous deposit takes the form of a pile of tubs so arranged that the overflow from one at a higher level falls into another at a lower level. The tubs are of various depths and diameters, and sometimes display lively shades of color—greenish, reddish, and yellowish. There are several terraces of deposits from which the water has disappeared; and the evidence is, generally, that the thermal energy of the region is diminishing.

Geysers in New Zealand and Iceland.

The phenomena of hot springs are well known in various parts of the world. Some of those of New Zealand present close resemblances to the Mammoth Hot Springs of Gardiner's River. Geysers occur also, in New Zealand; but the most celebrated is the Great Geyser of Iceland. To impart a conception of its behavior in eruption, the following description by S. Baring Gould is cited:—"Five strokes under ground were the signal, then an overflow, wetting every side of the mound. Presently a dome of water rose in the center of the basin and fell again, immediately to be followed by a fresh bell, which sprang into the air full forty feet high, accompanied by a roaring burst of steam. Instantly, the fountain began to play with the utmost violence; a column rushed up to the height of ninety or one hundred feet, against the gray night sky, with mighty volume of white steam cloud rolling about it, and swept off by the breeze to fall in torrents of hot rain. Jets and lines of water tore their way through the cloud, or leaped high above its domed mass. The earth



MOUNT VESUVIUS AND THE BAY OF NAPLES (Palmieri). (From Winchell's *Geological Studies*.)

trembled and throbbed during the explosion, then the column sank, started up again, dropped once more, and seemed to be sucked back into the earth." —*Pen and Pencil Sketches of Faroë and Iceland.*

Explanation of geyser action.

No one can contemplate the phenomena of a geyser or hot spring without feeling a conviction that heat is the essential condition. Somewhere within the earth is a repository of heat sufficient to warm, or even to boil, the water which rises to the surface. Strata whose outcropping edges appear at the surface, receive rain-water and convey it along the dip to unknown depths. The water rises through a tube, and in its lower part a temperature exists sufficient to boil water under the pressure there existing. But details of the mechanism are not unanimously agreed upon. They are probably somewhat as follows:—Water accumulates in the geyser pipe upon the steam formed in the lower part by the bottom temperature. The steam, for a time, is subjected to compression, and the compression increases with the continued development of steam and accumulation of water. Finally, the elastic force becomes sufficient to lift the column of water. The commencement of escape now diminishes pressure, and a large volume of steam is instantly formed, which causes the violent eruption. The heavy thumps sometimes heard before and during the action are due to collapses of steam in contact with the water, and are strictly the same in principle as the sharp detonations frequently heard in the steam-pipes employed for warming buildings.

XV. Among the Volcanoes.

INDICATIONS OF INTERNAL FIRES.

Description of Vesuvius.

Vesuvius and Ætna are the two volcanoes familiarly known to classical antiquity. Let us make the ascent of Vesuvius, taking the usual route from Naples. Driving a couple of hours down the coast to Resi′na, on the site of the ancient Herculaneum, we begin the ascent either on foot or on mule or horse back. For thirty minutes we follow a rough road through vineyards. The road then turns to the north and we enjoy a lovely view of the landscape and the bay. Here stretch two dark streams of cold lava—presenting somewhat the aspect of enormous beds of enormous cinders—fibrous and twisted and wavy. They are the lava streams of 1858 and 1868. Next appears the huge lava wall of 1858. In two hours from Resina, we reach the Observatory, 2,218 feet above sea-level, erected in 1844 for meteorological and seismic observations. Here Professor Palmieri, the celebrated vulcanologist, is engaged in making the most minute studies of the incidents in the history of the mountain. From this station and the "Hermitage" just below, where the traveler procures refreshments, the view over the black and herbless lava slope is desolate beyond description. Soon the road becomes impracticable for quadrupeds. Crossing the lava flood of 1871, we now reach the Atrio del Cavallo, at the foot of the cone. This is the valley which separates the highest and principal summit of the mountain from Monte Somma, a fragment of an ancient crater of much larger size than the modern one. The height of Vesuvius varies from 3,900 to 4,300 feet. Monte Somma stands 3,642 feet. The slope of the mountain near the base is 10°, while the active cone has a gradient of 29° to 30°. Monte Somma rises almost perpendicularly from the Atrio del Cavallo, while on the opposite side, it slopes to the plain at an angle of three degrees.

The entire mountain, so far as can be seen, is a vast pile of lava, lapilli (stones), sand, and ashes (powder-like lava), resulting from a long succession of eruptions. The molten mineral matter thrown out is lava. It escapes from the regular crater or bursts out through some new fissure near the summit, around which the erupted materials may accumulate and form a subsidiary crater. The molten lava has a temperature above 2000° Fah. Often vapor of water escapes with the lava, and with such violence as to break off fragments of the rock forming the crater wall and floor, the larger of which are known as lapilli and scoriæ, while the minuter fragments constitute volcanic sand and ashes. The vapors rise to a height of about ten thousand feet, and spread over the mountain like a vast umbrella or Cedar of Lebanon. Indeed, the height sometimes attained by this enormous canopy of vapor and ashes has been shown by measurements to reach twenty-three thousand to twenty-six thousand feet. Enormous quantities of ashes borne upward with the vapor, give the cloud a dark and angry appearance, and its frowning aspect is confirmed by the flashes of lightnings which dart through it. By night the vivid reflection of the light thrown upward from the crater gives the appearance of terrific flames roaring from the summit of a burning mountain. But no proper combustion exists. Often the condensation of the vapor results in rain which descends in a torrent. The ashes mingled with water convert the storm into a deluge of mud. This rushes down the mountain with destructive effects, and in several instances, whole villages and even cities have been buried in mud.

A moderate disturbance of the mountain is characterized by the ejection of vapors and stones, accompanied by a roar, resembling that of distant artillery. More serious eruptions are accompanied by loud subterranean noises, earthquakes, and vivid electric phenomena.

Examples of eruptions.

History records a large number of Vesuvian eruptions. According to Strabo, Vesuvius was once covered by beautiful meadows, except over the summit, which was level and sterile. "It has" he says, "an appearance like ashes, and shows rugged rocks of sooty consistency and color, as if they had been consumed by fire." At the same period the theater of volcanic activity was a few miles toward the west. Ischia, Procida, the Solfatara and the Monte Nuovo were then active craters. About A. D. 63, the volcanic nature of Vesuvius manifested itself; and in 79 occurred the terrific eruption which overwhelmed Pompeii, Herculaneum, Stabiæ, and other villages in a deluge of ashes and mud. In the eruption of 1631, heavy stones were thrown to the distance of 15 miles. One which fell at the village of Somma had a weight of fifteen tons. The earth was convulsed by a violent earthquake, and seven streams of lava poured from the summit, overwhelming Bosco, Torre dell' Annunciata, Torre del Greco, Resina and Portici. Three thousand persons perished on the occasion. In 1779 a vast number of red-hot stones were hurled to a height of two thousand feet. In April, 1872, after months of threatening, the lava burst forth on every side—on the northeast, southwest, and more particularly at the Atrio del Cavallo, from which a huge stream issued with such suddenness as to overtake and destroy twenty persons out of a crowd of spectators gathered to watch the spectacle. The torrent descended to Massa and St. Sebastiano, passing beneath these villages, which it partially destroyed, in a molten stream 3,000 feet wide and 20 feet deep. At the same time, amidst terrific thundering, the crater hurled forth immense volumes of smoke, mingled with red-hot stones and lava, to a height of 40,000 feet.

Mt. Ætna. Mt. Ætna is altogether a more majestic structure. It has a circumference at base of one hundred miles. It rises 10,840 feet above sea-level, and 3,000 feet above the forest-limit. The highest cone is a black and silent waste. The whole mountain, from top to bottom, is a series of frozen lava-sheets piled one above another. Some conception of the age of the mountain may be formed from the fact that Ætna has been known from the earliest ages as a volcanic mountain, and eruptions have occurred, on an average, once in ten years, yet, within the historic period its bulk and altitude have not increased to a perceptible extent. The eruptions of Ætna are attended by circumstances similar to those of Vesuvius. The lava, however, does not escape, in modern times, from the summit crater, but breaks through the wall at some distance below. In 1669, the Monti Rossi, so-called, were formed, and 27,000 persons were deprived of all shelter, and many lives were lost in the descending streams of lava. In 1693, an eruption was accompained by a fearful earthquake which partially or totally destroyed forty towns and caused a loss of sixty to one hundred thousand lives.

One of the greatest eruptions of modern times occurred in 1865. After violent premonitory symptoms two years previously, when the loftiest cone of the volcano opened on the side and emitted a large stream of lava, the wall of the mountain yielded to the pressure of its molten contents. Some subterranean roaring was first heard; slight agitations affected the whole eastern part of Sicily, and the ground was rent open for a mile and a half to the north of Monte Frumento, one of the secondary cones which rise on the slope of Ætna. This vomited lava for a few hours, when, seeming to be obstructed, fresh outbursts occurred a little lower down, and six cones of ejection were built up. These and smaller ones blended together in an elevation of nearly 300 feet. Soon the two upper craters hurled forth only lumps of stone and ashes, while the lower poured forth lava. Then followed the diversified phenomena of a prolonged eruption, which, however interesting, we have not space to describe. Of the volume of lava something may be said.

During the first six days, the quantity of lava issuing from the fissure of Monte Frumento was esti-

Volume of lava emitted in one eruption.

mated at 117 cubic yards a second. In the vicinity of the outlet, the speed of the current was not less than twenty feet a minute; but lower down the velocity was diminished. On the second of February, the principal current had traveled three miles. It was from 900 to 1,600 feet wide and 49 feet deep. Here it plunged like a cataract into a deep gorge. "It was a magnificent spectacle, especially during the night, to see this sheet of molten matter dazzling red like liquid iron, making its way in a thin layer, from the heaps of brown scoriæ which had gradually accumulated above; then carrying with it the more solid lumps which dashed one against the other with a metallic noise, it fell over into the ravine only to rebound in stars of fire." In a few days the ravine was filled and the lava stood 160 feet deep. From this the flow continued east toward Mascali, filling to its brink, on the way, the winding gorge of the dried up rivulet. By the middle of February, the river of fire was more than six miles long, and its flow was more and more slackened by incasement in a crust of cooled material. Through this, it continually burst, in front and on the sides, and new spurts darted off for short distances in various directions, giving to the solidified stream an aspect characteristically rough. Suddenly one of the outbursts far up the stream, resulted in a new river, which flowed toward the plains of Lingua grossa, swallowing up thousands of trees. The destructive action was not much longer continued, but months after the commencement of the eruption, the molten fluid within the incrusted river continued to burst forth in slowly advancing and overlapping outflows, leaving an exterior black and rough beyond description.

Other instances,—

This eruption may serve to illustrate the volume of molten lava sometimes emitted from a volcano. Perhaps a more striking example of volume is furnished by the volcano of Cosiguina, a hillock about 500 feet high on a promontory to the south of the Bay of Fonseca in Central America. The ashes thrown into the upper atmosphere spread out in a dark canopy several hundred miles in width. It covered the plains for a distance of twenty-five miles, with a layer of dust sixteen feet thick. The headland was advanced 787 feet into the bay. Two new islands were formed from the ashes and stones. The wind carried the dust westward more than forty degrees of longitude, and a layer of pumice was formed at that distance which vessels penetrated with difficulty. On the east the fall of ashes extended to Jamaica, 800 miles. The area covered by the fall was one and a half million square miles; and the total volume of matter which escaped was not less than 65½ billions of cubic yards. The sound of the explosion was heard at Bogotà, 1,025 miles distant. Impenetrable darkness reigned for forty-three hours throughout the region of the eruption.

Cosiguina,

Kilau-e-a.

The amount of lava from Kilau-e-a in 1840 exceeded six billion five hundred and fifty million cubic yards. That from Mauna Loa, in 1835, flowed seventy-six miles from the crater. The volcano of Skaptar Jokul, in Iceland, was cleft asunder in 1783, and gave vent to two rivers of fire, each of which filled up a valley; one attained a length of fifty miles, with a breadth of fifteen miles; the other was of less dimensions, but the depth of the mass was in some places as much as four hundred and ninety-two feet. The whole volume of lava erupted on this occasion was not less than six hundred and fifty-five billions of cubic yards—a volume equivalent to that of the whole mass of Mont Blanc.

Conditions of volcanic action.

Many thrilling narratives of volcanic violence might be cited; but these must serve as examples. They demonstrate the existence of enormous reservoirs of molten rock within the earth, and the exertion of such inconceivable forces as suffice to burst mountains, to hurl rock-fragments a mile into the atmosphere; to blow into atoms, while escaping with steam and gases, sufficient matter to bury thousands of square miles in ashes. It appears that isolated volcanic cones, like Vesuvius, Ætna, and Shasta, are composed generally of piles of ejected materials, inaugurated by the escape of matter through an initial fissure. The volcanic cone is hollow above, with a pipe leading down into the earth. Through this the lava rises into the cavity. When the strains have sufficiently accumulated, the lava is forced above its usual level—sometimes overflowing the lips of the crater; sometimes bursting the walls of the mountain, thinned by melting from within. Sometimes, also, the walls by internal fusion become so much weakened that the whole summit falls in, leaving an enormous open chasm. Over this a solid crust forms by exposure. Then, in subsequent ages, this is pierced by a new rupture, around which a new, and smaller, cone is built up, with the broken margin of the older one still more or less perfectly preserved. So, during the eruption of 79, the crater of Vesuvius collapsed, and the present crater has since grown up, leaving still on the north a vast rampart, Somma, showing where the line of rupture of the ancient cone was traced.

XVI. Frozen Seas of Lava.

ANCIENT LAVAS.

Contrast between vulcanism of the present and of the past.

THE spectacle of a volcano in a state of active eruption is a terrific demonstration of the forces of fire imprisoned within the earth, and escaping to our view only when their accumulated strength exceeds that of the restraints in which they are held. These are activities of the present ages of the world, and proofs of intense heat now existing within the cool exterior. Geology brings to our notice the records of still vaster and more terrific operations of intense heat. Vast as are the volumes of modern eruptions, they are slight compared with eruptions of former geologic ages. The limited amount of matter poured forth in modern times cools near the place of escape, and seldom flows to the distance of ten miles. It accumulates, therefore, around the vent, and builds up a volcanic cone. In earlier times the molten lava issued in such quantity as to retain its liquid state sufficiently long to flow away sometimes a hundred miles or more, and overspread with a sea of fire regions as broad as states. The modern volcano exhibits, perhaps, a greater explosive energy than the ancient one, and hence it may disperse greater volumes of ashes; yet some of the ancient volcanoes, Lava fields—

Columbia River districts;

near the beginning of modern geological history, have ejected vastly greater quantities of ashes than have been known to escape during any eruption of historic times. Let us make the acquaintance of some of the most remarkable of lava-covered areas.

Let us turn, first, to what is probably the most extraordinary outflow of lava lying on the earth's surface. A concise, but comprehensive description has been furnished by Professor Joseph Leconte: "Commencing in middle California as separate streams, in northern California it becomes a flood flowing over and completely mantling the smaller inequalities, and flowing around the greater inequalities of surface; while in northern Oregon and Washington it becomes an absolutely universal flood, beneath which the whole original face of the country, with its hills and dales, mountains and valleys, lies buried several thousand feet. It covers the greater portion of northern California and northwestern Nevada, nearly the whole of Oregon, Washington, and Idaho, and runs far into Montana and British Columbia on the north. Its eastern and southern limits are not well known. but its extent can not be less than one hundred and fifty thousand to two hundred thousand square miles, with a thickness of three thousand to four thousand feet in its thickest part, where cut through by the Columbia River. In another place, at least seventy miles distant, where cut into twenty-five hundred feet deep by the Des Chutes River, at least thirty successive sheets may be counted."

The Columbia has cut through the entire breadth and depth of the Cascade range, down to within one hundred feet of sea-level. Here is a cañon one hundred miles long, with the summits of the range rising twenty-five hundred to thirty-eight hundred feet above the river surface. The entire walls of the cañon are composed of ancient lava. When we reflect that the peaks of the Cascade range are simply results of erosion, we can well believe that the highest summits were originally not less than four thousand feet above the base of this astounding lava-deposit.

This vast and ponderous sheet of lava appears to have flowed through fissures from the Cascade Mountains, and naturally to have accumulated to greatest thickness along that range. The sheet extends across eastern Oregon to the Blue Mountains. From this range, also, other, but less copious, lava streams were poured forth.

The chain of volcanic outbursts continued southward into the Sierra Nevada. The lava vents here were more local and isolated. The lava, though enormous in quantity, was less than in Oregon, and overspread the surface less generally. Under these circumstances, great volcanic cones were built up—such as Lassen, Shasta, Hood, and Ranier. From Lassen's Peak the sheets of lava form a regular slope to the Sacramento River. Through this the streams have cut their channels five hundred to eight hundred feet deep.

Basin and plateau regions.

Nearly all the so-called Basin Ranges lying eastward of the Sierra Nevada, through Utah and parts of California and Arizona, are composed, at least in part, of ancient lavas. Through the Plateau Region, farther east, lavas are equally abundant. In the Sevier Basin, according to Gilbert, the great Sevier fault, or break, through the rocks, exposes a maximum thickness of two thousand feet. South of the Colorado is a much larger lava-basin, spreading several broad lobes over into New Mexico, the most easterly of which reaches nearly to the Rio Grande. Its extreme limits are three hundred and twenty-five miles apart. It includes the San Francisco, Mogollon, and Sierra Blanca mountains. This outflow proceeded from a large number of vents. In San Francisco Mountain we have a pyramid of compact lava nearly five thousand feet high, with slopes of ten to twenty degrees.

The later Tertiary a time of great vulcanism.

The examples cited are sufficient to impress the imagination and enable us to appreciate the magnitude of the work of heat in the geological æon not long antecedent to the dawn of modern times. We mark the Tertiary, and especially the later Tertiary, ages as signalized in the history of the world by outflows of molten lava—primarily from fissures, but secondarily building up small and moderate sized cones in great abundance, and not a few stupendous mountain piles reaching to eighteen thousand feet.

Older periods of activity:

In remote geologic ages lava eruptions were of frequent occurrence—but less frequent and less copious than in later ages. During the Triassic Age (see Table, p. 85) many eruptions of lava occurred, both in Europe and America. The Palisades of the Hudson;

Triassic,

the cliffs of Meriden, Connecticut, and East and West Rock, New Haven, are ancient lavas of this age. Much farther back in geological history, in

Cambrian and pre-Cambrian.

Cambrian time, or as some think before Cambrian time, vast and repeated outflows of lava took place which remain to-day uplifted in Keweenaw Point and Ile Royale. The native copper is found imbedded in these ancient lavas.

Dykes.

A fissure filled with rock-material solidified from a state of fusion, is a dyke. Sometimes the formation containing the dyke is more friable than the lava, and weathers away more rapidly. The dyke then projects above the surface like a vertical wall. Certain varieties of lava called basalt possess the peculiar property of assuming a columnar structure while cooling. The longer axes of the columns are ranged at right angles with the cooling surfaces. Thus, when the basalt cools in a fissure, the columns lie transversely from wall to wall. In most cases, the columns are vertical. This is thought sometimes to result from cooling under the sea; but probably when a sheet of basalt rests on the surface of the earth, the atmosphere above and the earth below are cooling surfaces of the requisite efficiency to develop vertical columnar structure. The columnar structure induced to an imperfect extent, in basaltic rocks of Ile Royale may be conceived as produced in the bottom of the sea; but the columnar structure in the cañon of the Columbia must have been acquired upon the land. The columns, in some cases, rest with their ends directly on a bed of pebbles and sand not over a hundred feet thick, and bearing the evidences of torrential action—therefore a shallow-water deposit, while the columnar basalt is three thousand five hundred feet thick. High cliffs of basaltic columns, like those exposed on the Hudson and Columbia rivers are often called palisades.

In some cases the uprising lavas have not been able to find their way to the surface. Either the fissures

Intercalated beds of lava and laccolites.

in which they started, from some unknown depth, never extended to the surface, or the streams lost their way and found themselves pent in the strata, and crowded in every direction in search of relief. In such case the lavas have sometimes insinuated themselves laterally between the strata to such extent as to separate the strata by a considerable interval, without being able to escape to the surface. The result is, a dome-like elevation of the surface, forming a peculiar type of structure called a laccolite—named and first described by Mr. G. K. Gilbert. In many cases, the arched strata become much fissured, and the lava sheets communicate quite freely with each other. Such laccolites exposed to the processes of erosion reveal the constitution of the interior. This subject is fully illustrated by Mr. Gilbert in his memoir on the Henry Mountains in east ern Utah.

Erosion results in lava fields.

River erosions of vast lava-sheets have resulted in many striking forms. As the most extensive sheets are the result of late geological action, they generally rest on incoherent materials—gravel and sand, as in Oregon and California. When the erosions of the streams have cut through the lava, and for some distance into the gravel, the less coherent nature of the latter causes an undermining of the lava-sheet. It thus projects like a table-top, beyond the gravel. When the erosion cuts the lava-sheet along parallel lines, it gives rise to the forms known as "table mountains." These are common in the volcanic region of central France; and especially so in eastern California. In Butte County, the ancient drainage wore channels stretching westward from the upland of the Sierra.

These were subsequently filled by outflows of lava. Then in modern times, a change of levels established drainage from north to south. The modern streams, therefore, have cut channels across the ancient ones, and lava-topped intervals remain. These are table mountains. Further south, in Tuolumne County, the ancient and the modern drainage both moved from north to south. The ancient channels, therefore, stretched north and south, and the lava-sheets which filled them stretched from north to south. The modern water-courses have shunned the hard lava, and have dug their channels alongside of the lava, in less consolidated materials—gravels or slates. These positions were formerly the elevated banks of the streams. Thus, the undisturbed, elongated lava-sheets, which rested on the bottoms of the ancient channels, now rest on elongated ridges. The ancient bottoms are beneath these tables. Over the ancient bottoms were distributed the auriferous gravels from the mountains; and here they are still found. They are the "deep placers"; and are explored by drifting in from the sides. The beds of the modern streams, strewn with auriferous sands from the same sources form the so-called "shallow placers."

XVII. Imprisoned Heat.

INTERNAL CONDITION OF THE EARTH.

In an *Artesian* well the water is forced up by pressure of other water standing somewhere, at a higher level, and freely communicating with this. You have learned, (Talk XIII), that strata often dip down from their place of outcrop to a great depth into the earth. Suppose a porous formation, like a sandstone, thus goes down from the surface; the rain which falls on its outcrop must soak into the rock and saturate it. This is then a water-bearing stratum. In descending obliquely it passes under many places; and if a hole should be bored from the surface to this stratum, the water would rise into it to the height of the place of outcrop. If the place of boring is lower than the outcrop, the water will rise above the surface. The water comes up with nearly the temperature acquired at the bottom of the well.

Depth to which the sun's heat penetrates the earth.

The sun's warmth penetrates daily but a foot or two in summer; and at night, much of this is lost by radiation. Not all, however, for the deeper warmth continues to descend; and next day's excess of warmth follows this. Thus the summer heat accumulates, and continues to descend. It grows less and less, however, and at fifty feet, can no longer be discerned. The winter's cold also penetrates slowly, and diminishing in intensity at every foot, ceases to influence the temperature at the depth of about fifty feet. At this depth then, the temperature is constant the year round. The depth of constant temperature varies, however, with the nature of the climate. If the surface fluctuations are excessively great, you can understand that the contrasts must be felt at a greater depth. In Minnesota, therefore, the depth of uniform temperature would be greater than fifty feet. In Florida, however, where the climatic extremes are

Depth of uniform temperature.

much less, the depth of uniform temperature would be less than fifty feet. The uniform temperature under any region must be about the same as the mean annual temperature at the surface.

The heat of midsummer and the cold of midwinter penetrate the earth at the rate of about one foot per week. Hence the cold of January 1st is felt at a depth of twenty-five feet about July 1st; and so of the cold or heat of any other date. At twenty-five feet the temperature of water is higher in winter and lower in summer. So the popular opinion about certain wells is not entirely unfounded.

Temperature increases downward.

If, however, we employ means to ascertain the temperature at depths below the plane of constant temperature, we find it regularly increasing as we descend. We do not find the rate of increase exactly the same at different localities, but the average is about one degree (Fahrenheit) for every fifty or sixty feet of descent. The Artesian well at Charleston, South Carolina, is 1,250 feet deep, and the bottom temperature is 87°. As the mean surface temperature is 66°, and the depth of uniform temperature may be assumed at 50 feet, the increase is at the rate of 57 feet for one degree. At Louisville, Kentucky, is an Artesian well 2,086 feet deep, with a bottom temperature of 86¼°. As the surface temperature is 55½°, the rate of increase is one degree for every 66 feet. The Belcher well at St. Louis with a depth of 2,199 feet, has a bottom temperature of 73°.4. The surface temperature being 55°, the indicated rate of increase is one degree for 116 feet. This is exceptional. At Columbus, Ohio, an Artesian well 2,775⅓ feet deep gives a bottom temperature of 91° with a surface mean of 52°.

Observations in artesian wells,

This implies a rate of increase of one degree for every 77 feet. Again, the well at the Insane Asylum, St. Louis, is 3,843½ feet deep and affords water at 105°, giving a rate of increase of one degree for 76 feet.

deep mines,

In deep mines, the temperature becomes intolerable, and measures have to be adopted for the introduction of fresh air from the surface. In the deep workings on the celebrated "Comstock Lode," the temperature of the water at 2,000 feet is 130°. The water which filled the Savage and Hale and Norcross mines for two years, had a temperature of 157°. At 3,080 feet, the temperature is 170°. To cool the air sufficiently for the endurance of the miners, over thirty tons of ice were consumed daily. [See further, Talk XXI.]

tunnels.

Tunnels through mountains generally attain oppressive temperatures. The Mont Cenis Tunnel through the Alps, between Turin and Chambery, lies 4,093 feet below the surface of the Pass, or 5,251 feet below the summit of Mt. Frejus, and is eight miles in length. The rise of temperature discovered in the rocks is about fifty degrees.

Existence of intense internal heat.

Assuming the rate of increase to be one degree for 60 feet of descent, we should obtain, in the latitude of New York, heat enough to boil water at a depth of about 9,000 feet. At the depth of 50 miles, the temperature would be 4,600°, which is far above the melting temperature of ordinary mineral substances. In this method of reasoning we find an easy explanation of the temperature of deep waters, and of the molten condition of rocky matter erupted from volcanoes. But we know that boiling and melting points, under the enormous pressure experienced within the earth, are materially higher than at the surface. There is much reason also, to argue, on theoretical grounds, that the rate of increase of temperature continually diminishes at any considerable depths. But, though the depth may be quite uncertain at which a rock-melting temperature would be reached, we have the demonstration that such temperature exists at some depth.

Movements of temperature beneath the earth's surface are slow. Many instances are known of permanent ice preserved in caverns. At Brandon, Vermont, permanent frozen gravel exists at a depth of sixteen feet. In the Caucasus, masses of ice lie buried permanently in the moraines, one of which is 1,500 feet distant from any glacier, and others are a mile below the termination of the glacier. In Siberia and in northern America, the earth remains permanently frozen at a depth of two or three feet. At Yakutsk in eastern Siberia, the earth is frozen to a depth of 700 feet. As these and other occurrences of permanent ice are not attributable to any climatic influences now existing, they must be the records and evidences of more rigorous climates in the past. In other words, the climate of the present is still contending with temperatures whose effects are lingering in protected situations long after the climates have become ameliorated. It has been demonstrated that an ice-cap resting several thousand years over any considerable portion of the surface, would so reduce the subjacent temperature of the earth that for many centuries after the disappearance of the ice, a *decrease* of temperature would be discovered in penetrating down-

Imbedded ice unmelted.

ward. Even centuries later, so much cold would still remain within the earth, that the rate of increase of temperature would be less than if the ice-cap had not existed; and after 3,600 years, that rate would be only half the normal rate.

Slow cooling of lava.

Masses of lava are singularly poor conductors of heat. A lava stream has been found still hot a century after its eruption. Some years ago a bed of ice was discovered on the slope of Ætna, buried beneath a stream of lava; and from this the city of Catania has since obtained supplies of ice. On Tierra del Fuego ice and lava are found interstratified for a great depth—each winter's snow being covered by a new lava-sheet. In 1860 the crater of the mountain Kutlagaya, in Iceland, hurled out simultaneously into the air lumps of lava and of ice, all intermingled together.

Bearing of these facts.

These are interesting facts, but I propose for them no other use at present than to show some possible reasons why the rate of increase is unequal at different localities or different depths. We know that some regions have been overlaid by sheets of snow and ice. We have also discovered reasons for believing that our northern states, as far as the bowlders are distributed, were covered by continental glaciers during a geological period. If this was so, it may be that their cooling influence is still left within the earth; and if it is, the rate of increase of temperature as observed is lower than it would be under normal conditions. A more rapid rate of increase implies a thinner crust of solid matter. But, while these considerations must not be forgotten, it must be confessed that most of the questions concerning internal heat are still imperfectly understood.

Though we are certain intense internal heat exists, we neither know at what depth it exists, at what ratio it increases, nor what is its cause or source. Nor do we know whether the deep interior is in a solid or a liquid state.

Theories of cause of internal heat.

(a)

As to the cause of the heat, two principal theories are held. The first conceives the internal heat to be the residual heat of a cooling and once molten globe. (Talks XXXVII and XXXVIII.) The earth is evidently cooling. The records of past volcanic action prove that heat has escaped in enormous quantities from the interior. Thousands of cubic miles of molten lava now solidified over the surface, imply some reduction of the earth's temperature, and the problem is one which might be solved. The traces of former intense action at the surface are retained also in enormous rock formations which have not been fused and reduced to lava, but have been softened and vitrified, and afterward cooled. Then the daily radiation of heat from the earth exceeds the amount received from the sun. If the earth is cooling, and has for geologic periods been cooling, it is not difficult to admit that some former temperature was high enough to reduce it to a molten condition. If that condition existed, the process of cooling would result in a film over the exterior, which would be the primitive or fire-formed crust, on which the first ocean descended, and the first sediments accumulated, while the protected interior retained a higher temperature. The fusing temperature now existing within may be but the residuum of primitive heat left after so long a process of cooling. This is one view.

(*b*) Again, it has been contended that the internal heat results (at least in part) from crushing and friction in the crust, produced by motions and pressures exerted. Mallet showed that the heat generated in crushing small cubes of granite might become sufficient to cause fusion. We know, also, that the cohesion of no substance is adequate to withstand all assignable pressures. No rock has the requisite rigidity to resist the crushing weight of a mountain twenty miles high. Whatever movements may take place in the earth's crust, involve masses so great and forces so enormous that the resistances of ordinary matter are inconsiderable. The most solid rocks are essentially fluid or viscid. Now, such movements must necessarily result from two causes: First, a slow shrinkage of the earth through loss of heat; secondly, the attractions of the sun and moon, which cause tidal protuberances on the surface of the earth, however rigid it may be; and these, continually shifting their positions, as the oceanic tides do, result in daily motions adequate to develop a large amount of frictional heat.

What is the condition of the earth's interior.

But, whatever the cause of the internal heat existing, we can not demonstrate that the whole interior is molten; nor that the earth is solid to the core; nor that we have a solid core and a solid crust, with an irregular zone between, in which the matter is molten, or, at least, in a plastic state. We have many facts; we are building our theories cautiously, and in the meantime we must all hold tightly to the facts and loosely to the theories.

XVIII. The Unstable Land.

PHENOMENA AND CAUSES OF EARTHQUAKES.

When men feel the earth beneath their feet growing unstable, the most paralyzing sense of insecurity seizes them. Yet the solid earth has not only been shaken by throes which have ingulfed cities and populations and mountains, but there is scarcely a moment when its movements or its tremblings may not be felt by the delicate means of research employed by modern science. The stability of the solid earth is instability itself.

Earthquakes: duration,

The destructive shock lasts but a few minutes, or even seconds. The successive vibrations which devastated Calabria in 1783 were felt during barely two minutes. On the occasion of the destruction of the city of Lisbon, in 1755 and the loss of 60,000 lives, it was the first shock, lasting five or six seconds, which caused the greatest damage. As to extent of damage, Sicily, in 1693, and Calabria, in 1783, have been among the greatest sufferers. Each, according to best estimates, lost a hundred thousand lives. In Syria, Japan, and the Sunda Archipelago, earthquakes are reported to have been attended by still greater fatalities. In the year 526, more than 200,000 people met with death at Antioch and the adjacent towns. The volcanic eruption of Kra-kat′o-a, in August, 1883, was attended by a sea-wave and earthquake which, according to reports, caused the death of twenty thousand persons.

damage,

motions.

The motions which constitute an earthquake are various. Sometimes they are vertical, either slow or rapid. More generally they are horizontal. In such case, they consist mostly of short, sudden vibrations which travel through the earth at the rate of one or two thousand feet a second. The rate of transmission varies with the intensity of the shock and the nature of the rock materials. When mines of powder were exploded near Holyhead, in Wales, the waves of disturbance were propagated through wet sand at the rate of 951 feet a second; through friable granite 1,283 feet, and through compact granite 1,640 feet a second. Mr. Mallet calculated that during the earthquake of Calabria in 1857, the waves traveled through the earth at the rate of 820 feet a second. It appears thus, that the transmission of the waves of disturbance is favored by the solidity of the medium.

Velocity of transmission.

Center of disturbance.

The surface movement of earthquake waves is radially from a center. The cause of the disturbance must be regarded as acting with greatest violence at the center, while the effects gradually die out, as the distance from the center increases. But the distances to which the effects are transmitted are not equal in different directions; and this fact is, undoubtedly, attributable to the unequal distribution of the rocks. Generally, the disturbance should be farther felt in the direction of the strike of strata, than in a direction across the strata; since in the latter direction, the waves have to cross all the interruptions which characterize the stratified condition. So, if on one side of an earthquake center, the country is granitic, and in the opposite, is underlaid by Tertiary clays and sands, the granitic region will be most widely and most severely shaken. It is not supposable that the actual center of an earthquake disturbance is at the surface. It must exist at some considerable depth beneath the surface. Careful study of the directions indicated by the effects produced, have led not only to the determination of a radial progress over the surface, but to a center of disturbance, in each case, some miles beneath the surface. According to Mallet, the center of disturbance of the Calabrian earthquake of 1857 was seven to eight miles below sea-level. From this point, the waves traveled in every direction, assuming positions like the concentric shells of successively larger spheres. Dr. Oldham found the focus of the great Cachar earthquake of 1869 in India, to be considerably deeper.

No twisting movement.

It has been a common opinion, from ancient times, that earthquakes are sometimes characterized by vortical or twisting motions. The latest investigations, however, do not sustain this view. Every position assumed by objects moved can be explained by motions of a rectilinear, vibratory character.

Sounds.

Sounds often accompany earthquakes, even when not coincident with volcanic eruptions. Sometimes they resemble explosions as of distant artillery; more frequently it is a rumbling sound as of heavy vehicles moving over a city pavement. I have myself experienced but one noteworthy earthquake; and that happened in Michigan and neighboring regions on the 19th of September, 1884. It lasted about ten seconds. The floor on which I rested was very perceptibly vibrated, and a rumbling sound was extremely audible, like that of a train of cars, with the beats quite rhythmical.

Effects of earthquakes.

Among the effects of earthquakes, though of a secondary character, are the drying up of springs, the sudden increase of their volume, the augmentation or diminution of their temperature and the production of muddiness in the water. Artesian wells are similarly affected. Sometimes the occasion is signalized by the escape of mud, water, gas, or flames. Occasionally, as in the Andalusian earthquakes of 1884, the ground is rent open for considerable distances. During the frightful disturbances of Calabria in 1783, the phenomena of ground-ruptures ranked among the grandest and most fearful effects of the catastrophe. Whole mountain sides, undermined by water, slid down in mass, and tumbled into the plains below, covering all the cultivated ground. Cliffs fell down in a body, and rocks opened, swallowing the houses which stood upon them. At the western base of the granitic chain of the peninsula, the ground affected by the shock was cleft open for a length of more than eighteen miles, and in some places, the fissure was several yards in width. In another place, a cleft occurred 131 feet deep, over a mile long and 32 feet wide. Sometimes the disturbances of an earthquake leave the surface permanently elevated or permanently depressed. In one remarkable instance in the country of Cutch, the Great Runn sank down over an extent of some thousands of square miles, so that, during a part of the year, it remained inundated by the sea, and during another part was a desert without water.

Through the monumental patience and industry of M. Perrey, we have been placed in possession of thousands of statistics of earthquakes between 1842 and

1850. Through the similar labors of Mr. Robert Mallet and his son John W. Mallet, we have been placed in possession of the facts respecting other earthquakes between 1606 B. C. and 1842. From both sources we have a record of six or seven thousand separate earthquakes. The laborious discussion of this immense catalogue shows very important results respecting the distribution of earthquake occurrences through the year. Earthquakes are found to occur most frequently at new and full moon, also more frequently at perigee than at apogee; also, more frequently when the moon is on the meridian than when in the horizon; also, more frequently in winter than in summer; and finally, more frequently at night than during the day.

Distribution of earthquakes in time.

It requires but little acquaintance with the phenomena usually ascribed to earthquakes, to discern that they do not all belong to one class. Most widely destructive earthquakes are characterized by vibrations of the earth, and these alone are admitted by Mallet as true earthquakes. These may be denominated *earthquakes of vibration.* Other movements of the earth are translatory. The surface is bodily uplifted or depressed, or both alternately. This may be denominated an *earthquake of translation.* This species may become destructive, especially in a secondary way, when occurring either on land or under the sea, in such relation to sea-level as to cause a rush of the sea upon the land. With this discrimination in view, let us consider what causes may be assigned.

Varieties of earthquakes.

The earthquake of vibration is evidently caused by a sudden *blow* or *jar;* the earthquake of translation, by a *lift*, either permanent or transient.

Causes of earthquakes.

From time immemorial earthquakes have been connected in the minds of men with volcanic action; but careful study shows no uniform correlation between them. Volcanic action, moreover, is too local and too feeble. Some, in modern times, attribute earthquakes to the movements of the molten interior of the earth acting against the walls of its prison; or as resulting from some other mechanical action within the crust. This opinion is supported by most reputable names—Humboldt, Scrope, Sir William Thomson. Movements of translation are undoubtedly produced by volcanic forces. Portions of mountains are lifted or even blown away; fissures are caused and many distinct movements result, which are commonly embraced under earthquakes. Undoubtedly, it sometimes happens, also, as an incident of volcanic action, that sudden blows, or violent explosions occur which impart vibratory tremors on a *narrow scale*, in character like those which sometimes spread over kingdoms and work vast destruction. But it can not be admitted that earthquakes as best known—earthquakes of vibration—are ascribable to any volcanic agency.

It may be mentioned, also, that the fall of large rocks, mountain-slides, great explosions, whether natural or artificial, sometimes occasion genuine earthquake tremors. The jar of a train of freight cars, or of a loaded wagon on the city pavement, generates real earthquake tremors; but in all these cases, on a scale too insignificant to be dignified with the name.

What is it, then, which stands as the physical cause of those *blows* or *shocks* which, originating at certain foci in the earth, spread radially in earth vibrations which sometimes level cities? I venture to affirm, with Mallet, Oldham, Schmidt, Höttinger, and Bocardo, that it is a sequence of accumulated strains resulting from lateral pressure in the earth's crust. There are two assignable causes of enormous lateral pressure. First, as maintained by Constant Prévost, the solid crust formed around a cooling molten globe, becoming too large for the shrunken nucleus, strives to adapt itself to the diminished interior (molten or solid). It is, therefore, laterally pressed. Relief is obtained, in part, by the development of wrinkles, as in the skin of a shriveled apple, and in part, by a process of crushing together. The strains are temporarily resisted, but soon the crust must yield. As the crust is not homogeneous, there must be stronger and weaker portions. The motion which results, in the crisis of yielding, is accumulated in isolated spots. If the pressure is a direct and simple crushing pressure, then heat results from the crushing, lava is formed and the pressure existing squeezes it, or the formation of steam lifts it, to the surface. If the pressure has not a simple, crushing tendency, there may arise a fracture. Then, in an instant, the strain is removed; the rocks recoil, and the vibratory motion is generated.

The ultimate cause.

These lateral strains are augmented and localized by the attractions of the sun and moon, which cause real tidal elevations and subsidences, and thus bring the crust to a snapping tension, where the slow processes of terrestrial contraction had not yet reached it. These tidal strains are greatest when the moon and sun are nearest the earth, and also

Why most common at new and full moon.

when they act together, as at new and full moon.

Relation to tornadoes.

To add another word. While a tornado or cyclone is at its acme of violence, the barometer is low; the pressure of the atmosphere on the earth is diminished at the spot, and elsewhere correspondingly increased; the terrestrial crust must, therefore, tend to develop movements of the nature of tides; and the predisposition to earthquake actions must be augmented. Observation indicates the frequent actual coincidence of earthquakes and cyclones. Similarly, a connection has been observed between the pressure of the atmosphere and the flow of springs, and the discharge of oil or gas from natural or artificial openings. Many springs and wells show a daily periodicity in the volume of the flow, corresponding with the diurnal variations in the pressure and temperature of the atmosphere. Such facts increase the presumption that lunar and solar tidal actions may affect the flow of molten matter, and also the distribution of stresses and movements in the earth's crust.

XIX. The Framework of the Mountains.

MOUNTAIN STRUCTURES.

Mount Marcy.

Let us imagine ourselves standing on the bald summit of Mount Marcy the highest peak of the Adirondacks, 5,400 feet above sea-level. Beneath us, on every side, spreads a wilderness of mountain swells and intervening wooded valleys. In the dim and smoky horizon, in some directions, we glimpse the indications of white villages and smoking chimneys, and here nature still rules in one of her wildest moods.

Notice the forms of these summits. How symmetrically the contour sweeps from the lower and flatter slopes upward. How gracefully these mountain swellings dissolve in the green ground of the landscape beneath. Look at our feet; the naked rock lies cracked and weathered by the frosts of unnumbered Winters. The chips of the mountain strew the cone for eight hundred feet below. There the mountain firs, shrinking from the weather, begin to appear, but only as prostrate, crawling, and stunted shrubs. These rocks are Eozoic. How hard and crystalline and stubborn they look. These black crystals are *pyroxene;* the dark, dusky ones are a species of feldspar called *labradorite.* The mixture forms a rock known as *Norite.* Polished surfaces present a highly pleasing appearance. This rock forms all the central mass of the mountain under us. It is but indistinctly stratified; but we believe it was originally formed from ocean sediments. It has a granitic aspect, and, in a general way, we speak of it as having a granitic character.

Form.

Material.

It is not an easy matter to travel down the slope of this summit, over the loose crags, down into the border of the forest, through the forest to the foot of the mountain, into the lumber camps, down to the clearings, amongst the log cabins, on to the village, over the highway and the railroad, and ascertain at every step, what kind of rock underlies. There is too much rock-rubbish, too much soil, too dense an undergrowth.

Structure. When we descend from the summit of Mt. Marcy, we come, part way down the slope, to massive gneisses. They rise up into view from the lower levels. They present their crumbling and hoary outcrops looking up toward the summit of the mountain, as if ambitious to attain the apex, but wearied and wasted, and arrested by the way. Here they lie, resting on their granitic bed. All around the mountain, the upward looking outcrops of gneisses occur. The head of Mt. Marcy rises above the heavy blanketing of gneiss.

Down the mountain to the lower levels we continue our exploration. Here the exposed outcroppings of other gneisses are seen enwrapping the lower and older ones; here schists—hornblendic and micaceous—come into view in succession, overlying the beds whose outcrops are higher up, and all dipping steeply down; here is a thick bed of crystalline marble, green-stained with intermingled serpentine. Here are beds of iron-ore, and other schists and conglomerates, all dipping still down the slope, and each new one in succession reposing on the top of the last.

Should we descend the slopes of the Adirondacks in a hundred directions, such would be the succession of the formations—such, at least, the plan of the mountain structure, though the particular kinds of gneiss or of schist would vary on different sides. Let us think about the nature of this arrangement. It looks as if the gneiss and schists had once lain horizontal, and the head of Mt. Marcy, and the heads of the other mountain giants, had been thrust up through—bursting the sheets of gneiss and schist—parting them to the east and west, the north and south—continuing to push up a mile toward the sky, and leaving the parted borders of the bedded rocks far down the slopes—separated by the diameter of the mountain mass.[1] It *looks* so—and that is the ground for the inference that it was so. We have been contemplating forces possessed of the ability to perform such a piece of work. Kra-kat′-o-a was split from bottom to top in 1882. If volcanic forces should prove inadequate, we can invoke other forces. We will invoke them. But let us see further what there is to summon them to accomplish.

The geology of the surrounding country.

We are strolling upon the flanks of the Adirondacks. We are now on the borders of civilization. Mt. Marcy looks down on us from the cold blue sky against which his profile is printed. We tread now on another soil. Here are massive cliffs of sandstone. If we wander around by the east, we may trace the Au Sable toward its source. We find it roaring through a cleft in a gray sandstone with perpendicular walls one hundred feet high, and along a chasm which splits the formation for a distance of two miles. This is the chasm of the Au Sable. But see, this sandstone is not a metamorphic rock. It lies above all the gneisses and schists. It is not so steeply inclined. Evidently it is not within the Eozoic Great System ; it is Palæozoic. Follow it as it stretches under the country to the eastward. It extends to Lake Champlain. It reappears on the Vermont side, and continues to the Green Mountains. If we carry our observations to the north flanks of the Adirondacks, there too, we find this

[1]Compare this with the second paragraph on p. 142. The two ideas are not exactly the same. F. S.

sandstone. The charming village of Potsdam is built on this sandstone—a classical spot which has given its name to a formation that reappears in all countries. This sandstone spreads out horizontally to the St. Lawrence River. If we examine the Adirondack slope on the west, the Potsdam sandstone is found in its place, and even limestones come in succession, in higher geological positions above the sandstone. On the south we still find the sandstone.

How the Adirondacks were made.

The appearance now is, that after the granite center had burst through the gneisses, and all these rocks were standing at a level somewhat lower than at present, the ocean still covered the flanks now overlaid by the Potsdam sandstone, and on the bottom of that ocean the sands were spread which were destined to become consolidated as sandstone; then, after this, there was a farther uplift of the Adirondack mass, bringing the Potsdam sands above sea-level, around their border, and giving them also a tilt, while the gneisses received an increased tilt. So the granitic center of the Adirondacks was at first a small island; then, by further upheavals, the island was enlarged progressively on all its borders.

The Laurentide Hills

Now let us proceed across the St. Lawrence valley. Here we find horizontal Potsdam sandstone stretching up and down the valley; and above this a thick series of limestones. Continuing toward the Laurentide Hills, we see the horizontal strata turning up gently. We ascend a gradual slope, and by and by, the limestones end. A steeper ascent is still underlaid by the Potsdam sandstone. Here now, is the end of the sandstone and we step on schists and gneisses and crystalline limestones, each rising from under the preceding, until we reach granitic rocks, which continue to the summit of the ridge. Then passing still northward, we meet various formations like those seen in ascending the ridge, but in the inverse order. In fact, the nature of the rocks, their altitudes and their order of arrangement are exactly like what we found in descending the Adirondacks.

repeat the story.

The Laurentian, therefore, has the same constitution as the Adirondacks. It is an elongated elevation, however, instead of a cluster of peaks. It presents an *anticlinal* structure. The oldest or bottom rocks are in the center, and rise to the highest altitude. The rocks geologically higher in position attain to successively lower and lower altitudes; they dip down on each side of the granitic axis, like a series of planks leaning against a stone wall.

Mountains of upheaval.

This is the general plan of a *mountain of upheaval.* We find the same in the Blue Ridge, in the ranges of the Rocky Mountains and many others of the great ranges of the country. Mountains, therefore, exist as long folds of the earth's crust; and very generally, where one fold exists, two or three others exist parallel with this, as in the Appalachians.

Secondary mountain forms.

It will be borne in mind always, that every orographic or mountain feature has undergone a great amount of alteration. The summits of the mountains have been much lowered. The strata enwrapping their flanks have been cut back; they stretch to less distances than formerly toward the summit. In many cases, indeed, we have room to conjecture that they extended originally over the summit, and have been worn away in the course of ages, uncovering the granitic nucleus only in later geological time.

In some cases, the erosion of parallel and contiguous mountain crests has proceeded so far that the summits are lower than the valleys between them. The valleys then become the mountains, and in place of the original mountains are valleys of erosion. So we sometimes find a *synclinal* structure in mountains, and an *anticlinal* structure under valleys. Sometimes we find a river cutting through a mountain from side to side and from top to bottom. The Green River in Wyoming, affords a striking example. It cuts through the 15,000 feet of the altitude of the Uinta Mountains. It seems quite evident that the river was here before the mountain. The mountain rose gradually under the river, and as it rose, the river sawed its gap to the bottom, and the walls of the gap were left to rise precipitously on each side. Other mountains have been rent by fissures. These generally run lengthwise of the range—most frequently along the center. When they exist, the strata on one side are generally found depressed below the level of the corresponding strata on the other side. Such a case is a *fault*. In the Appalachians are faults of five thousand to twenty thousand feet.

Faults. A greater one cuts through the Uintas. The Sierra Nevada, for three hundred miles, has been split lengthwise along the middle, and the eastern half, for a large part of the distance, has gone down three thousand to ten thousand feet. So the west half the Wahsatch went down forty thousand feet for a length of at least one hundred miles.

Mountains of relief. Of *mountains of relief*, like the Catskills and the Cumberland Table Land, something has already been said in Talk IX, and nothing more is necessary here. Mountains composed of volcanic accumulations are mentioned in Talks XV and XVI.

XX. How the Mountain Framework is Reared.

MOUNTAIN FORMATION.

By what machinery were these mountain masses upraised? By what motive force was it actuated?

Old theories of mountain making.

Generations past, which had witnessed the tremendous power of Vesuvius and Ætna, thought the volcano adequate for the production both of earthquakes and mountains. It was steam and gases trying to find vent, they said, which shook the ground and bulged the terrestrial crust into mountain saliences. They had seen mountain caps blown off, and mountains cracked open; they had even seen Sabrina and Graham's Island and many Ægæan islands lifted from the bottom of the sea, and sustained at an elevation of some hundreds of feet. Were not these efforts at mountain-making and unmaking? Had it not been ascertained, too, in more recent times, that Vesuvius and Ætna, with all their loftiness and massiveness are mere piles of stuff brought up by volcanoes, and built by volcanic action into mountain forms?

Vulcanism not applicable to Adirondacks, etc.

Yes, the reasoning is good for a certain class of mountains. But the Adirondacks are not a pile of lava; nor the Laurentides; nor the Appalachian ranges; nor the White Mountains; nor the Rockies.

Here has been lifting to which all volcanic work bears a very feeble comparison. If Ætna and Hood are piles of volcanic *débris*, consider how small a part was lifted at once. The ascent of the mountain materials has been like that of wheat in the grain elevator—little at a time, but much in the aggregate. Look at the Adirondacks, on the other hand—here is a vast framework; all the parts were formed and adjusted together before the uplift; and when the time arrived, the total mass was raised in one stupendous mechanical effort. We must seek a greater power than the volcano.

Contraction of the earth's crust the great cause.

It is not a trivial problem. It has puzzled the most expert of brains. But I think you have made the acquaintance of forces and modes of action which furnish us a real clew to the mechanism of mountain-making. Your attention has been directed to many indications of the presence and action of heat in the earth. You have even reached the inference that the earth is a cooling globe. [But see further in Talks XXXVII and XXXVIII.] Now, you have often witnessed the power of heat. When it enters a solid or liquid, expansion takes place, and the power of expansion surpasses human control. When it leaves a body contraction ensues, and the strength of this tendency can not be resisted by any means in our power. Loss of heat is regularly attended by contraction.

Now, ever since Leibnitz, two hundred years ago, enunciated his theory of a once molten earth, geognostic students have been considering what must be the natural course of events in the cooling of such a globe. Constant Prévost advanced a suggestion sound in theory and fruitful in consequences. That molten globe, he said, must have become incrusted. By degrees the crust would thicken, and the transmission of heat from the interior would be retarded. By and by, the radiation of heat from the exterior would become diminished to such an extent as to just equal the heat received at the surface by transmission through the crust. That is, a constant temperature would exist at the surface of the earth—a constant temperature at the mid-zone in the crust. But the interior would still continue to lose heat through the crust, though the crust retained a uniform temperature. If the interior did not supply heat to the crust, the latter would grow colder.

As the interior contracts, the crust wrinkles.

So the interior, in consequence of loss of heat would contract; but the crust, losing no more than it receives, would *not* contract. That is, the crust would become too large for the shrunken nucleus. What would result? Do you conceive that the crust would rest raised above the nucleus, leaving vacant, or even steam-filled spaces between the two? Remember the enormous weight of the atmosphere—fourteen pounds on every square inch. Remember the enormous weight of the crust, and the utter impossibility of its sustaining the strain of bulging over a vacuum of one, ten, or a hundred miles. Assuredly, the crust *must* settle down as fast as the molten nucleus grows smaller.

The force is a lateral pressure.

But now, in settling down, its circumference must constantly become less. How can its circumference be made less? Only by squeezing together from all directions. There must be a lateral pressure experienced at every point. It arises from the weight of the crust, and is proportional to the weight of the crust. If the crust is thus subjected everywhere to an enormous lateral pressure, then, either the parts of the crust must be *mashed together*, producing a thickening in proportion to diminution of circumference ; or else, if the crust is too solid to be crushed, it will *wrinkle*—just as the skin of an apple is wrinkled, when the pulp within shrinks through the evaporation of juice.

The wrinkles are mountains.

Now, suppose that stage of things has been reached. Some wrinkles have made their appearance on the surface of the earth. They are the beginnings of mountains. If ocean waters rest now on the earth's surface, they may, indeed, totally cover these wrinkles—but they are the germs of mountains, nevertheless. As long as the earth's interior continues to lose heat and contract, so long wrinkling tendencies will exist. But, after a set of wrinkles has been first developed, the wrinkling tendency afterward finds relief in the same wrinkles—in the enlargement of the first wrinkles. The power to enlarge and further elevate the old wrinkles will be attained before the power to initiate wrinkles in new places. In this way the germinal mountains would grow. In this way, the first uplifted masses would afterward be uplifted higher, as new relief had to be sought. Did we not observe the successive stages of uplift in our study of the Adirondacks?

Relation of vulcanism to mountain making.

There is no volcanic uplifting here. It is true, however, we may get volcanic phenomena. The crust presses with enormous weight on the molten ocean. Compare it with a field of ice a mile square and three feet thick, floating on a lake. If you make a hole through the ice, the water rises in the hole, nearly to the surface of the ice. If the hole is suddenly made, the water may rise with such velocity that its momentum will carry it quite to the surface, or over the surface. This is like an outflow of volcanic matter through a fissured crust. Suppose a great number of piles of ice be heaped up on this ice field in various parts. Then, if a hole be pierced through, the water will rise with increased likelihood to overflow. Now these piles of ice exert an effect similar to that of upraised wrinkles in the crust. So it appears that volcanoes may be an incident of the earth's contraction, as before stated, and that mountain-making may be another incident of the same. But there is more to be said. In many places must occur some crushing together. In the mountain folds where the internal constitution and firmness have been strained by flexures, there must be weakness; and there must occur some of that *mashing together* which develops heat, independently of any supply from the molten interior. It is quite intelligible, therefore, that a mountain wrinkle or fold is a zone where *heat* must be generated, even if lava is not produced, and does not escape from within. Along a mountain fold, in other words, is a zone where the rocks must be subjected to that baking or semifusion in connection with water, which produces the changes called *metamorphism*.

Why do mountain ranges trend mainly north and south?

It would not be proper to leave the subject in this state, though you have already the gist of the theory of mountain making. All our great mountains exist as long ranges—mostly as groups of ranges, and the prevailing direction of mountain trends is approximately north and south. Now, when we consider the wrinkles on the skin of a withered apple, we find them short, and having also, no uniformity of trend. The analogy, is imperfect. There must have been some other cause than uniform shrinkage to develop the actual mountain folds.

Effect of tidal action.

Let us glance back over the early history of the earth. They tell us it once revolved much more rapidly on its axis than at present. It is not difficult to understand why its rotation has been retarded, but we will pass that by. If the rotation has slackened, then the equatorial protuberance has diminished. That is, the equatorial circumference has been shortened more than the polar; and consequently there has been more lateral pressure around the equatorial region. That pressure too was exerted east and west, and that was just the direction which would give to the wrinkles a north and south trend, and a considerable elongation. Besides this, there was a powerful tidal attraction exerted by the moon (see also Talk XXXVIII). That body was then much nearer the earth than now, and exerted important influences on the earth. In our times, it raises the ocean and the whole hemisphere in a tidal swell; then, though no ocean existed, the tidal swell was raised with the forming film over its surface. But the rise of the swell was not instantaneous; it reached its height after the moon had passed the meridian to the west, and the moon acting on it from that position, pulled the apex slightly westward, and thus established changed conditions in the crust which necessarily had a north and south trend, and contributed something to give the wrinkles, which were then forming, the north and south axes which we see in mountain ranges.

Another peculiarity of mountains is the greater thickness of the formations and the greater proportion of fragmental strata. This has led some to conceive that the materials of mountains were accumulated in the bottom of the sea, in situations to which ocean currents brought unusual quantities of coarse deposits from neighboring continental shores. It is supposed that these sediments depressed the bottom and thus preserved such depths as would continue to invite the currents to a continuance of their work, until the mountain mass was completed. The sinking of the great synclinal must have subjected the materials to the metamorphic influence of internal heat, even without any crushing together. Probably, in this state of things, metamorphism resulted from both causes. Then in due time, the synclinal was upraised, with additional crushing, and the mountain was completed.

Mountain ranges and sedimentation.

These are but glimpses of the theory of mountain-making; but I hope they will stimulate you to further study. Let me recommend the re-reading of this Talk, after Talk XXXVIII.

XXI. Down in a Mine.

MODES OF OCCURRENCE OF THE METALS.

Who has not heard of the Comstock Lode? Who has not read something about the hundreds of millions of gold and silver extracted from its deep depositories?

Description of the Comstock Lode.

What is the Comstock Lode? It is a body of gold-and-silver-bearing mineral matter lying in the Virginia range, a spur of the Sierra Nevada, about 25 or 30 miles east of the Sierra crest. The range trends a little east of north, and the lode appears to be the filling of an imperfect fissure four or five miles long —the principal part of which is about 10,000 feet. The fissure extends into the mountain with an eastward dip varying from 33° to 45°. At the north end it divides into three or more diverging and somewhat irregular branches, and at the south end it terminates in two branches. The fissure has, at its broadest part, along the middle, a width of about 600 feet, which becomes 1,400 feet when measured along the sloping surface; and it narrows toward each end. The lode also narrows downward, and at about 1,800 feet vertically, has a thickness of about 120 feet. The part above this seems to be formed from two fissures and the wedge-shaped mass of "country rock" included between them. This wedge of country rock was cut off from the east side, where the rock is diabase—that is, composed of grains of augite and a plagioclase feldspar. On the west side, the country rock is diorite—that is, composed of hornblende and a plagioclase feldspar. In miners' language a fragment of country rock included in a lode is a "horse." The fissure along each side of this enormous "horse" is filled chiefly with quartz. The east wall in this case, is the "hanging wall," and the west is the "foot-wall." The hanging wall is much decomposed, and the decomposition extends through the diabase for five thousand feet.

The contents of the lode are somewhat miscellaneously disposed. Besides the great prismatic horse just mentioned, are many smaller fragments of country rock, together with clay, quartz and silver-bearing minerals. Most of the ore contains both silver and gold, but the proportions of the two metals vary in different parts of the lode. From the whole lode the yield of gold has been 43 per cent and of silver 57 per cent. The richest quartz lies nearest the hanging wall. A mass of ore rich enough to pay for working is styled a "bonanza." An ore must afford fifteen or twenty dollars a ton to pay. The celebrated "great bonanza" averaged $80 to the ton. It was composed of crushed quartz, including fragments of country rock, and carried a few hard, narrow, vein-like seams of very rich black ores; while nearly the whole mass of the crushed or "sugar quartz" was impregnated to a moderate extent, with native gold and stephanite, which is an arsenical sulphide of silver known sometimes as *brittle* silver glance. Even the country rock was also charged with these ores.

Mode of working the lode.

It would not be proper to enter further into particulars of this kind. But glance a moment at the mechanical operations. Perhaps you think the miners attacked the wonderful lode at its outcrops, and followed it down on a slope into the earth. Not at all. As soon as this method of exploration had revealed the position and promise of the lode, great capitalists laid out the work according to methods sanctioned by centuries of experience in other countries. Going some hundreds of feet to the east of the lode, a vertical shaft would be sunk until the lode was struck. At frequent intervals, horizontal passages were excavated westward to the lode, and through the lode to the foot wall. From these, other passages or galleries were excavated along the lode. From these numerous galleries, the various ore-bodies were discovered and worked out, within the limits of the claim. There is a large number of claims or properties along the lode, and there are twenty-four shafts sunken on the east. In course of time, the various mining operations have been brought into some degree of concert and system. Without this, the difficulties of the deep exploration of the lode would have been insuperable. The country has thus become honey-combed to a depth of 3,000 feet. The total length of the galleries driven exceeds 150 miles.

Obstacles. Heat and water have presented obstacles most formidable. The high temperature of the rock and of

1. Heat. the water escaping from it is very extraordinary. On the 3,000 foot level of the Comstock, floods of water have entered the mines at 170°. Water at this temperature will cook food, and will destroy the human epidermis. A partial immersion in it is therefore fatal. The atmosphere, as a consequence, is not only intolerably hot, but is saturated with vapor. From prolonged exposure to these unnatural conditions, many miners have lost their lives. In the Savage mine, in 1879, the miners struck a hot spring having a temperature of 157°, and the incline was filled with scalding vapor ; picks could only be handled with gloves, and rags soaked in ice-water were wrapped about the iron drills. Occasionally, perspiration would cease, the miner would begin to talk in a rambling fashion, and his death would soon

ensue, unless removed by his comrades to a place of relief. The conditions of mining are greatly ameliorated by most efficient ventilation through the 150 miles of galleries and the shafts. Still, the air leaves the mines nearly saturated with aqueous vapor, and at an average temperature of 92°.

Abnormal temperature of the lode.

The increase of downward temperature here greatly exceeds the general average. In one shaft at 100 feet, the temperature was 50°; at 200 feet, 55°; at 500 feet, 68°; at 800 feet, 76°; at 845 feet, 80°; at 1,100 feet, 92°. In another shaft, at 1,500 feet the temperature was 105°; at 1,600 feet, 107°; at 1,700 feet, 108°; at 1,800 feet, 111°; at 1,900 feet, 112°; at 2,000 feet, 113°; at 2,230 feet, 121°. Mr. Church, who investigated this subject very carefully, estimated the mean temperature on the 2,000 foot level, at 130°. The water at 170°, with which the Gold Hill mines were flooded in the winter of 1880-1, entered on the 3,000 foot level, and was struck at 3,080 feet. All the data together indicate an increase of temperature of one degree for 28 feet of depth. This abnormal increase appears confined to the vicinity of the lode. The great Sutro Tunnel, which approaches the east wall at a depth of 1,900 feet, indicates a great increase of temperature in approaching the wall. At the distance of 128 feet, the temperature is 110°; at 1,048 feet, 108°; at 2,052 feet, 96°; at 3,651 feet, 89°; at 5,008 feet, 87°; at 7,175 feet, 85°; at 9,512 feet, 83°; at 10,849 feet, 79°. This great increase of temperature cannot be attributed to the increase in depth of the tunnel below the earth's surface. The extraordinary temperature, therefore, is a phenomenon of the lode. It appears to rise from some greater depth, and the indications point to ascending water as the probable agent in bringing up the heat from a deeper region. It acts, therefore, like an enormous hot spring. Thirty miles away is the Sierra Nevada range, and from the altitude of perpetual snow, the eastward dipping strata descend into the earth for a great depth. The waters which accompany them reaching the deep portion of the Comstock Lode, their course is in part arrested by the impervious clays. When reached therefore by the mining operations, the relief of pressure causes them to rise from depths much below the bottom of the works.

2. Waters. The waters just mentioned constitute the second powerful obstacle to mining on the lode. In the deeper works, the volume has assumed portentous proportions. The water was originally pumped to the surface through the vertical shafts. Steam-pumps of ever increasing capacity, however, proved successively inadequate to the demand. Hence, the dar-

The Sutro Tunnel. ing enterprise of Adolf Sutro conceived the tunnel which bears his name, and which through thirteen years of opposition, he fought to successful completion in 1878, at a cost of two million dollars. The outlet of the tunnel is 20,000 feet from the east wall of the lode. From the entrance, a lateral branch is extended north along the lode 4,403 feet (to October, 1880), and another lateral, southward, 4,114 feet. The tunnel is seven feet in height, and eight feet in width in the clear, with a grade of one inch in 100 feet. In the bottom is a drainage channel five feet wide and three and one-half feet deep. After the mining companies began pumping water into the tunnel, over three and a half million gallons were discharged every twenty-four hours. During 1880, the aggregate was over a billion and a quarter gallons, and it was estimated that double this quantity would be discharged when connection should be made with all the mines. The temperature of the mixed water entering the drain is 137°, and its temperature at the mouth is 118°. Little use is made at present of this stream of water, amazing equally for volume and for temperature. It is apparent, however, that this vast stream of hot water possesses capabilities of usefulness which American enterprise will not permit to run to waste indefinitely.

Yield of the lode. During twenty years, up to 1881, the bullion yield of the Comstock Lode had been $306,000,000. Since 1874, business on the lode has been much depressed.

Source of the metals. Investigations have been made for the purpose of ascertaining the source of the precious metals in the lode. Mr. George F. Becker has shown the presence of gold and silver in the unaltered diabase rock on the east of the lode, and demonstrated it practically absent from that part contiguous to the lode which has undergone decomposition. It results from his studies, that after the region had been shattered by earthquake disturbances, floods of heated waters rose through the rocks, carrying carbonic and sulphydric acids, and saturating the east country, dissolving out silica and metallic salts, and redepositing them again in the spaces comparatively open. He finds by calculation that the total metal taken from the lode is not in excess of that originally contained in the diabase on the east, within the region now occupied by the decomposed rock.

This explanation will apply to the accumulation of

True veins. ore in veins of a more typical character. The Comstock Lode can scarcely be called a "true vein" in the accepted sense. A vein proper is a fissure extending to a great depth in the earth, and having generally a considerable longitudinal extent, with a width varying from a few inches to several feet, and with its contents often arranged in layers upon each of the two walls, in the same order from the wall. Each of these layers is called a *comb*, and the whole is styled the *gangue.* The metalliferous layer is the *ore.* Many of the most important Old World mines are based on true veins. Many, also, in America; but in many of the most celebrated mines, the mode of occurrence of the ore is different.

The Eureka district. In the Eureka mining district, in Central Nevada, we have a regular succession of strata consisting of limestones, shales, and quartzites, ranging from the Cambrian to the lower Carboniferous, but mingled with porphyritic eruptions and all shattered by a process of faulting. The silver-bearing lead ore is found imbedded in the lower Carboniferous Limestone, within masses of hydrous iron oxide. The deposits are discovered and worked out by a regular system of mining through shafts and galleries; though, in the works of the Richmond company, these formalities are discarded, and the deposits are reached and worked out by the shortest cuts. It can scarcely be said that the ore occurs here in veins. It lies in masses having cavities above. Its origin is from below; but the stratified rocks have not served as its source. But the quartz-porphyry of the region, by leaching with hot alkaline waters, may have afforded the ore; and this is thought by Curtis to have been its probable source.

The silver-bearing galena of Leadville, in Colorado, according to Emmons, has a similar mode of occurrence. The deposit of the silver-bearing minerals took place in the lowest member of the Carboniferous System. They were derived from circulating waters, which obtained them in passing through eruptive rocks. How introduced into the eruptive rocks is a matter for speculation. Leadville.

In the lead-producing region of Wisconsin, Iowa, and Illinois, the galena and blende occur as a lining on the walls of cavities or caverns in a magnesian limestone of upper Cambrian age. In Missouri, similar cavities in the Lower Magnesian Limestone, of lower Cambrian age, are found lined with galena and quartz. Lead of Wisconsin, etc.

XXII. The King of Metals.

IRON AND ITS GEOLOGY.

The most useful of the metals is most abundant and most universal. Iron is found in formations of every age, from the Laurentian of the Eozoic to the Quaternary and even the bogs which are forming in the age of man. It may be of interest to point out the fact that we find iron most useful, not because most abundant and most accessible, but because its properties give it preëminent superiority. Gold and silver and platinum are wanting in the hardness and rigidity which suit iron to many of its most important adaptations. Neither of these metals could be Value of iron.

made into useful rails for the steam train to move on. Neither would furnish a tool having the edge and temper of fine cutlery

How concentrated: Iron is almost universally disseminated, as a constituent, through the rocks and minerals. It sometimes imparts a black, and sometimes a red or yellowish color; and many times its presence is unannounced by any color. This red soil which, in some regions, prevails extensively, is colored by iron. This red sandstone is colored by iron, this red shale, this red brick—like this red rust on the stove-pipe. This yellow precipitate in the bottom of the stream is the same with water in combination. These are *oxides.* They hold all the oxygen which the iron can take, and hence they are called *peroxides.* But the yellow oxide holds water also, and hence is known as a *hydrated peroxide.* Now follow this hydrated peroxide—this yellow ochre—down to the bog which the water saturates. Here is black muck —a fine peaty material—but it is colored and charged with this ocherous deposit. After some years, the peaty matter decays, and disappears, to some extent. Then we see the iron compound aggregated and compacted in irregular masses. It has now become *bog iron ore.* It is a kind of *limonite,* so-called. It can now be smelted in a furnace and the pure iron extracted.

Bog iron ore.

Limonite. If this swamp should be sunken below sea-level, and heavy layers of marine sediments spread over it, the bog ore would be compressed into a compact stratum. Then if all these formations should be converted to solid rock, our bed of bog ore would be exactly such a bed of limonite as we actually find in some situations deep in the rocks. It would be an old fossil swamp. But suppose some thousands of feet of sediments should be piled over it. Then the heat of the earth's interior would come up and bake the ore-bed. Very likely the water would be expelled from our limonite, and it would become simply a peroxide—it would assume a red color—it would be *hæmatite*, which means blood-red ore. Now such beds of hæmatite form many of our most valuable deposits of iron ore. Much of the ore in the Lake Superior region is of this kind—also in northern New York and in other regions. But if this old hæmatite is left exposed to water for some years—if the bed becomes soaked with water, it changes back to limonite; it becomes yellow and somewhat soft. The miners sometimes call it "soft hæmatite." It is easily quarried and easily smelted, and everybody likes it—though ton for ton of ore, it contains less iron than hard or true hæmatite. **Hæmatite.**

I do not assert that all limonite and hæmatite have come into existence in this way. But I am sure this theory is highly plausible for some beds of iron ore. But now, I have noticed iron ores in such situations that perhaps a different explanation is more reasonable. I have seen great masses of iron ores inclosed in the midst of great stratified formations. The ore-masses are huge lenticular accumulations—sometimes of great purity, sometimes mixed with rocky matter, sometimes bounded abruptly, and sometimes blending gradually with the contiguous strata. The ores occur in this way at Lake Superior. Such masses of ore are almost always in crystalline metamorphic rocks. They have been heated—probably subjected to the action of hot water.

Magnetite.

There is another species of iron ore very commonly associated with these. It is *magnetite*. This is composed partly of peroxide of iron and partly of *protoxide* of iron—that is, iron with only one proportion of oxygen combined with it. Magnetite is richer, therefore, than hæmatite—ton for ton of ore it contains more iron. While powdered hæmatite is red, and powdered limonite, brownish yellow, powdered magnetite is black. Magnetite attracts the magnetic needle. "Lodestone" is magnetite—so-called, probably, because it *leads* by its attraction. Now, magnetite is often found in great imbedded masses, like hæmatite, and is regarded one of the most desirable of ores. Often hæmatite and magnetite are mingled together in the same bed; and the indication is, that one is capable of conversion into the other.

Disseminated iron: Can it be concentrated in other ways than as bog ore?

We often find, also, considerable formations in which much iron ore exists in a disseminated state, imparting a highly ferruginous character to the rock, but constituting only a very "lean ore." It may be a hæmatitic quartzite or a silicious hæmatite. We find all stages of transition from pure ore masses to simple rock. The theory is often suggested to me by the conditions under which these metamorphic ores exist, that they are simply accumulations of ores gathered together from wide contiguous regions in the rock. It seems settled that ores of lead, zinc, and silver are thus eliminated from the country rock, as was explained in the last Talk. Hot, alkaline waters are supposed to have had principal agency in the work. But where the native metals occur, as gold, silver, or copper, we must suppose that a dry fusing heat has been present to reduce the ores previously formed, or drive together metallic particles disseminated through the rock; or we must suppose that an electro-chemical deposition has taken place from a metalliferous solution, as in the electro-plating process. In some way, at least, particles of a particular kind become aggregated in "veins," in "lodes," in "segregations": and thus the huge lenticular masses of hæmatite may have been formed.

Perhaps this theory is sustained by the relations of iron ores to the stratification. Often all stratification is obscure or wanting; often the stratification of the country rock can be traced through the ore-body; not unfrequently the ore-mass is a vast stratified formation. Pilot Knob, in Missouri, is a great iron-schist —a schistose formation in which the once disseminated iron particles appear to have been driven by some agency, into a particular part of the formation. In this case, the richest part of the formation is at the pinnacle of the knob, and the schist decreases in richness as we descend to the base.

The various modes of accumulation.

Now, there are two suggestions in reference to the way in which iron ore particles have been accumulated—first, fossilization of ancient iron-bogs; second, segregation. If the great masses found in metamorphic strata seem rather to be the results of segregation, some of the younger iron deposits appear to be of the nature of fossilized swamps. Probably, too, some rich stratified ores, like those back of Milwaukee, and those near Rochester, New York, were precipitated in shallow seas—the iron brought in by springs. This is a third suggestion.

There is still another way in which iron combinations appear to accumulate. It is a modification of the segregation process. You have seen, sometimes, in a yellowish or reddish sandstone—that is, a ferruginous sandstone—some concentric bands of a deeper color—bands formed by an increased amount of oxide of iron. Now observe that the lines of stratification of the rock pass quite through these spheroidal forms. It is manifest, therefore, that the spheroidal aggregations took place after the sediments were laid down—after the rock was formed. If so, then the iron material must have moved through the consolidated rock. How did it move? Could solid particles of iron-oxide travel from all directions toward a common center, and all halt at a common distance from that center? Evidently not, only pure water or clear solutions could thus move. We may, therefore, conclude that the iron was transported and accumulated in spheroidal or *concretionary* forms in a state of solution in water. It must, therefore, have existed as a protoxide, and must have combined with further oxygen or with carbonic acid subsequently. When combined with the latter, it forms iron carbonate, and this is one of the ores of iron. As an ore it is *siderite*. It possesses various degrees of purity. Often it occurs as a concretion five to eight inches long, formed in the rock as I have just explained. It may thus embrace much sand or clayey matter, and this is the condition in which the siderite nodules or "clay iron stones" are found in the coal measures and other formations.

Concretionary iron.

So you perceive that iron ores do not occur in proper veins. They are isolated masses, or they are strata. They are not mined out through shafts and drifts and chambers, like the ores of gold and silver,

Iron occurs in masses or beds; not in true veins.

but mostly in open excavations. In Salisbury, Connecticut, the excavations extend into cavernous, deranged stratified rocks, and many of the cavities are lined with a black, polished coating of ore which when scratched is yellow, and therefore limonite. This limonite has been in solution. It has filtered through the interstices of the formation. In many of the cavities are beautiful stalactitic forms hanging from the roof, or stretching from roof to floor. These are much sought as fine specimens for the cabinet.

Why is the earth's interior so heavy?

The mean specific gravity of the whole earth is twice that of the heaviest rocks. Is that due to compression of the interior, or to the presence of some substance heavier than the ordinary materials at the surface? Some have suggested the probability that the earth's central mass is a vast ocean of molten iron. It will be remembered, also, that iron is a chief constituent in meteoric masses.

XXIII. The Crystals of the Sea.

SALT AND GYPSUM.

The Black Gulf.

Look over a map of the Caspian Sea and notice on the eastern side a roundish bay nearly cut off from the main body. This is the Karabóghaz or Black Gulf. Though appearing so small, this bay is about ninety miles across. The channel which connects it with the Caspian is only one hundred and fifty yards broad and five feet in depth. The water is shallow, though that in the central part of the Caspian attains a depth of twenty-four hundred feet. Through the strait connecting the Karabóghaz with the sea, a current of water sets out from the Caspian at the rate of three miles an hour. The inhabitants of the region fancy that an underground passage exists from the Karabóghaz to the Persian Gulf or the Aral Sea. This, however, is impossible, since the Caspian is eighty-four feet lower than the ocean, and one hundred and seventeen (some assert 250) feet lower than the Aral. The vast volume of water discharged into the Karabóghaz is lost by evaporation from its surface. No large rivers empty into it, while the climate is dry, and the summer intensely hot.

A natural salt vat. The water of the Caspian, as you know, is salt. It has been calculated that three hundred and fifty thousand tons of salt are carried by the current into the Karabóghaz daily. The process of evaporation must consequently increase the saltness of the water in the bay; and the great drain from the sea must tend to diminish its saltness. Now, as a fact, the Caspian possesses only about half the saltness of the open ocean, while the Karabóghaz has become so intensely salt that the animals which once inhabited its waters have disappeared. In fact, the concentration has gone so far that layers of salt are being deposited on the mud at the bottom. In all probability these processes will continue in the future, and it must be anticipated that the salt deposit will increase in thickness as long as this gulf exists. Should there be an elevation of the strait connecting the gulf with the sea, the gulf would speedily dry up, and all the salt contained in its water would be precipitated in a vast bed of rock-salt. Then, should a depression of the isthmus connecting this low salt formation with the sea take place, there would be a new influx of the sea. The sediments of its waters would be deposited upon the bed of rock-salt; and new precipitations of salt would occur. The site of the Karabóghaz would then be a great salt-bearing formation, like those formed in ancient times in various ages of the world.

Other concentrating basins.

On other portions of the Caspain shores, the process has been brought nearly or quite to completion. On the peninsula Apsheron, on the west side nearly opposite the Karabóghaz, are ten salt lakes, in one of which, evaporation has gone so far that ten thousand tons of salt are annually removed from it. Again, in the neighborhood of Novo Petrovsk, the deep indentation on the east shore was once a large bay, which is now divided into a number of basins presenting every degree of saline concentration. One of these still, occasionally receives water from the sea, and has deposited on its banks only a thin layer of salt. A second, still full of water, has its bottom covered by a thick crust of rose-colored crystals like a pavement of marble. A third exhibits a compact mass of salt on which are pools of water, whose surface is more than a yard below the level of the sea. A fourth has lost all its water by evaporation, the stratum of salt left behind being uncovered by sand. A similar concentration is taking place in the Karasu, or long inlet setting southward from the northeastern extremity of the Caspian.

The whole Caspian is greatly dwarfed from its ancient dimensions by the process of evaporation, and it would be naturally expected that the salinity of the water would be intensified, as in the Dead Sea, instead of diminished. The intensification has really taken place, but under such circumstances that only marginal portions have increased in saltness, while the main body has been weakened by the influx of the great rivers Volga, Ural, Kuma and Terek.

Similar conditions once prevailed in our salt districts.

This account of changes taking place on the borders of the Caspian, well illustrates, as I have long believed, the method of accumulation of the great salt formations of geological times. In western New York, in certain regions great beds of rock salt may be reached by boring to a certain depth. They lie underneath solid sheets of limestone and thick beds of shale. In the vicinity of Goderich, Ontario, and also in Michigan at sundry localities—Marine City, St. Clair, Alpena on the east shore, and Manistee, Muskegon and Ludington on the west shore—vast deposits of rock salt are found, at depths from a thousand to two thousand feet. The best of evidence exists that the salt bed is the same on opposite sides of the state, and extends continuously under the state. This is also the formation which supplies brine for the works at Syracuse.

Another salt formation occurs in Michigan, occupying a higher geological position than that just mentioned. The first is the Salina formation in the Upper Silurian (see Table, p. 85); this is the Michigan Salt Group, in the Lower Carboniferous. From the last, the wonderful supplies of the Saginaw valley are mostly obtained. From the Salina formation the supplies eclipse even those of the upper group. At Marine City, on the St. Clair River, a delightful steamboat ride from Detroit, are works of astonishing magnitude and productiveness. The great salt industry of Cheshire, England, is supported by beds of rock salt sixty to a hundred feet thick, and underlying strata of clay and gypsum, and having indurated clays and gypseous beds underneath. Much of the salt is mixed with earthy materials, and hence is redissolved in sea-water, settled and re-evaporated. Other salt deposits of world-wide celebrity occur in Poland, Austria, and Germany. The boring at Stassfurt, Germany, penetrated 1,066 feet of rock salt, and that at Sperenberg, 5,084 feet without reaching the bottom.

Why brines in Syracuse and rock salt in Michigan?

It appears, therefore, that the evaporation of sea-water has taken place on a large scale in various ages of the world. In many localities the salt has been again dissolved by fresh water from the surface, and porous formations underlying have become saturated with brine. This is the case with the Michigan Salt Group and the Onondaga salines of New York, as also those on the Kanawha and Ohio Rivers. In some cases the home rocks possess sufficient porosity to retain the brine. In other localities the solid salt exists, but it is so mixed with clay as to require redissolving and purification. This as I said, is the case in Cheshire. In some countries, as in Poland and Austria, great mines are excavated in immense salt formations. In Michigan the rock salt possesses great purity, but it lies so deep that the expense of sinking and maintaining shafts has so far, led to the expedient of dissolving the salt in its place, and then pumping out the saturated brine. At Marine City, water pumped from the St. Clair River is forced down the bore-hole, where it dissolves the salt, and is then forced out by the same process into great tanks, where the brine settles, and then in other tanks undergoes evaporation by means of heat from steam pipes immersed in the brine. The precipitated salt is raked out by automatic rakes, allowed to drain, then dried and barreled. At Syracuse and in the Saginaw valley, the brine is pumped from the wells and settled and evaporated. Formerly much evaporation was done in kettles over a fire. More recently, pans and steam have been employed. A large amount of salt is produced, especially at Syracuse, by spontaneous evaporation in shallow vats exposed to the sun and air, and covered in rainy weather, by light roofs moved on rollers.

Order of precipitation from brines.

The natural brines of Saginaw and other regions contain impurities. In the process of evaporation those least soluble are first precipitated out, and then the other substances in the inverse order of their solubility. Thus the brine, which is limpid and sparkling on its escape from the earth, after exposure to the air forms, by peroxidation of the iron (see Talk XXII) a red deposit which is insoluble, and falls to the bottom of the settling vat—generally hastened by some coagulable substance. When transferred to the kettles and heated, gypsum is the first deposit, and this adheres firmly to the surface. Next, common salt crystallizes out, which forms on the bottom and is raked from the kettle, drained and placed in bins. The water remaining is called "bitterns," in consequence of other bitter and nauseous substances still remaining. Should the evaporation be further continued, Epsom salts (magnesium sulphate) would be thrown down in needle-shaped crystals. Finally, the chlorides of calcium and potassium possess such affinity for water, that they could only be separated completely by bringing the residue to a red heat.

The same order in nature.

This order of precipitation possesses much geological interest. In some salt formations, as that of the Salina group, the same order of succession has been noted. At the bottom we find red ferruginous clays. Above are gypseous clays and often beds of pure gypsum. Next occurs brine or salt. Above all are found limestones still retaining the needle-shaped cavities from which the crystals of Epsom salt have been dissolved, or in which crystals of some other substance have been deposited as pseudomorphs—minerals having the crystalline forms which characterize other minerals. This succession observed in nature is a confirmation of the theory of origin of salt formations by evaporation of gulfs and bays. It is evident, however, that such order of deposit can not generally be observed as one single circuit; because irregular irruptions of sea-water, alternating with floods from land and periods of dry weather, must break up any continuous succession from beginning to end of the history of a salt basin, and must lead to many repetitions of strata of the various kinds. This, however, is the fact universally observed, that all salt formations are characterized by the presence of all or nearly all the substances found existing in sea-water. Gypsum, especially, is always associated with brine and salt; and that is the reason the two have to be discussed together. Other substances, found equally in sea-water and natural brines, are magnesia, potash, bromine, and iodine.

XXIV. Liquid Sunlight.

PETROLEUM.

The search for oil.

The history of the search for native oil is romantic. Known for ages, it remained a mere curiosity till 1859. Even in America, where popular intelligence is supposed to utilize every possible advantage, petroleum rose only to the importance of a quack remedy for aches and other evils. But suddenly it assumed the scepter of king. Men pursued it with the sound and fury of dogs on the track of their prey. They lost their power of reasoning on the subject. They could not be convinced that mineral oil is a geological product, fixed in its relations to the earth and to the strata, as unchangeably and as intelligibly as iron or salt. They would not listen to the counsel of science. Every man was confident in his self-wisdom, and never inquired on what grounds he believed and acted as he did. There was oil—millions of barrels of it; and many investors were fortunate if not wise; and many, though wise, were not fortunate.

It was a new situation. It must be confessed that geology took up the subject as a novice; though with the great advantage of a knowledge of certain geological principles to which the generation and accumulation of petroleum must necessarily conform.

Principles true regarding oil and its occurrence.

Now, some of the scientific principles which must hold true without any regard to the particular causes and conditions of oil-accumulation, are such as these:

1. Oil is not a direct deposit from the sea; it is the

product of some changes in substances which formed part of the ocean's sediments.

2. Being composed of carbon, hydrogen, and oxygen, it must have originated from *organic* substances, either vegetable or animal.

3. Being lighter than water, it must tend to *rise* through the water which saturates all rocks, instead of *sinking*. The source of the oil, therefore, could never be in any formation situated at a higher level than the place of the oil. This is a principle which the crazy crowd could never be taught. The oil, for them, was always a "drip" from the Coal Measures.

4. A good "surface show" is not favorable, since it is only caused by the escape and waste of the oil; while the thing wanted is an accumulation or retention of the oil—that is, an absence of surface show. This the contemners of scientific guidance could not understand.

5. There must consequently be an overlying stratum which is impervious to oil, to prevent the product from rising to the surface, to be wasted in a "surface show." If a fissure, even, passes through this, the oil will escape. A bed of clay or compact shale might serve as such a cover. Compact limestone might serve; but most limestones are too much shattered. Indeed, shattered limestones, in some cases, serve as reservoirs for the accumulation.

6. The accumulation of oil must be determined, among other things, by the attitudes of the strata. The trends of "oil territory" must conform to the trends of formations. The situations of creeks at the surface could have no bearing on the underground distribution of petroleum. The junction of two

streams and the location of a sand-flat could sustain no relation to strata three or four hundred feet beneath. Whether the situation were in a ravine or on the upland could make no difference except in the depth of the boring. The notion of "ranges" and "lines" in the distribution of productive territory was illusory; since this is determined by the direction, the length, and the breadth of the formations which furnish the requisite conditions.

7. Petroleum is not confined to any particular formation. For many years it has been known in limited quantities, from the Eozoic gneisses to the Tertiary. The assumption was misleading, therefore, that every oil region must be supplied under the same stratigraphical and topographical conditions as Venango County, Pennsylvania. It was a matter of scientific certainty that another region might be fed from strata of a different geological age, of a different lithological constitution, dipping in a different direction, trending to other points of the compass, and overlaid by different topographical features at the surface.

All these principles, I have said, were known to science, and secured to the scientific man certain important advantages in arriving at judgments concerning prospects of success in a proposed enterprise. All of these principles were disregarded by a majority of the "oil prospectors." Some men under pay from capitalists even resorted to the witch-hazel fork in quest of knowledge on which capital might venture investment.

Let me now add some principles which experience and observation have pretty well established, and you will have the whole philosophy of oil-finding and oil-production. It is generally admitted that the porous stratum in which oil accumulates must have an arched or anticlinal form. Otherwise, the oil will spread laterally to an indefinite distance, and no local accumulation will take place. On the contrary, the oil will somewhere find an outlet to the surface.

Another doctrine generally accepted is the *vegetable* origin of the great supplies possessing commercial importance. It is admitted that animal remains may be a source of petroleum to a small amount.

The source of oil.

Again, it has been observed that every great oil-containing reservoir has below it—not always immediately below—a formation of the nature known as black bituminous shale. This is soft, easily cut with a knife, and contains a large amount of vegetable matter. Such shales are generally thought to contain quantities of remains of sea-weeds. If so, they exist in a comminuted and obscure state.

Probably a majority of geologists entertain the opinion that petroleum is produced from these black shales by a slow spontaneous distillation, through the action of the heat in the rocks. By artificial distillation, oil is readily obtained from them, and little doubt is entertained that at a comparatively low temperature a slow natural distillation proceeds.

Observation has shown that while black shales manifest a predisposition to the production of oil, pure vegetable deposits are more fixed. Thus, from proper coal-beds no oil proceeds; but from cannel coal and coaly shales oil is spontaneously evolved, as it also is from the black shales where the vegetable matter has not attained a coaly condition. The mixture of argillaceous matter with the vegetable material seems to favor the oil-making process.

Gas and oil.

Natural gas has an origin very similar to that of petroleum. The inflammable gas now so extensively employed as a substitute for coal, is also composed, like petroleum, of carbon and hydrogen, but with a larger proportion of hydrogen. It must be derived, in a similar way, from a similar source. Petroleum, in fact, is generally associated with gas. It seems to be composed of the heavier and more fixed compounds of carbon and hydrogen—containing much carbon, while gas is a lighter compound with more hydrogen. Petroleum, however, is not a simple compound of definite composition, but a mixture, apparently of many compounds—the more fixed, like asphalt and paraffine, being dissolved in the fluids kerosene, naphtha, and others. It is evident that natural gas may wander farther away than oil from the formation in which it originates; and hence there may be more difficulty in tracing it to its real source. It may become widely separated from apparent connection with oil. It may also be distilled from shales not possessing the requisite richness to afford oil. Hence, in some regions, as Fremont, Cleveland, and other localities in northern Ohio, it issues from Cambrian strata which furnish no indications of oil. In western Pennsylvania, within the Coal Measures, the great supplies of gas are yielded probably, by the same formations as supply petroleum. This, however, is a question still under investigation.

Oil districts:

Now let us look into the relations of things in some of the principal oil-producing regions. The most famous is that of northwestern Pennsylvania. The surface rocks are Coal Measures or Lower Carboniferous Sandstones (Waverly or Catskill sandstones) or Chemung sandstones—according to the locality. The oil is found accumulated in the sandstones; but its source is believed to be the Genesee Black Shale, near the top of the Hamilton Group (See Table, page 85). There are in all productive situations, shaly strata also, above the sandstone reservoir, which prevent the oil from escaping to the surface. The situations are similar in eastern Ohio and southern New York.

Pennsylvania,

Eastern Ohio and New York,

In Ontario are two kinds of oil, and two different reservoirs. The thick lubricating oil accumulates in a gravel bed at the bottom of the Drift, and is confined by the clay sheets of the overlying Drift. Its source is probably the Genesee Shale, which immediately underlies, but thins out a half mile further east. The more abundant petroleum is found stored in fissures and cavities of the Hamilton limestone; and its source is probably the black Marcellus shale next below the limestone. These cavities often contain water under the oil, and gas above. If the auger enters the upper part, gas escapes at first, but when this is exhausted, oil may be pumped. When the oil is exhausted, water follows. If the auger enter below the surface of the oil, the reaction of the gas forces the oil to the surface, and a "flowing well" exists. When the oil becomes lowered to the place of the perforation, gas escapes till the pressure is relieved. Then, if any oil remains, it may be pumped. Lastly, the water may be pumped. If the auger enters the cavity below the surface of the water, the reaction of the gas forces first water to the mouth

Ontario,

of the well; then when the bottom of the oil is lowered to the orifice, oil is forced out till its surface subsides to the orifice, when finally the gas escapes. No oil now remains in the cavity.

California, In California an oil-producing shale extends through the Eocene (Tertiary) of the Coast Ranges; but south of San Francisco these strata mostly stand on edge, and most of the fluid oil has escaped, leaving large quantities of tarry asphaltum, which hardens on exposure to the air. North of San Francisco, however, these shales are horizontal, and oil has accumulated in considerable quantities. But the chief supply of petroleum in California is found in the less disturbed regions south of San Francisco, chiefly in Los Angeles and Ventura counties. The total product of the state in 1884 was 262,000 barrels.

Russian oil district. In foreign countries, the most productive territory is the Baku region in Russia, near where the Caucasus abuts against the Caspian. Here is an area of 14,000 square miles which is producing, under treatment assimilated to that employed in America, quantities which promise to interfere seriously with the export of American oil. Six hundred wells have been bored, and one spouting well is represented to have produced 50,000 barrels a day. The most copious Pennsylvania well flowed 9,000 barrels a day, and the most productive Canadian well, 7,500 barrels.

XXV. Gaseous Sunlight.

NATURAL GAS—ITS WONDERS AND ITS GEOLOGY.

Illuminating and Heating Gas is one of the products of the earth. Its escape is a geological phenomenon. It was stated in the last talk that its origin is undoubtedly similar to that of oil, and that oil is chiefly the product of the distillation of shales charged with vegetable matter—probably ancient seaweeds. As sunlight is the active agent in vegetable growth, a stem or a leaf is simply a body of transformed sunlight. When imbedded in the rocks it is strictly and literally fossil sunlight. In petroleum, ancient sunlight is preserved in liquid form ; in natural gas it is gaseous.

Earlier knowledge of natural gas.

The escape of burning gas from the earth has been observed for ages. For more than fifty years, the gas escaping with the brine from the wells of the Kanawha Valley, West Virginia, has been employed in the evaporation of the brine. It has long been utilized in some salt mines where it escapes through crevices. In a similar way, it enters coal mines, and is known to miners as *fire damp*, since, mixed with a certain proportion of atmospheric air, it becomes violently explosive. The Chinese have for centuries employed natural gas for lighting and heating. On the Cumberland, in Kentucky, gas accumulates in underground reservoirs, and the elastic pressure is sometimes attended by explosions, constituting earthquakes of local extent, and lending some plausibility to the ancient theory of those phenomena. At Fredonia, New York, are gas emissions which have attracted attention for many years, and have long been utilized for lighting and heating. A gas spring was discovered here in 1821. The gas at that time accumulated was used for lighting a mill and several stores. It was also introduced into a few public buildings, and was brought to the attention of Lafayette when he passed through the village in 1824. Subsequently, a shaft was sunk, and sufficient gas concentrated to supply thirty burners. Thirty-seven years afterward, another shaft was sunk thirty feet, and two borings were made—one to 150 feet. In 1858, two thousand cubic feet of gas were delivered daily through the village.

Recent discoveries.

Knox Co., Ohio,

During the years of the great oil excitement, from 1860 to 1870, many of the borings for oil reached only gas. In Knox County, Ohio, in 1860, two wells were sunk for oil. In both, streams of salt water were intercepted, and, at about six hundred feet, an immense reservoir of gas was struck. The gas ejected the water with great violence. The first well was bored in the winter, and the water soon covered the derrick with ice, forming a kind of chimney sixty feet in height. Through this, the water was thrown, at intervals of about one minute, to double that height, or 120 feet. After the water, and with it, came a great rush of gas, which continued until the pressure below was relieved, when the water again began to accumulate, and was again ejected. The process was entirely analogous to the action of the geysers described in Talk XIV. In the Knox County well, gas took the place of steam in the geyser.

When the derrick was covered with ice, the gas escaping from the well was frequently ignited, and the effect, especially at night, of this fountain of mingled fire and water, shooting up to the height of one hundred and twenty feet, through a great transparent and illuminated chimney, is said to have been indescribably magnificent.

When I visited the spot, in 1866, a two-inch gas pipe had been fixed in the orifice of the second well, and the gas was escaping with a power and volume which were startling. The sound could be heard for a quarter of a mile. The pressure was two hundred and sixty-two pounds to the square inch, as reported by Mr. Peter Neff. The ignited jet formed a flame twenty feet in length, and as large around as a hogshead. It was an exciting spectacle. If the stop-cock were closed a few minutes and again opened, the accumulated pressure gave a volume of flame as large as a house. The supply of gas here was sufficient to illuminate a large city. Ten years afterward, personal information from Mr. Neff, under whose direction the work had been done, assured me that these wells continued to "blow," and he was then manufacturing from the gas a refined quality of lampblack.

In Michigan, certain parts of Wayne, Oakland, Michigan, and Macomb counties appear to be underlaid by considerable reservoirs of gas. In 1875, a gas well was struck three miles west of Royal Oak, at the depth of a hundred feet. In 1877, a well eight miles southeast of the village, at the depth of one hundred and fifty feet, reached confined gas which threw the tools into the air. It is said that much sand escaped, and a stone weighing "several" pounds was thrown over a barn "forty rods distant." The well was subsequently filled — evidently after the high pressure of the gas had subsided. In 1879, at a place five miles northeast of the same village, a well bored one hundred feet secured a supply of gas which has since been used for illuminating purposes. Three miles south of the village, a powerful explosion revealed the uncovering of a gas reservoir in 1880. After burning two years, two other gas wells were bored, and the united illumination rendered newspaper print legible at night, at the distance of one hundred yards. In 1883, a gas vein was reached at ninety-eight feet, which furnished a flame twenty-feet high. In 1884, on deepening this well, water was found, and additional gas which threw the water to the height of twenty feet. Many other occurrences of a similar nature have been known in this part of Michigan.

Elsewhere.

At West Bloomfield, New York, a well bored five hundred feet emitted gas with great force. At Erie, Pennsylvania, Conneaut, Painesville, Cleveland, and Fremont, in Ohio, a number of wells have been successfully bored. At Buffalo, New York, gas with a pressure of one hundred and thirty-one pounds to the square inch issued from a well six hundred and forty feet deep. At Cumberland, Maryland, a gas well burned for two years. Some six miles east of Crab Orchard, Kentucky, is a burning spring, the water in which is in a constant state of ebullition from the escape of gas. "Regularly every day," says J. F. Henry, "between four and five o'clock in the afternoon, it overflows; a large quantity of gas is liberated, and if a torch is applied, a flame results." At Fairview, Pennsylvania, a well drilled for oil, in 1870, to the depth of one thousand three hundred and thirty-five feet, yielded an immense volume of gas through a six-inch pipe, with so much noise as to be heard for a distance of two miles. The pressure was eighty pounds to the square inch. The gas was employed in establishments in Fairview, Petrolia, Karns City, and Argyle, besides furnishing fuel used in drilling some forty other wells. In the same year, a well bored near Titusville discharged four million cubic feet per day. At East Sandy, in the same oil district, a gas well struck in 1869 resisted all efforts to extinguish its burning. "It roared like a cataract and could be heard for miles."

Within a couple of years, large supplies of gas have been obtained in northern Ohio, by boring down to the Trenton Limestone—at least, into the Cambrian; for some doubt exists as to the precise formation. It is announced (January 1886,) that Fremont, Ohio, has reached a supply of two million feet daily. It is also reported that gas and oil have been obtained at Lima, Ohio, at the depth of one thousand two hundred and fifty-one feet. The gas produces a jet of flame thirty feet high.

Natural gas near Pittsburg.

The vicinity of Pittsburg, however, surpasses all other regions in abundance of gas-supply. The surrounding country seems to be underlaid by reservoirs of incredible capacity. These, or some of these, have been tapped, and the product has come into extensive use in furnace and other operations. Mr. William Metcalf, writing in November, 1884, said: "An observer standing on a hill-top in Allegheny township, Westmoreland County—say about three miles southeast of the confluence of the Allegheny and Kiskiminetas rivers—can see, on a dark night, on the northwestern horizon, the reflection of the lights from the Butler County wells; to the north, the lights from the wells in the direction of Kittanning; to the northeast, the Leachburg and Apollo wells; to the southeast, the Murraysville wells, and to the southwest, the lights of the Tarentum wells. Off in Washington County, and down toward Steubenville, there are other wells, while at Hulton, in Pittsburg, in the east end at Soho, at Brownstown, at Sligo, and in Bayardstown, there are wells upon wells, roarers and gushers. Some of these wells give out their gas at an enormous pressure. A gauge on a six-inch pipe situated some miles from the wells, registered one hundred and twenty pounds to the square inch, and the noise of the rushing gas indicated that the gauge was about right."

The Burns and Delamater wells.

Two of the most prolific of these wells, the Burns and the Delamater, have been described by the late Professor J. Lawrence Smith; "These are separated by at least half a mile, and are located in Butler County, seven miles northeast of Butler, and about fifteen miles from the Harney wells, of which the gas is conducted to Pittsburg. The two wells are located about thirty miles in a straight line from Pittsburg. Their depth is about one thousand six hundred feet, down to the fourth sand stratum so well known, at least by name, to those engaged in the petroleum production. The Burns, it is believed, has never yielded oil; but the Delamater first carried to the third sand layer (the oil men mean sandstone when they say ' sand'), was a petroleum well at one thousand six hundred feet. Sunk afterward to the fourth stratum, it gave gas at such a pressure that the tools, of one thousand seven hundred and sixty pounds weight, could be withdrawn by hand. Each well is five and five eighths inches in diameter."

The Delamater is the more remarkable. It furnishes light and fuel to all the vicinity, including the village of Saint Joe. It is situated in a valley surrounded by high mountains, which reflect and concentrate the light of the ignited gas. Many conduits start from the well; one leads the gas directly to the cylinder of a strong motor, which, by its pressure, acquires a prodigious velocity. Another pipe feeds a flame capable of reducing as much iron ore as half the furnaces of Pittsburg. At sixty-four feet distant is the principal escape orifice of the well. From a tube three inches in diameter, a column of fire forty feet high shoots forth with a roar that fairly makes the hills tremble. During a calm night the noise can be heard at a distance of fifteen miles. At four miles, the sound resembles that of a railroad train crossing a bridge near at hand, and finally, as the escape orifice is reached, the roar is like that of a thousand locomotives blowing off steam together. At the well, in a tube of five and five eighths inches, the pressure is about one hundred pounds per square inch; in a tube of two inches, in which the gas is led to Freeport, fifteen miles distant, the pressure is one hundred and twenty-five pounds. The ascending velocity is one thousand seven hundred feet per second, and if this be multiplied by the area of the tube, 24.7 square inches, a yield of two hundred and eighty-nine cubic feet per second, or about one million cubic feet per hour, is determined. This is one thousand four hundred and eight tons of gas daily. This, for heating purposes, is estimated as equivalent to two thousand tons of bituminous coal.

Importance of gas to Pittsburg.

A year ago, the daily consumption of natural gas for fuel purposes in the city of Pittsburg, was fifteen to twenty million cubic feet. The Consolidated Fuel Gas and Penn Fuel companies were delivering from Murraysville, through four lines of pipe, ten million cubic feet per day. Another line then building was intended to increase the flow to fifteen or seventeen million cubic feet. The Washington Gas company had a pipe line twenty miles in length from the famous McGingan well in Washington County. To this they were adding an eight-inch line, which would increase their capacity to five million feet. The Philadelphia company was then constructing three gigantic lines—one from Murraysville, another from Tarentum, and a third from the famous Westinghouse wells at Homewood, within the city limits. These lines would have a combined capacity of about thirty million feet per day. The Carpenter company were arranging to deliver four million, and the Chambers company three million cubic feet. Thus the enormous aggregate of sixty million feet was provided for; and even this would not exhaust the supply already existing. Sixty-five to seventy million cubic feet were daily wasting—in the Murraysville district alone.

Wastage.

The aggregate wastage as indicated by data still more recent, surpasses all which would be suspected from the facts given above. It is alleged (March, 1866), that in the entire gas field about Pittsburg, two hundred and sixty-four million cubic feet of gas are daily wasted. One thousand cubic feet are estimated to equal one bushel of coal in heating property. This would make an equivalent of two hundred and sixty-four thousand bushels of coal burned in the air each day. A miner can, on an average, dig seventy bushels of coal a day. The waste then, would be, in round numbers, equal to the daily work of thirty-eight hundred miners—or about the whole number employed in the Pittsburg district.

Composition of natural gas and fuel value.

This gas is a complex mixture of hydrocarbons. It differs from coal-gas, as also from gas made from petroleum. Its main ingredient is "Marsh gas," which, next to hydrogen, is the lightest substance known, consisting of seventy-five per cent of carbon and twenty-five per cent of hydrogen, and having a specific gravity of 0.5576, that of air being unity. The mixed natural gas has a specific gravity ranging from 0.51 to 0.7. That supplied to Pittsburg may be averaged at 0.6, from which it would appear that the gas for which provision was making in 1884, was equivalent to about forty-nine hundred tons of bituminous coal in heating capacity.

For heating purposes, natural gas excels coal gas thirty-three and one third per cent. Used in the crude way twenty cubic feet of gas equal one pound of coal. Used in the ordinary way, 11.29 cubic feet equal one pound of coal. Used in the most economical way, 8.92 cubic feet equal one pound of coal. For illuminating purposes it possesses only half the value of good coal gas; although it has been asserted of the Fredonia gas that it equals coal gas in respect to intensity of light, and is consumed but half as fast.

The industrial changes effected in the city of Pittsburg by the use of natural gas, are of a revolutionary character. In the city and surrounding country, not less than ten million dollars have been invested within a year, said a writer in 1884. "A year ago the business was insignificant; to-day, it ranks in importance with the iron, steel, glass, and coal interests of western Pennsylvania. There are at present ten iron and steel mills in this city using this gas in their puddling furnaces and under their boilers; a dozen more are busy making arrangements for its introduction, and almost every manufacturing firm using steam is awaiting the completion of the necessary pipe lines. Six glass factories in the city, and seven others in the immediate vicinity are using it. Every brewer in the city uses it. Two of the largest hotels use it exclusively for cooking purposes. For general household use, on account of its cheapness, cleanliness, and convenience of application, it has no rival."

The city of Buffalo is also said to be laying pipe lines for gas from the Pennsylvania gas districts.

Thus, strange as it seems, the sea-weeds which waved their graceful fronds in the oceans of millions of years ago, are smelting the iron for the pipes destined to bring their transformed constituents to the sites of gigantic industries, and warming the dwellings of the populations which conduct them.

The future of natural gas supply.

Will these marvelous supplies hold out? That is the question which the owners of the millions invested are anxiously asking. Probably, as has been proved with petroleum, particular wells will gradually diminish in supply; many will cease to yield; some will continue indefinitely. But probably, also, as in the case of petroleum, new supplies will be discovered, and even increasing demands will be met for many years in the future.

XXVI. Solidified Sunlight.

COAL AND COAL-BEDS.

Coal is a marvel.

I sit by my genial grate, this pinching winter evening, and watch the play of the flames which leap from the coal and play with the draughts of air passing up the chimney. Curious, is this coal—this combustible rock, wonderful, and abounding in suggestions. This warmth is yielded by combustion. This rock burns up. That which burns up is essentially carbon, or a hydrocarbon. Carbon, as we see in charcoal, burns without any brilliant flame, and without smoke. Hydrocarbon, as we see in kerosene and illuminating gas, burns with a bright flame. The coal in the grate emits a moderately brilliant flame. It is a mass of carbon saturated with some liquid or gaseous, or perhaps, bituminous, hydrocarbon. We are induced to trace its carbon to a vegetable origin. Now, if we look over a pile of coal we shall probably detect some indications of vegetable tissue. In some coals of the soft kind, we may find masses of woody fiber—black and brilliant, like some charcoal. In some of the shale attached to pieces of coal, or mingled with the coal, are some impressions like fern fronds. If we go to the mines, we even discover stems of moderate sized trees imbedded in the shales

Vegetable origin of coal.

above the coal, and occasionally in the coal itself. Again, if we prepare exceedingly thin slices of coal, and remove the black matter by proper treatment, we may detect, by means of the microscope, minute structures, such as belong to vegetation. All these circumstances then, conspire to convince us that the coal is of vegetable origin, and much of it from tree-like vegetation. With other observations, we detect, many times, innumerable spores scattered through the coal. These are cells produced by vegetation which is flowerless. They answer for the fruit, but are not fruit, as the term is usually employed. The coal vegetation, therefore, was without flowers or fruits. Much of it, as we readily discover, was of the nature of ferns—some of them tree-ferns, such as grow in our times, in some tropical regions. If we were to search further we should find traces of vegetation resembling our Horsetails and Ground Pines. So we may regard ourselves quite justified in concluding that the coal which blazes and cheers on the grate, was once in the condition of a flowerless tree, rooted in an ancient soil, spreading its green fronds to the sunlight, decomposing the carbonic acid of the atmosphere, fixing the carbon in its own tissues, and setting oxygen free.

Locked-up sunlight.

So, the sun was shining in the heavens so long a time ago. The plans of vegetable structure were in existence, and the forces of vegetable growth. The sun's emanations of light and heat became transformed into stem and frond and tissue. The coal is ancient sunlight that has been locked up like a treasure and buried in the earth for ages. Here, in this flame, the tissue-substance goes back to its primeval condition

—it becomes again carbonic acid, and mingles again in the atmosphere from which it was selected. Here, in this flame, the old warmth reappears; it is the warmth of the sun which shone in the Carboniferous Age. Here, in this flame, the old sunlight is regenerated; this is the very sunlight which became latent in vegetable cells so long ago. It is locked-up sunlight set free after a long imprisonment.

Varieties of coal.

There are several varieties of coal; let us look them over. The plumbago of your pencil is essentially carbon. We can take common coal and by subjecting it to pressure and heat while excluded from the air, convert it into something much like plumbago. It often occurs in iron-furnaces. This is sometimes called black lead; but it contains no lead; its more appropriate name is graphite. It is found among the metamorphic rocks. Whatever it was, it has been pressed and baked through the same processes which have so transformed the original Eozoic sediments. Since graphite can be prepared from coal, we may safely assume that graphite is only metamorphic coal. Indeed, there are regions where graphite occurs in the same formation which in other regions we know as *Coal Measures.* But the strata are all metamorphic. Most graphite, however, belongs to a remoter geological age. We find it in Vermont and most of the New England States; also in northern New York and many other American and foreign localities. It can only be burned at a high temperature.

Graphite.

Anthracite.

Next in respect to hardness and difficulty of combustion is *anthracite.* This breaks in irregular lumps, with shining surfaces, and burns with only a feeble bluish flame. It has a relatively high specific gravity, and furnishes more heat per ton than any other species of coal. Anthracite is found in situations where it appears to have been subjected to a baking and hardening process which has driven off most of the volatile hydrocarbons found in other coals. In the United States, southeastern Pennsylvania is the chief anthracite region. It has afforded an enormous quantity, and some of the best varieties are said to be about worked out.

Bituminous. The other varieties of coal are *bituminous.* That is, they contain hydrocarbons partly of the nature of bitumen. But the term as a designation for a variety is restricted to the black coals occurring in the region east of the Rocky Mountains, chiefly in the Palæozoic System. In structure they are distinctly stratified—sometimes with films of earthy matter between the laminæ. They are apt to break in flattish or thin fragments, and they possess an earthy or resinous luster. They burn with much bright flame which arises from the hydrocarbons expelled and ignited. These coals are the source of the illuminating gas of our cities.

Cannel. From the typical bituminous coals we may separate the *Cannel Coals.* These have an earthy luster, a fine compact constitution, and are often thick bedded, with only obscure stratification within the bed. They burn freely and brightly when rich, and were used in the earliest manufacture of illuminating gas and kerosene, or "coal oil." This manufacture had attained a prosperous stage of development when the discovery of the large supplies of petroleum caused its ruin. Cannel coal has no standard degree of purity. It consists of carbonaceous and aluminous particles mixed in varying proportions. It degenerates, on one hand, to a mere black shale, and on the other, attains a state in which it is almost free from earthy admixture.

Caking and non-caking. Among the typical bituminous coals, we distinguish the *caking* and the *non-caking*. The former, when ignited, seem to fry with an exudation of a fluid bitumen, which evolves much gas and hardens into a crust somewhat impervious to the air, and thus obstructing the draft. The latter burn freely, without an incrustation.

Bituminous coal of Mesozoic Age. Besides the Palæozoic bituminous coals we find excellent Mesozoic bituminous coals. These are solid, but less valuable than the others; though they are a boon to many regions otherwise scantily supplied with fuel. Of this kind is the coal mined near Richmond, Virginia, and in the Deep River region of North Carolina; also the excellent coal of Wyoming and that of similar excellence in the state of Washington, in the Cascade Mountains. The latter exists in great abundance and of several varieties, one of which has the appearance of anthracite. It is widely exported—to San Francisco and the Hawaiian Islands.

Brown coal. *Brown Coal* is of Cænozoic age. It is next in order of hardness and value. It varies, however, from a variety quite firm and compact, with a blackish color, to varieties of brown color and composed distinctly of vegetable fragments.

Peat. *Peat* is a vegetable accumulation formed at the present surface, from mosses, leaves, and sticks, and is not yet consolidated into the condition of a coal.

It is used, however, extensively as a fuel, especially on the continent of Europe, where the traveler may see it cut out in blocks and piled up like bricks drying in the sun. The city of Paris is warmed chiefly by peat. Many efforts have been made in America to reduce peat to a cheap and efficient fuel; but for the present, it is unable to compete with our other natural combustibles.

Mode of occurrence of coal.

Coal occurs in strata—not in veins—interbedded with sedimentary rocks. Shales, clays, and sandstones exist extensively in Coal Measures; and in some regions, limestones are interstratified. The latter contain fossil shells, and are manifestly of marine origin. The coal must have been produced on the land. Some of the clays are apparently the soil in which the vegetation grew, since the roots are found extending into them. The shales were deposited in quiet, muddy waters, within easy reach of the products of the land, since they contain immense quantities of fronds and other vegetable matters, generally in a fine state of preservation.

Method of mining.

In regions somewhat disturbed, like Pennsylvania, the strata of coal make outcrops like limestones, shales, and sandstones. Mining is then prosecuted from the "crop" by carrying an excavation or *drift* along the slope of the coal stratum. If possible, the place is so selected that the slope may ascend from the mouth, so that the water reached may flow out spontaneously. If this is not practicable, then pumping must be resorted to, and this sometimes becomes enormously expensive. In regions where the strata repose in nearly horizontal positions, the underlying coal beds are reached through vertical shafts. In such cases, pumping machinery is essential. Not unfrequently, one shaft is extended down to a second or third bed of coal. In any case, after the coal is reached, chambers or galleries are excavated in rectangular directions in the bed. The roof is supported by large blocks of coal left undisturbed. After most of the coal has been thus removed, the supporting blocks are worked out successively, and the roof of the mine may be permitted to fall in.

XXVII. Monsters of a Buried World.

EXTINCT QUATERNARY MAMMALS.

"Mr. John Smith, of the town of Sharon, in digging a ditch to drain a swamp on his farm, exhumed some very large bones which must have lain buried for many thousand years. They appear to be the bones of a giant. They will be offered to the University for sale."

Remains of mammals from bogs.

"Mr. Peter Jones discovered last week in a peat bed, a nearly complete skeleton of some antediluvian monster. Mr. Jones will have the skeleton set up as soon as possible, and will then start on a tour of exhibition. He feels confident there is a fortune in these bones."

The above are samples of paragraphs frequently appearing in the newspapers. They indicate that the peat bogs of our country contain many relics of beings no longer in existence, and no longer remembered.

Such relics have been discovered also, in the Old World, and former generations have been strongly inclined to attribute them to a race of giants now extinct. An intelligent inspection of these bones, however, shows that they never belonged to human giants, and can not, therefore, be the remains or testimonials of the "giants" of antediluvian times. Modern science has shown that they belonged to elephant-like creatures, of two different genera. One of these was the true Elephant, and the other is known as Mastodon. The Mastodon has not been seen during historic times; but we conclude from the relics remaining, that it was very similar to the Elephant, and differed chiefly in the structure of the grinding teeth. The molars of the Elephant are enormously large, and only one is in use in each jaw on each side, at one time. It may be regarded, however, as a compound tooth, consisting of ten or twenty simple flat teeth standing closely and firmly compacted together by means of a substance called *cement.* The molar of the Mastodon has more the appearance of an ordinary tooth, with three, four, or five transverse prominences, rising like steep and furrowed ranges of mountains. It is smaller than the elephant molar; and three or four were in use at once on each side of each jaw.

Similar remains from modified Drift.

Commonly, as already indicated, the bones of the extinct Elephant and Mastodon have been discovered in peat deposit. Such deposits are explained in Talk VIII, and rest upon the top of the Drift, and are more recent than the Drift. But in Europe bones of the Elephant have sometimes been met with in the modified Drift. They also occur in many caverns which are believed to have been occupied by wild beasts in the Drift epoch. We may conclude, therefore, that the Elephant came down from the Tertiary Age. Indeed, we shall see from the facts to be stated in the next Talk, that both Elephant and Mastodon began to exist before the Quaternary Age.

Mammoths of Siberia.

Some very remarkable facts have come to light from northern Siberia. That inhospitable region was once a home for Elephants. More than a hundred years ago, not only their ivory, but their carcasses were known to exist in Siberia imbedded in solid ice. The first discovery was on the borders of the Aleseia River, which flows into the Arctic Ocean beyond the Indigirka. The body was still standing erect, and was almost perfect. The skin remained in place, and the hair and fur were still attached in spots. In 1772, the body of a perfect two-toed rhinoceros covered with hair, was found preserved in frozen gravel near the Vilhoui or Wiljui, a tributary of the Lena, in latitude 64°. The head and feet of this animal are preserved in St. Petersburg. The most celebrated discovery was made in 1799. A Tungusian fisherman named Schumachoff was exploring along the coast of the frozen ocean for ivory. Near the mouth of the Lena he noticed, in a huge block of clear, glacier ice, a dark, strange object deeply imbedded. His half savage curiosity was not strong enough to lead him to undertake the work of exploration. In 1801 the melting of the ice had exposed a portion of the carcass. It was a beast like those whose ivory lay strewn along those frozen shores. In 1804, the Tungusian was able to remove the tusks. They weighed three hundred pounds, and he disposed of them for fifty rubles, to an ivory merchant. In 1806, Mr. Adams, who was collecting for the Imperial Museum at St. Petersburg, found the carcass still on the shore, but greatly mutilated. It appeared that the Yakutski had actually regaled their dogs upon the flesh ; and bears, wolves, wolverines and foxes had gladly feasted upon it ! Thus this priceless relic of a prehistoric world was allowed to waste away. But it was not completely lost to science ; for except one fore-leg, the skeleton remained perfect. A large part of the skin had also escaped destruction, together with one of the ears, which still retained its characteristic tuft of hairs. The skin was of a dark tint and was covered with reddish wool an inch in length, interspersed with reddish-brown hairs four inches long, and sparser black bristles twelve to sixteen inches long. Everything of value was now collected, including more than thirty pounds of fur; the tusks were repurchased, and the whole was transported to St. Petersburg, where the mounted specimen at present stands, in the Imperial Museum. This individual was nine feet high and sixteen feet long, exclusive of the tusks.

Other discoveries have been made more recently. In 1843, a mammoth was found by Middendorf in so perfect a state that the bulb of the eye is still preserved in the museum at Moscow. In 1858, a mammoth was discovered in the delta of the Lena, twenty-three miles from Sagastyr. The head and tusks had already been removed by a Russian merchant. The Yakuts soon after the discovery took a leg, several ribs for making spoons, parts of the skin for straps, and fat for painting their sledges. The body was reported in 1884 as lying on its side in the lower part of a crag of alluvial deposits thirty feet high. Dr. Bunge, who undertook to excavate on the spot, found the material a frozen mass of snow "as hard as sugar." Still another mammoth was discovered in 1878 on the Moloda River, a tributary of the Lena, which it joins on the left thirty miles above Siktyakh. We shall have to inquire, hereafter, what was the nature of the catastrophe which buried these huge quadrupeds in their common tomb of ice. The same mammoth dwelt in Alaska. His tusks are extensively sought and sold for ivory.

Restoration of mammoth.

The great original skeleton standing in the Museum at St. Petersburg was duplicated at Stuttgart under the direction of Dr. Fraas, from various bones collected from different parts of Europe. Dr. Fraas, from samples of skin and hair still existing, ventured to give the extinct mammoth a complete restoration. Professor Ward, the great museum-builder of America, saw this monster of mammoths standing in the Museum at Stuttgart and purchased it. Transporting it to Rochester, he reared a duplicate, which stood for months in the Ward Museum, where I had the opportunity of subjecting the creature to a careful study. Let us go back and repeat the visit.

"As we enter the door of the building which has been erected for the accommodation of this antediluvian, a dark mountain of flesh rises before us. We had gauged our apprehension to the familiar bulk of the elephant, but here the eye must be lifted to a higher altitude; the whole thought must swell to take in the idea of the towering form which looms above us and frowns darkly and severely down upon us. The monster's brow rises like some old granite dome, weather-beaten and darkened by the lapse of geologic ages. Two winding streams of ivory descend like glaciers from the base of the dome, while the corrugated and beetling proboscis swells between them like the embattled crest which divides two Alpine glacier-torrents. Behind expands and uprises the mountain mass of which these are the accessories.

"All this dark and towering mass is conscious. There are eyes which open on us and take cognizance of our movements; there are ears which take in the sounds of our voice. This creature contemplates us.

"He stands sixteen feet in height. His extreme length is twenty-six feet, and the distance between the tips of his tusks is fourteen feet. His body is thirty feet in circumference close to the skin. The sole of his foot is three feet in diameter. His tusks are fourteen feet long and one foot in diameter at base. Between his short, post-like fore-legs a man can stand upright with his hat on, without touching the animal's body. The whole exterior is clothed with dark shaggy hair, quite unlike the modern elephants, and under the throat it attains a length of twelve to fifteen inches."

Other mammalia remains from the Drift.

Europe, Asia, and America had their Mammoth and Mastodon in the Quaternary Age; and their bones and carcasses still lie preserved in Drift deposits to testify to their existence. South America, however, had its *Megatherium*, its *Mylodon*, its *Scelidotherium*, and other strange giants of the order known as Edentates. These have been found imbedded in the "Pampean Formation," which extends from Brazil nearly to the Straits of Magellan. It is mostly a level and sparsely wooded plain, covered by a rich soil underlaid by gravel and sand. Numerous marine remains indicate that it was covered by the sea during a period geologically recent. In this formation have been found the ponderous bones of a colossal ground-sloth, now known as *Megatherium*. The first relics were discovered in 1789, near the city of Buenos Ayres. A nearly complete skeleton was sent to Madrid, where it still stands, the chief scientific attraction of the Spanish capital. Through various other discoveries, entire skeletons have been reconstructed, the most perfect of which stands in the British Museum. Plaster copies of this have been made under the direction of Professor Ward, and the Megatherium is now a familiar sight in American museums. *Megatherium.*

This was one of the most anomalous creatures of the strange past. It was one of the last of the great "comprehensive types" which appeared in the progress of the history of life, and of which you will hear much, as we trace this history backward. It was studied by the great Cuvier, among many others, and he first revealed its true affinities. Some regarded it as tree-inhabiting ; some thought it subterranean ; Owen decided that it must have lived upon the ground. As represented by Hawkins, it stands semi-erect, resting on its massive hinder-extremities, with auxiliary support from a vast pillar-like tail, with anterior extremities clasping the trunk of a tree and relatively diminutive head and tapir-like snout turned upward toward the foliage which probably served as its food.

The length of the skull is thirty-one inches ; its breadth, eighteen. The brain-box is very small for the bulk of the animal. The molar teeth have hollow fangs for continuous growth, as in the sloth and many modern rodents. The spinal column is 15½ feet long. The circumference of the skeleton at the eighth rib is ten feet. The scapula is a vast expanse of bone two and a half feet long. The distal (farther) end of the humerus is 13 inches wide, while that of the elephant is only one fourth as great. The pelvis is a mountain of bone. It is far more massive than that of the elephant or any known animal, living or extinct. Its extreme breadth is upward of five feet—that of the Asiatic elephant being sixteen inches less. The socket for the head of the femur presents a surface of 44 square inches, which is 200 times the same surface in the pigmy shrew-mouse. The thigh bone, in the Mastodon and Elephant, appears weak and slender compared with that of the *Megatherium.* It is two feet two inches in circumference at the largest part. The hind legs look more like columns for the support of a bridge than like organs for locomotion. The circumference of the tail at its largest part was six feet.

We have to imagine this gigantic framework clothed with flesh and instinct with life. It towers before us a huge, ungainly beast, eighteen feet in length and eight feet high, having a tapir-like head, an elephantine body, and hind feet and tail which find no match in geologic or historic time. Such super-mammoth haunches, nearly six feet across; such singular, half-hoofed, half-clawed extremities; so slow and awkward in his movements; so stupid in look—he seems the lord of the Pampas. His thick and callous hide is scantily clothed with coarse, stiff hair. He seeks his food from the leaves of the forest. Other leaf-eaters possess various provision for securing their food. The elephant is furnished with an elongated proboscis. The giraffe is uplifted on fore-legs of extraordinary length, supplemented by a neck of length equally extraordinary, and lips and tongue co-ordinated with other parts of his outfit. The sloth ascends the tree and places himself in the midst of the foliage on which he must subsist. Our Megatherium has none of the provisions of the elephant or giraffe, and is too ponderous to be borne by the branches of a tree. He raises himself in a semi-erect attitude, supported by that tripod formed of tail and hind feet, and reaches with his fore-limbs to the foliage and gathers it in. When the supply falls short, he employs his powerful effodient feet to hurl the earth from the roots of the tree, and bring it down by his colossal strength. Then he stretches himself alongside of the prostrate tree and gathers its foliage at his leisure.

North American types.

These are samples of the relics of the Quaternary Age. In North America are found remains of a pig-like creature, a gigantic beaver, and some Edentates. They are found imbedded in sand and fluviatile deposits, accumulated, like the elephant-bearing peats, after the Drift. The bowlder Drift is mostly destitute of organic remains. Probably the severity of the temperature and the prevalence of ice rendered animal life impossible.

XXVIII. The Cemeteries of the Bad Lands.

TERTIARY FOSSILS.

The Bad Lands.

The "Bad Lands" in the dialect of the trapper and Indian, are regions unfavorable to the pursuit of their occupations; as the snow-covered slopes of the Alps are *Monts maudits* (cursed mountains) in Savoy, and an unavailable ridge in the Pyrenees is *Monte maladetta* to the Spaniard. The Bad Lands of the United States are underlaid by Tertiary strata which have been worn and wasted in innumerable fantastic shapes, and excavated on so vast a scale as to expose to view the relics of the creatures buried beneath the rubbish of hundreds of thousands of years. In order of succession these strata lie further than the Quaternary deposits from the completed surface. Still, there are extensive regions where nothing more modern covers the wastes of the Bad Lands.

Tertiary strata in America.

Inspect the rocks of some Tertiary district; we are pretty sure to find them horizontal or nearly so. Along the Atlantic and Gulf coasts they slope gently toward the sea. In some parts of the Pacific coast, the Tertiary strata have been tilted to high angles and subjected to metamorphic action. In the interior of the continent they generally lie in positions nearly horizontal. Tertiary strata which slope down to the sea and under it—or once had such a slope—are of marine origin, and contain relics of marine populations. In the interior, we find the fossil remains mostly those of fresh water and the land. In some of the deepest Tertiary of the interior, the aquatic forms are brackish-water species; and those from the lowest beds are sometimes salt water species. These facts are important in setting in order the history of Tertiary times.

Description of the Bad Lands.

Let us visit one of these desert spaces of the continent. We leave the valley of the upper Missouri and travel overland across plains parched by drouth and clothed only with scattered sage brush. The buffalo is not found grazing here; birds and insects avoid the herbless waste. Our mules toil on in the withering heat of summer, and reach with weariness the border of a shrunken stream on which to encamp. With patient progress we arrive at a region which shows symptoms of a change of scene. Ahead, appears a less monotonous landscape. Some breaks in the surface are revealed. There, in the distance, are forms which remind us of architectural structures. We seem to see gables and towers.

We press on. The illusion dissolves. Before us stretches a wide excavation, down into the formations underneath. Where are the materials removed from this emptied basin? What power plowed up the strata and carted away the *dêbris*? We come to the brink of the basin—a vast rock basin cut through beds of horizontal shales and soft limestones. The sloping walls have been worn for a thousand centuries by the rills formed from the winter rains. The fluted columns have been grooved by water. The salient abutments have been chiseled by the storm.

A cemetery.

The rock-layers are visible all around the depression. We descend to the floor and trace their continuity from side to side. Each layer was once a lake bottom. But, behold the relics of a former population scattered over this floor. Here are the skulls of sheep-like creatures which are also pig-like; the carapaces of turtles unlike any turtles living; the shin-bones of rhinoceroses which no longer roam in the jungle. We turn our eyes again to the rocky layers, and lo! like shelves of a vast cabinet, they hold the specimens which illustrate a fauna passed away—a classified cabinet, where each shelf is stored with the relics of its epoch, and the lower shelves are filled with the souvenirs of the older time.

Life once thrilled through all these torpid frames. These were conscious creatures. These were joyous creatures walking on the green earth. These were beings which inhaled the vital air, and basked in the life-giving sunlight, and enjoyed each other's society. They fed on the productions of the forest and the glade. They wandered over a land which was to be Dakota and Nebraska. They slaked their thirst at the border of the wide lake; they cooled themselves in its waters, and sometimes sported with its waves. Death came to them, as to their thousands of predecessors—as it comes to us. They were mired in a slough; they were hunted in a jungle; they lay down in the shade of a friendly tree; some force of nature bore them to their burial. The lake was their tomb, and the lake preserved its trust.

Localities of Tertiary deposits:

The formation in which these creatures are entombed stretches from eastern Nebraska to Laramie, and from the Cheyenne River, Dakota, into northwestern Kansas. It is called Neocene or Upper Tertiary. Other smaller areas of the same exist in Colorado, Wyoming, Montana, and Nevada. A very large area exists also in Oregon and Washington. Upper Tertiary strata also border the Gulf of Mexico, from Mobile to the Rio Grande, stretching inland a hundred miles, and up the valley of the Mississippi to Cairo. Near the gulf shore, however, and along the delta of the Mississippi the Neocene is concealed by alluvial deposits. Neocene Tertiary stretches along the Atlantic coast also, from Montauk Point to the southern part of Florida—from Charleston southward, however, overlaid next the shore by a narrow belt of alluvial or recent deposits. There are few remains of land animals in the *marine* Tertiary; but shells and corals are plentiful. A majority of them belong to the same species as are now living in the nearest parts of the Atlantic. Near Charleston, however, have been found the remains of a horse more resembling the domestic horse than those in the Bad Lands. Indeed, the Carolina horse was extremely like the species long afterward brought to America from Europe. As this species is not known in the Neocene of Europe, the indications are that it lived in America before it did in Europe. That is, the late Tertiary horse originated in America; afterward found its way to Europe and Asia, and finally was brought back to the New World by immigrants in the sixteenth century. Almost the same story has to be told of the camel. Neocene,

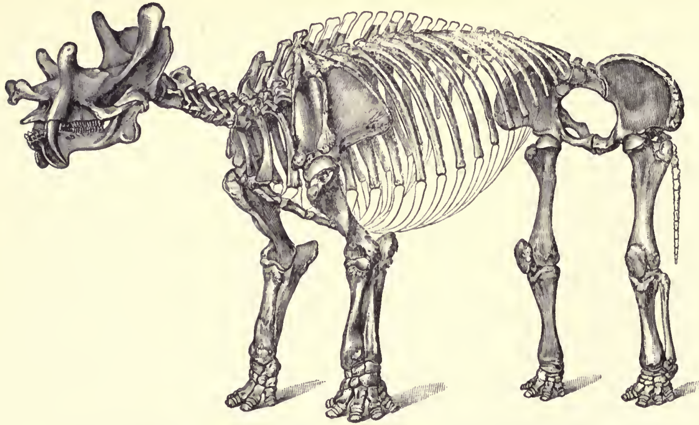
But there are older Tertiary deposits called Eocene, which means the "dawn of the recent," because the marine shells found in them contain a few recent Eocene.

species, and only a few, while the shells of all older formations are specifically distinct from any now living. The Eocene strata are seen passing under the Neocene all along the Atlantic and Gulf border, and up the delta of the Mississippi. When these strata were deposited, the Atlantic and Gulf extended to the inland limit of the Eocene. The valley of the Mississippi as far as Cairo was under the Gulf—a bay setting northward to Cairo from about the latitude of Montgomery, Alabama. In this sea sported the great *Zeuglodon*—a vertebrate of whale-like nature, but serpent-like form, which on the first discovery of its remains, was supposed to be a real sea-serpent. Its length was sixty to eighty feet. A skeleton dug up in Clarke County, Alabama, by Dr. Koch, was named *Hydrarchos*—king of the hydras—and was formerly exhibited in Barnum's Museum, New York—afterward sent to London, where Professor Richard Owen determined its true nature. The vertebræ of this curious whale are found strewn over the corn and cotton fields of southern Alabama. I have seen them used for andirons in the rude fireplaces of the country, and set for steps of a stile over the front fence of the door yard.

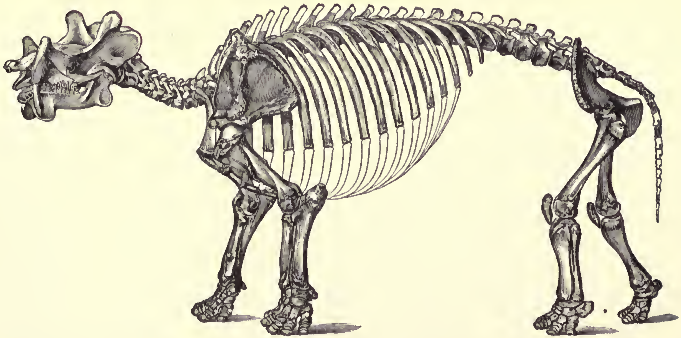
Zeuglodon.

Other Eocene fossils.

The region underlaid by the Eocene abounds in shells and corals and fish-teeth washed out by the weather. The strata are mostly friable, and some almost incoherent. The rivers and creeks have excavated deep channels, and thus caused many fine exposures. The most celebrated river bluffs in the Alabama and Mississippi Eocene are at Claiborne, St. Stephens, and Vicksburg. All these localities abound in fossils, but especially the first and last named;



RESTORATION OF TINOCERAS INGENS (Marsh). One thirtieth natural size.



RESTORATION OF DINOCERAS MIRABILE (Marsh). One thirtieth natural size.

and the fossils exist in a perfect state of preservation. At St. Stephens we find the "White Limestone" which incloses the remains of *Zeuglodon*. Eocene fossils are found in great abundance also, along all the creeks and ravines, and by the roadsides.

Fresh-water Eocene of Wyoming, etc.

For many, the remains inclosed in the fresh-water Eocene of our western territories possess still greater interest; for they are the bones and teeth of strange and often gigantic quadrupeds which dwelt on the land. In the southwestern part of Wyoming, and extending south to the Uinta Mountains, is a great expanse of such strata. On the south of the Uinta Mountains is another, extending southeastward into Colorado, and south and southwestward into Central Utah. Another vast Eocene region stretches from southern Colorado into New Mexico. It is chiefly from the Eocene of Wyoming that Professor Marsh obtained the mammalian bones which, during many years back, he has described for the astonishment of the world. Some very unique material, however, was procured in Oregon. The equal work performed by Professor Cope, has also been based partly on specimens from Wyoming, but more largely on material from New Mexico and Texas. These wide, western regions pastured herds of herbivores in the early Tertiary time, as they have continued to do down to the invasion of the locomotive and the transformations of civilization.

The Eocene mammals are of "comprehensive types."

I cannot undertake to convey to your comprehension, in a few lines, any adequate conception of the aspects and characters of these long extinct beings. If we speak only of mammals, we can say that they generally differed widely—often grotesquely—from any forms now living. It was then near the beginning of mammalian development on the earth. Still those creatures presented unmistakable resemblances to modern mammals, in all fundamental respects. If there were no elephants, there were the *Brontotherium* and *Dinoceras* and *Tinoceras*, and especially in the Old World, the *Dinotherium*, which seemed like uncouth and undeveloped pachyderms trying to become proboscidians. But the *Brontotherium* had no tusks, no trunk, no elephantine molars. The "comprehensive" character of these and other early mammals was the most interesting fact; but I reserve more particular mention for a later opportunity.

XXIX. Lesson from a Lump of Chalk.

MESOZOIC ROCKS AND FOSSILS.

The chemistry of chalk. THIS white lump, soft enough to be cut with a knife, effervesces very briskly when any strong acid is applied to it. Even strong vinegar causes the formation of a multitude of small bubbles. Effervescence is caused by the escape of some gas. Almost always, the gas is carbonic acid, or as we now say, carbon dioxide. Chalk is a compound of this and calcium. The latter is familiar in the form of lime. Carbonic acid is feeble, and when the strong acid is applied to the chalk, it drives off the carbonic acid, and takes possession of the calcium for itself, forming a different compound. The carbonic acid when freed from combination, resumes its gaseous form. It therefore swells up, and mixed with the water of the strong acid, produces the bubbles which constitute effervescence. Chalk, however, has essentially the same constitution as limestone and marls.

Structure and origin.

If we pulverize some of this chalk and examine the particles with a microscope, we discover that the greater part consists of minute shells or shell-fragments. Indeed, here is *Globigerina* again! We found *Globigerina* in our "Walk Under the Sea" (Talk IX.). Billions upon billions of these minute shells accumulated together, have formed that white ooze which overspreads so large a part of the deep sea-bottom. If some of that ooze should be compressed and dried, it would be exceedingly like chalk. There is little doubt that the real chalk so abundant in Europe, was originally a white ooze in the bottom of the ocean, when much of Great Britain and the continent was buried in its waters. What we found in the depths of the Atlantic must be a modern picture of the condition of the ancient ocean which covered Europe some millions of years ago. The bottom of the Atlantic was then the bottom of the Atlantic. Its present condition has been perpetuated from the Cretaceous Age; and many of the minute forms accumulating there to-day are generically identical with the forms which lived when the chalk was a sea-bottom.

Dogma of "the continuity of chalk."

A few years ago, when these things were first ascertained, and the first announcement was made that the fossil forms of the chalk were still living in the Atlantic, a triumphant outcry was made through the newspapers by the ignorant enemies of geological science. It has, since Cuvier, always been a fundamental doctrine in geology, that the earth's surface has been occupied by a succession of populations showing progressive advancement toward the modern aspects of the world. But "here," they affirmed, "we find no change since the chalk. The foundation of geology is disrupted. The so-called science is a baseless mass of 'theories'! There is no sound evidence of the great age of the world. The 'days' of Genesis were twenty-four hours long. Hurrah!"

The true explanation of the present existence of cretaceous forms.

The life of geology was scarcely conscious of a ripple. The old principles rest firmly. The facts cited, instead of proving destructive, confirm another doctrine even more dreadful than that of successive faunas and great antiquity—the doctrine of correlation of organic structure with environment. Faunas change as the physical surroundings change; but if the physical surroundings remain changeless, the faunas remain changeless. Down in the deep sea, with a constant temperature of freezing water; with perpetual absence of the stimulus of light: without motion; without change of chemical conditions—with almost absolute changelessness for ages, why should organisms change? They are now suited to the environment; they could not change without becoming *unsuited* to the environment. The forms from the Age of Chalk have survived because a deeper principle than that of succession of faunas has been dominant. It is the principle of *correlation of environment and organism.* The animal must be adapted to its surroundings. Nearly all the populations which have lived dwelt on land or in comparatively shallow water, where environment was undergoing progressive change; hence succession of faunas. A few deep sea species have dwelt where change of physical conditions is almost unknown; hence a nearly changeless fauna. Thus a piece of chalk reveals a deep and important principle.

Cretaceous rocks: kinds and distribution.

The position of the chalk-beds in the series of geological formations is nearly at the top of the Cretaceous System. The System, besides the beds of chalk, contains strata of sand and clay. One variety of sand is green, and in New Jersey, opposite Philadelphia, it is dug extensively for fertilizing soils, since it is not a purely silicious sand, but contains a large percentage of potash. The Cretaceous strata extend along the belt parallel to the Atlantic and Gulf coasts, into Mexico; but from Maryland to Georgia, the Atlantic belt is mostly covered and concealed by the Tertiary beds. From middle Georgia, a broad belt extends into eastern Mississippi, and thence north to the Ohio River near Cairo. West of this, the Cretaceous strata are concealed by Tertiary and Mississippi alluvium, as far as Little Rock. Near here an exposed belt begins which widens extensively toward the southwest, through Texas. Remember that the place of the Tertiary strata is always between the Cretaceous and the ocean. The Cretaceous strata go down under the Tertiary, and probably under the Gulf and a portion of the Atlantic.

Eastern and southern localities.

There is no proper chalk in the Cretaceous beds of the United States. In the Gulf States, however, is a buffish soft limestone, called the "Rotten Limestone," slightly resembling chalk. As it disintegrates and mingles with vegetable matter, it forms a very rich, black soil. This underlies the very best cotton lands of Georgia, Alabama, and eastern Mississippi. The lower part of the System contains beds of sand interstratified with clays and shales. These convey rain water down and southward from their belts of outcrop. So when holes are bored from the surface down to these water-bearing sands, supplies of water are obtained. Hence it is, that at Selma, Cahaba, and throughout the Cretaceous region, Artesian wells abound.

Fossils.

The Cretaceous rocks of the Gulf States are rich in fossil remains; often, in riding along the highway, one's eye is arrested by some weathered knoll close by the roadside, thickly overstrewn with teeth and vertebræ of sharks and rays of various extinct species—as if one were traveling over a sea-bottom. Here also, are multitudes of small and curious oyster shells, and many other sorts of shells. Where the rivers and creeks have cut through the Cretaceous strata we find excellent sections. One of the most famous of these is at Prairie Bluff, on the Black Warrior River, in Greene County, Alabama. Here the "rotten limestone" is at the top; then come beds of sand formed evidently, not far from the ancient shore, which lay on the north, just beyond Selma and a little south of Tuscaloosa. These sands contain bits of wood, and, in one instance, I remember seeing the trunk of a tree projecting several feet from the cliff toward the river. The wood contained a good amount of *iron pyrites*, but some of it could still be cut with a knife. Here is one layer of cemented sand completely

Oysters.

packed with small oysters. In other strata I have picked up oyster shells seven inches in diameter, and nearly round. Single valves, I think weigh sometimes two or three pounds. The Cretaceous strata seem to have been a literal oyster cemetery.

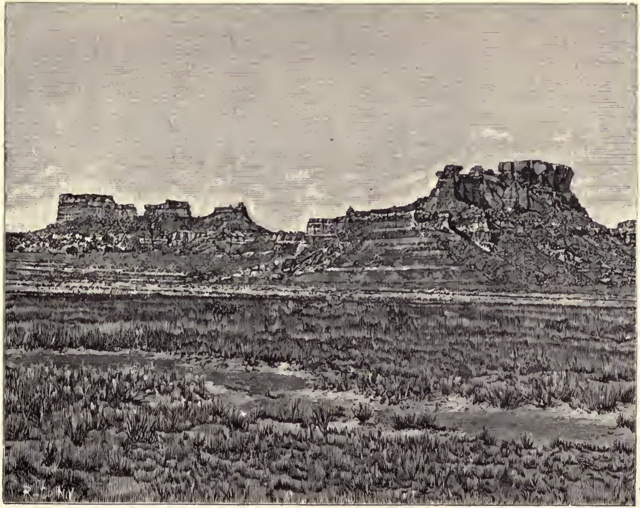
We do not find any bones of horses or oxen, or any of our domestic and useful animals. Nor do we find remains of any of our fruit-bearing trees—or berries of any kind. Instead of relics of domestic animals, we discover teeth and vertebræ of sharks of different tribes—some with tapering, lance-like teeth, some very long and slender, and some flat and lying like paving stones on the bottom of the mouth. Here too are the vertebræ of a long and snake-like reptile known as *Mosasaur*. It was probably a genuine "sea-serpent." The relics of these ancient populations are now plowed up in the cotton fields. In the region south of Selma I have seen the precious relics of curious and extraordinary shells, which we call *Rudistes*, carted together and burned for lime to whitewash log-cabins.

Mosasaur.

Rudistes.

From Texas, the great Cretaceous belt can be traced northward to Kansas, Nebraska, Minnesota, Dakota, and British America. It extends, indeed, along the east flanks of the Rocky Mountains, apparently to the Arctic Ocean. These are interesting facts. They demonstrate that there was a time when an ocean stretched from the Gulf of Mexico, through the middle of our continent, to the Arctic. These Cretaceous strata contain neither chalk nor "rotten limestone." They were not formed in a deep sea. There are vast formations of clay and shale, and at the bottom is a thick sandstone, often conglomeritic, which can be traced from Kansas to the Wahsatch Mountains—but not in one continuous sheet. All these Cretaceous strata being formed of fragments coarse or fine, are called *fragmental*. Evidently they were laid down in waters mostly shallow, and to a great extent, near

Western localities.



BUTTES AND MESAS OF THE MIDDLE CRETACEOUS OF THE PLATEAU REGION OF THE WEST. Showing the destruction of the land since the middle ages of the world.

the shore. The western Cretaceous beds contain many strata of *coal;* and this is other evidence of water so shallow as to become frequently dry land. The fine coals of Wyoming and of the Cascade Mountains in Washington are Cretaceous.

Reptiles.

These strata are the burial places of gigantic reptiles—dwellers in the sea and dwellers on the land. Some of their forms were amazingly elongate. Some attained a length of fifty to one hundred feet. I must give you the name of one of these—*Ca-mar″-o-sau′-rus.* The bones were found by Cope in Colorado. He says: "One of the vertebræ of the neck was twenty inches long and twelve inches in transverse diameter. The shoulder-blade was 5½ feet long, and the thigh-bone five. The total length of the reptile must have been 72 feet." *Am-phi-cœl′-i-as* had a thigh bone six feet in length and a body over a hundred feet long. Marsh has discovered, also, enormous reptilian bones in Kansas, and some of them are remarkably peculiar. I can not enter into details at this place; but by and by we will take a general view of the wonderful empire of reptiles.

Camarosaurus.

Amphicœlias.

The Jurassic System.

Another system, the Jurassic, underlies the Cretaceous, and we find its shales and limestones widely distributed in the far west. It was a closed record before the activities of Cretaceous life began. It incloses the memorials of huge and numerous Dinosaurian reptiles, and it was in fact from these repositories that Marsh derived the material to give interest and romance to his reptilian memoirs. Lower still lie the sandstones of the Triassic, and these are the solid tombs of the hoar forerunners of the swarming dynasty of reptiles. The Triassic is represented

Triassic System.

in the eastern states by the red and brown sandstones of North Carolina, northern New Jersey and the valley of the Connecticut. From the quarries along the Connecticut are obtained the materials for the fine brownstone fronts of New York. But these stones are rich in interest for the geologist as well as the builder. They contain the records of a daily life which opens vistas into a wonderful past where Nature is seen in one of her stages of transition from type to type. We glimpse the stalking forms of bird-like reptiles as we uncover the tracks which they made in the world's middle ages.

XXX. Lone Burials in the Coal Lands.

COAL-MEASURE FOSSILS.

The Carboniferous Age.

Still deeper in the series of strata which compose the upper portion of the earth's crust, we come to the coal-beds which were described in Talk XXVI. We wish now to consider very briefly the organic forms which the coal strata inclose. We refer here to coal strata of "Carboniferous Age," such as found in the United States east of the Rocky Mountains—excepting the Richmond and Deep River fields in Virginia and North Carolina. You will remember that we detected evidences of the vegetable origin of the coal.

The forests of time.

We conclude that it was formed from trees and herbaceous plants which had grown in the places where the coal accumulated. Generally, that ancient vegetation has become broken, comminuted, and decayed —like the forest leaves gathered in a pile and left to the influence of the weather during one or two seasons. Still, many distinct traces of the coal-plants lie bedded in the formless rubbish of the ancient forest. Pressed upon the black surfaces of the shales are innumerable traceries of fern fronds, as neatly preserved as if gathered last week from the forest and pressed by careful hands for the herbarium.

Lepidodendron.

Here too, are imbedded stems covered all over with seal-like impressions arranged in diagonally winding series. Such a tree was *Lep-i-do-den′-dron*, or "scaly tree," which grew to a height of a hundred feet with a stem twelve feet in circumference. Some of the smaller samples of these stems or branches bear a remote resemblance to the exterior of a snake; and I have had specimens brought as petrified snakes!

Sigillaria.

We find also another kind of stems, with similar seal-like impressions, but arranged in lines lengthwise of the stem and more remote from each other. This kind of tree is *Sig-il-la′-ri-a* or "seal-tree." Quite often we find the stump and roots of these trees deeper down in the sandy clay in which the tree originally grew. These are marked by scattered, deep impressions, as if made by a sharp stick. Before these were known to be the roots of *Sigillaria*, they were named *Stig-ma′-ri-a* or "mark-tree."

These were comprehensive types.

These trees were not like any species now living. They produced no flowers or fruits which could be compared with those of modern vegetation. Yet we must admit that they possessed resemblances to several different kinds of modern vegetation. When we get a fossil organism of this kind, we say it is "comprehensive." Thus, *Lepidodendron* had some structures which affiliated it with our modern "ground pine" (*Lycopodium*). In another particular it was like the Cycads of tropical regions. In some characters of the wood it was a fir or pine, while in others it was a fern. The "scars" referred to were left by the fallen fronds or leaves, and in these it also resembled ferns. We base these inferences on the study of specimens imbedded in the strata associated with the coal. All comprehensive types are primitive and low in rank. The low rank of these plants is evinced also by the absence of flowers and fruit.

Animals of these forests: Snails,

But we find here, also, the relics of once animated forms. As the coal was produced on the land; as the vegetation grew on the land, the animal remains would be those of the land. They would be air-breathers. So here they are—Snails—air-breathing mollusks. Every one has noticed the snail crawling about with his house on his back. He lives in damp retired places, and feeds on the leaves of herbs. The situation must have been sufficiently retired ten million years ago in a forest where the woodman's axe never resounded, and footstep neither of man nor beast was ever heard. We find two types of land-snails in the Coal Measures; one is like our modern genus *Helix*, and the other resembles *Pupa*.

Vertebrates—both fishes and Amphibians.

I just now intimated that these humble air-breathers were not disturbed in their retreats by man or beast. This is simply a conclusion from the fossil remains. These are the most important records of the past. We have got down to a geological horizon or level which answers to a time when the higher organisms had not appeared. So we see that they have not enjoyed an eternal existence on the earth. But we do find bones of vertebrates—backbones, skulls, limbs, and teeth. It is doubtful whether they belonged to vertebrates as high even as reptiles. The bones here seem to be those of Amphibians and Fishes. Amphibians, perhaps you understand, are reptile-shaped animals which breathe water when young and air when adult. Frogs and toads are living Amphibians without tail. Salamanders, tritons, axolotls, and fish-lizards are Amphibians with tails. But fish-lizards retain their gills throughout life. The gills are beautifully fringed, scarlet, external appendages, projecting from the neck on each side. We call them Amphibians because in their structure they so much resemble salamanders. Moreover, the axolotl, while in the elevated regions of Colorado it retains its gills permanently, in less elevated regions, absorbs them and becomes a salamander. So it happens that the permanence or absorption of the gills is not a circumstance of very great importance.

What are Amphibians?

The eggs of Amphibians are deposited and hatched in water, and the young must, therefore, be fitted with gills. All vertebrates below Amphibians have gills for a permanency; all above, have lungs for a permanency. The Amphibian is on the dividing line. In the lowest phase of its existence, it goes with fishes; in the highest phase it goes with reptiles. Its life is double. But, on the one hand, the separating line leaves the fish-lizard wholly on the aquatic side; and so, on the other it leaves the toad, in some cases, wholly on the land side; since toads sometimes rear their young without finding their way to the water.

These amphibious border-land creatures possess very great interest; and so this type of creatures fossilized in the Coal Measures, throws much light on the problem of life and organization. They are border-land creatures here in an additional sense. Contiguous to them in earlier time, lived only water-breathing fishes; next following them in time, were the air-breathing reptiles. Here you notice a certain succession in geological history which is reproduced in the life-time of the individual Amphibian. Why this parallelism? What causes it?

Some Carboniferous Amphibians.

Let us look a little more closely at some of these Coal Measure Amphibians. At Linton, Ohio, and Morris, Illinois, and at the Joggins in Nova Scotia, we find their blackened bones in greatest abundance. There is one type in which the animal was but a few inches long and had the shape and aspect of a salamander—that is, with a long tail and four limbs. Another type was similar, but was covered with scales or small bony plates. Still another had no limbs, or at most only two, and the form was long and snake-like. All this is ascertained from the ruins of skeletons found in the Coal Measure shales.

Labyrinthodont.

The most characteristic and striking of all Coal Measure types of animals was the *Lab-y-rinth′-o-dont.* In size, some were as large as an ox, and larger. The head of one species was three feet long and nearly two feet broad. The teeth of Labyrinthodonts, like those of all Amphibians, were conical, but on making a cross section, the cement and dentine—the two substances of which the tooth is composed, are found intricately infolded in a labyrinthine fashion, and hence the name of this type. In some of the Labyrinthodonts, the figure was somewhat frog-like, with hind limbs much the largest. Whether they practiced leaping we do not know. That they sometimes walked as quadrupeds is certain, for in some instances, their footprints have been preserved on the surface of sandstones. They were found, for instance, near Greensburg, Pennsylvania, and also in other American localities. The print of the hind foot is four-toed, with a thumb standing out at right angles; and the appearance is so much like that of the human hand, that when the animal was only known from its foot-prints, it was named *Cheir-o-the′-ri-um* or "hand-beast." In some Labyrinthodonts the head and some other parts of the body were covered with sculptured bony plates.

The story told by a stump.

Numerous remains of smaller Amphibians are found in Nova Scotia, in company with numerous snail shells, in the stump of an old *Sigillaria.* In the same situation were found, also, galley-worms, scorpions, and spiders. These, undoubtedly, all served as food for the Amphibians. Nearly all the forms of insect life are represented among the relics of the coal epoch—myriapods of various groups, scorpions and spiders, cockroaches, dragon-flies and other netted winged insects, and also a few beetles. But we find no remains of the highest insects—flies, butterflies, ants, wasps, and bees. Many insect forms discovered are aquatic, and undoubtedly served as food for fishes and Amphibians.

The life forms from Carboniferous limestones.

If we examine the limestones associated with other strata in the Coal Measures, especially from Ohio westward, we find them stocked with a rich and varied fauna of marine remains. Besides numerous tribes and genera of sharks and ganoid fishes, these limestones abound in corals, crinoids and various families of univalve and bivalve mollusks. Oysters, however, are almost or totally wanting; and no fish remains resembling the modern perch and whitefish occur. There is a strikingly antique aspect to these relics. The affinities are with the old forms which we shall next discover, and not with the forms of the modern world. We have here penetrated to the records of the Palæozoic Æon.

XXXI. Terrible Fishes and Their Companions.

REMAINS OF THE DEVONIAN AGE.

We now descend another stage in our examination of the strata and their contents. We come down to the Devonian System. Do not think these rocks are everywhere covered by all the later ones. In many regions they come to the surface because none of the later ones are there present. But where the Devonian strata disappear they go under the Carboniferous strata; and these go under all the newer strata which may be present. Remember, however, as before said, that a whole formation may be found missing in particular places. Strata were deposited only where sea-bottom existed. If the spot was uplifted so as to be dry land during a particular age, the formation belonging to that place can not exist. But if the spot became sea-bottom in the next age, the formation belonging there was deposited, and it does not now lie on the formation of next preceding age, but on the one before that.

So do not imagine ourselves penetrating deeper and deeper into the earth. We examine the systems of strata in the regions where they come to the surface. We may presume they continue under the newer formations to great depths; but I have the opinion that if we could follow them, they would be found gradually growing thinner.

Localities of American Devonian rocks.

Let us begin by learning where the Devonian strata occupy the surface. Nowhere in New England are they distinctly revealed. Nor in any of the Gulf States. A belt of Devonian strata stretches east and west through central and southern New York, from the Helderberg Mountains to Lake Erie. Thence it passes under Lake Erie and along both shores to the extremity of the lake, and into southeastern Michigan. Here the outcrop divides; one branch passes south, through the west center of Ohio to the Ohio River, and the other, turning north, goes under Lake Huron and along its western border to the Straits of Mackinac. This branch here bends westward and southwestward, so as to underlie the central and eastern part of Lake Michigan, and border that lake on the east. This branch goes down through Indiana to the Ohio River, at the Falls of the Ohio, lying along the eastern border of the great Coal Field of Indiana, Illinois, and Kentucky. A belt also extends from Rock Island, Illinois, northwestward by Iowa City, through the state of Iowa. This system is found also in Missouri, Kentucky, Tennessee, and other states.

There is a very useful key to the distribution of the rocks of any system. There is always a great limestone formation from the middle to the upper part

Limestone formations in various rock systems.

of the system—not always extending to the top of it —and this is generally quite conspicuous, in consequence of its solidity and prominence and great usefulness. The great central limestone mass of a system may be traced through all the windings of its outcrop, by a line of quarries and cliffs and rocky ridges. If you can say where this conspicuous central limestone belt is located, you can at once understand that the older strata of the system must lie on the side from which the limestone dips, and the newer strata must lie on the side toward which the limestone dips. Now, the great limestone mass of the Devonian is the Corniferous Limestone. Throughout the west, the overlying Hamilton formation is also a limestone, though mostly shaly at the east. The limestone mass, therefore, from Ohio westward, is Corniferous-Hamilton. Some of the points where the Devonian limestone mass rises conspicuously are the following: Syracuse, Leroy, Caledonia, Buffalo, Ingersoll, London, Sandusky, Kelly's Island, Columbus, Monroe, Alpena, Mackinac, Petoskey, Rock Island, Iowa City, Louisville. At all these points we find a limestone of nearly the same age, containing generally an abundance of marine fossils. The corals are very conspicuous, and at the Falls of the Ohio, and the head of Little Traverse Bay, appear to have been gathered together in literal reefs.

The Devonian Limestone —or Corniferous.

Fossil corals: *Acervularia.*

At Petoskey and vicinity occur those exquisite coral masses which are so extensively polished and sold to summer tourists. The masses range from the size of a hickory nut to that of a man's head; but the most common are of the size of the fist. They are shaped somewhat like cakes made in "patty pans." The upper surface is covered with six-sided cells about a quarter of an inch in diameter. A delicately crenulated wall runs around each cell. In the middle of the cell appears to be a small cylindrical wall running down along the length of the coral tube. Within this sinks a pit abruptly an eighth of an inch. Really, however, there is no true inner wall. From this apparent wall regular radial lines run to the outer wall. These are the upper edges of vertical radiating plates called *septa*, which extend the whole length of the coral tube. These forms are beautiful enough without polishing. Still, certain internal structures are by polishing, brought out with admirable clearness and beauty. For instance, if the cake is split vertically and one surface polished, you see that the space between each two *septa* is divided from end to end by delicate horizontal *dissepiments*, giving the whole polished surface the appearance of a piece of very fine woven cloth. The dealers in these specimens give them various names, some of which are quite absurd. The scientific name of this species is *A-cer-vu-la′-ri-a Da-vid-so′-ni.* The first word signifies a little hillock or cake; the second, means Davidson's; and we might call it "Davidson's coral-cake." This Davidson was a very distinguished English writer on fossil Brachiopods.

This species is found in America nowhere except in the Hamilton Group, which you will remember, runs into the Corniferous Limestone. It is found nowhere in the world in such beauty and abundance as on the south shore of Little Traverse Bay. The perfect specimens occur imbedded in soft blue clay forming beds ten or twelve inches thick between sheets of solid limestone. One can extract them with the naked hand. By Drift action these coral cakes have been transported like bowlders, from the northern part of the state all over the southern part. The same coral is found also near Iowa City and sparingly at other localities.

Favosites. There is another fine coral found on the shore of Little Traverse Bay, which has been named *Fav-o-si′-tes Al-pe-nen′-sis*, which means the "Alpena Favosite." Alpena is at the head of Thunder Bay on the east shore of the state, and this coral occurs very abundantly, also, in that region. It is shaped like a potato, roundish or oblong, and is covered all over with small cell-mouths which are nearly circular in outline, but often angular, from mutual crowding. When one of these coral potatoes is split open, and one surface polished, the tubes which run down from the surface can be beautifully seen—as also the transverse divisions or *tabulæ*, and the perforations or *pores* along the outer walls of the tubes.

Small parasitic shells and corals. It is quite wonderful to see the number of parasitic creatures which attached themselves to these and other corals. The surface of *Acervularia* was sometimes a whole world. Here is a little bivalve shell spreading its fibrous rootlets out to make itself secure (*Crania*). Here are numerous little coiled shells (*Ser′pula*) of the class of Worms. Here is a little coral consisting of a branching chain of cornet-shaped tubelets attached with the small end of each to the under side of its predecessor, near the upturned aperture (*Au-lop′-o-ra*). There are half a dozen species of these. One aggregated itself in dense, thick masses. One was beautifully small and delicate. One was extremely fine, almost like a spider's web trailing over the surface—really a distinct genus. Then we find patches an inch in diameter and less, which look like films of varnish pricked full of pin-holes at equal distances. There are coarser and finer sorts (*Fis-tu-lip′-o-ra* and *Cal-lop′-o-ra*). Another incrusting coral is like excessively fine lace (*Mon-tic-u-lip′-o-ra*). At Thunder Bay, on Partridge Point, is an amazing quantity of delicate coral structures composed mostly of little bars, slightly divergent, lying in one plane, and having cross-connections, forming a structure in some cases like woven cloth, with open meshes. One finds an amazing number of variations in details. I have picked out from this locality alone one hundred different species of these (*Fe-nes-tel′-li-dæ*) and related forms (all *Bry-o-zo′-ans*). Then, at Widder in Ontario, we find a regular bank of bivalve shells of a certain species (*Spi-rif′-e-ra mu-cro-na′-ta*) called "petrified butterflies" by the boys of the vicinity. The deposit has been cut through by the Great Western Railway. The Hamilton strata are almost everywhere well stocked with the treasures of the ancient sea; and I have observed that the small and parasitic species are more abundant than in other formations. The greater part of the good fossils found in the Drift of the northwestern states are derived from this group.

Bivalve shells—*Spirifera.*

But after all, the most astonishing relics of the Devonian Age are the fish-plates and fish-teeth found in the upper part of the System. Some years ago, a German-American clergyman came to me with fine specimens of fossils from Ohio, among which were teeth and jaws of fishes, which he had laboriously

Fishes: *Dinichthys.*

worked out of concretions found in the vicinity of Delaware, Ohio. The concretions were imbedded in shales immediately above the Hamilton formation. This was Rev. Hermann Hertzer; and he urged with much persistence that I undertake the description of the fossils. Knowing, however, that Dr. J. S. Newberry was at work on fossil fishes, I finally induced him to turn his fish-remains over to Dr. Newberry; and they now constitute a part of the palæontological collection of Columbia College. Dr. Newberry's description of these and other Ohio fishes may be found in the first volume of the Report on the Palæontology of Ohio. The two principal genera have been named *Din-ich′-thys* (terrible fish) and *As-pid-ich′-thys* (shield-fish).

The cranium of *Dinichthys* was composed of thick bony plates, strengthened with massive internal arches, and was at least two feet in length and the same in breadth. The jaws have on their margins, near the middle, a number of conical teeth soldered to the bone—not inserted in sockets—and at the front of each jaw, two strong, curved, triangular teeth, interlocking together. These teeth are shaped from the solid bony tips of the jaws. The body was protected by bony plates which on the back were large and thick. The body must have been about three feet in diameter, and its length from fifteen to twenty feet. Other fish remains of the same age, named *Aspidichthys* belonged also to a bony plated fish as large as *Dinichthys;* but its plates, as far as known, are covered with large, hemispherical, smooth, enameled tubercles.

Aspidichthys.

In the Corniferous Limestone we find also quite numerous bones and teeth of fishes. They all belong, however, to those orders which include the modern Sharks and Gar-Pikes or Ganoids. No trace of soft-scaled fishes is certainly known below the Mesozoic. Some of these sharks had enormous bayonet-like spines inserted in front of certain of their fins; and the Ganoids were armed with strong, conical teeth, and protected by bony enameled scales.

Every one has read or heard of the "Old Red Sandstone." In some parts of this Scottish formation were found fish remains which Miller, a quarryman, described years ago, in a popular and fascinating style which attracted much attention. This was one of the earliest attempts to interest the public in fossil remains—and we might even add, in any branch of geology. The renowned fishes of Scotland were mostly Placoderms, like *Dinichthys.* But no European fishes possess any greater interest than our own.

The Old Red Sandstone.

XXXII. Ancestry of the Pearly Nautilus.

SILURIAN REMAINS.

The Pearly Nautilus still lives in the deep waters of tropical seas.

Our Pearly Nautilus is no sailor. He can indeed float with all his tentacles outspread, but his normal place is on the bottom of the sea, and his normal gait is a sprawling crawl on a set of flexible, slippery tentacles, with mouth to the ground and back up.

The Pearly Nautilus represents an old dynasty.

This Nautilus is the representative of a venerable dynasty. The type is a survival from remote Palæozoic times. It perpetuates a plan of structure so ancient that its Chambered Shell lies imbedded with its contemporaries in strata of Carboniferous, Devonian, Silurian, and Cambrian age. We have turned over their remains in searching for the relics of those ages; but we have reserved to this time the mention of this diversified type. But let us first glance at the rocks which we are to explore.

Rocks of the Silurian Age and their distribution.

We shall call them Silurian. Very commonly they are known as Upper Silurian. They lie many thousand feet down from the surface, in regions where the series of strata is complete. But in other regions, they rise up to sunlight and atmosphere, with all their treasures of the ancient world embosomed in their solid mass. Here, also, is a great limestone formation—the Niagara Limestone. We find it at the Niagara River, which gives its name. It is seen along the gorge from Lewiston to the Falls. It is the top rock of this gorge, and over its brink at the Falls, the vast body of water is precipitated. The reaction of the water against the underlying shale wears it away. The limestone is undermined, and huge pieces break off from time to time. So the Falls recede; so the gorge is continued backward; so the seven-mile gorge was formed; and we have recently ascertained that during thirty-three years the recession has been three feet a year.

From the Falls eastward, this limestone continues its outcrop to Rochester and beyond. Westward and northwestward it trends toward Cape Hurd, a promontory separating Georgian Bay from Lake Huron. Continuing under the northern part of Lake Huron, it forms the southern portions of the Manitoulin Islands; it borders the northern shore of Lake Michigan; separates Bay de Noc and Green Bay from Lake Michigan, and borders the western side of the lake to Chicago, extending beyond and into northwestern Indiana. From northwestern Illinois, a belt stretches northwestward diagonally across Iowa. At Sandusky, Ohio, an area expands like a great spatula over parts of Ohio, Indiana, and Kentucky, stretching to the southern part of Kentucky. But through the broadest part of this spatula is a great oval perforation, within which are embraced Cincinnati, Richmond (Ind.), Madison, Frankfort, and Lexington (Ky.). On the great Silurian mass of limestone are situated Rochester, Niagara Falls, Milwaukee, Chicago, Joliet, Huntington (Ind.), Sandusky. Next below the *Niagara Limestone* lies the *Niagara Shale*, and then the *Clinton* formation; but both of these become limestones at the west, and unite with the Niagara limestone to augment the central mass. Next above the Niagara limestone comes the Salina formation, of shales, clays, and marly limestones—a formation which, as we stated in Talk XXIII., yields the country a vast amount of salt and gypsum. At the bottom of the Silurian are found two fragmental formations, the *Oneida Conglomerate* and the *Medina Sandstone* above it—proclaiming intelligibly that the waters were disturbed when the Conglomerate was deposited, more quiet when the materials of the sandstone were laid down, and still quieter when the fine sediments settled down which formed the Clinton marls and the Niagara shale. Please bear in mind this law

"Cycle of sedimentation."

of the succession of different kinds of sediments.

Silurian fossils: Now let us examine the contents of these Silurian strata. In the lowest beds—the Oneida Conglomerate—nothing of much importance has been found. This does not surprise us, for shells and corals must have been ground to powder, had they been mingled with the rolling stones of which that formation is composed. The Medina sandstone was fine enough to allow the accumulation of some organic remains. We find small heaps of petrified seaweeds. One sort

Seaweed. is regularly jointed, and presents a somewhat elegant appearance (*Ar-throph′-y-cus*). We are much interested to be able to discover which way the currents set over the soft sand. In New York it is common to find a sandstone surface with a little shell lying, convex side up, and beyond it a train or drift of sand a few inches long, and diminishing to a point. How similar were the conditions of the sandy beach then and now! How surprising that a little ridge of soft sand formed millions of years ago, should have been so carefully preserved through all the storms and revolutions of the world to our day!

Chambered shells. It is in the limestones, and especially the *Niagara Limestone*, that we find the relics of the ancestors of the Pearly Nautilus. It may seem strange that most of them are straight rather than coiled. But their structures are the same, and the coiling is a

Orthoceras. circumstance. These straight nautiloid shells we call Or-tho-cer′-a-tites (the technical name of the genus being *Or-thoc′-e-ras* or "straight horn"). Like Nautilus, the shell is divided by cross partitions or *septa* at frequent intervals. Like Nautilus, it is a gradually tapering tube. Like Nautilus, there is near the center of each septum, a small perforation from which leads a little tube to the next septum, and thus through all the septa and intervening *chambers.* This tube is the *siphuncle.* Like Nautilus, each septum is simply and plainly concave with the concavity turned toward the larger end of the shell. As in Nautilus, the last chamber is deep, and undoubtedly this was the portion to which the animal was confined. If Nautilus should be uncoiled, it would be precisely an *Orthoceras.* We can think back the wide-tentacled bodies which rested in the outer chamber. We can see them, in thought, spreading their strong arms, glaring with their great glassy eyes, pursuing with hungry ferocity their prey, tearing with their lance-like mandibles, and feeding with the gusto and relish of a true carnivore.

We notice among the dead chambered shells some variations. In form, a few are slightly bent, while most are straight. In some, the traverse section is oval, while generally, it is almost circular. In some, the place of the siphuncle, instead of being central, is a little distance away from the center—but not in the margin. We notice, also, that the septum is sometimes undulate around the margin, instead of plane. Thus nature shows a susceptibility to vary. Her forms are fashioned after fundamental plans, but not all cast in one mould. For some reason which may be inscrutable, she seems always playing off from the main path, with a sense of freedom rather than necessity.

Right here, in the midst of these ancient Orthoceratites, are the relics of organisms decidedly divergent. Here are coiled chambered shells which almost any person would identify with Nautilus. They really have all the essential characters of Nautilus; but you will notice that they are not closely coiled; we do not find each whorl overlapping and concealing all the others; and the last whorl is even a little separated from the preceding one (*Lit-u-i′-tes*). Many others are coiled, but somewhat loosely, and the siphuncle is one side of the center—sometimes close to the outer margin (*Gy-roc′-e-ras*). Still others are curved enough to form one whorl, but not properly coiled, and the siphuncle is close to the outer margin (*Cyr-toc′-e-ras*). But we have not time to trace all the varieties of the type of chambered shells even among the Silurian limestones.

Lituites.

Gyroceras.

Cyrtoceras.

In strolling through the quarries excavated in the Niagara limestone—in the suburbs of Chicago, for instance, or at Joliet or Waukesha—our attention is constantly arrested by the remains of shells, corals, and crinoids. The bivalve shells are chiefly *Brach′-i-o-pods.*[1] They are lower in rank than clams and river mussels. They may always be known by having the beak and hinge in the center of the valve, with the valves presenting the same slope and curvature each way from the beak. They may also be known by having one valve more swollen than the other. Many also, have a deep depression (*Sinus*) along one valve from the beak to the opposite margin, and a corresponding elevation (*Fold*) in the opposite valve. Brachiopods are now nearly extinct. The univalve shells are mostly *Gas′-ter-o-pods.* These are higher in rank than clams and mussels.

Brachiopods.

Gasteropods.

[1]Many zoologists regard the Brachiopods as worms—not mollusks. F. S.

The Crinoids were plant-like forms (*Zo′-o-phytes*) but strictly animals in nature. The most common kinds were rooted to the muddy sea-bottom. The old roots are found going down into the clay like the roots of an oak. Above the root rises a stony stem, ten or fifteen inches high, and from an eighth to half an inch in diameter. This is simply a pile of little button-like discs, each one with a hole through the center, and some radial striæ on the flat sides. So there is a perforation through the whole length of the stem. Sometimes several of the *segments* remain attached together; but generally they are separated and scattered through the rock. In some European countries they have long been known as "St. Cuthbert's beads." We find them in great abundance in the Drift of the northwestern states. At the top of the stem we find a little urn composed of many stony plates nicely joined together by their edges. The urn has a cover similarly formed. Most of these bodies are found disjointed in the rocks; but there is one which seems to have held together very firmly (*Car-y-oc′-ri-nus*) and is found in the Niagara strata almost everywhere. The external surfaces of the plates of the cup are elaborately chased and embossed; but this I must tell you is not an armed and rooted crinoid; it is a *Cystid*, having no arms and with a tail-like stem. In the true crinoids we find a row of arms—generally ten—rising from the border of the urn or cup; and these often branch or give off a delicate fringe. The arm and its subdivisions are composed of flattened stony plates or pieces joined together according to the general plan of the animal.

Crinoids.

Caryocrinus.

We thus see that when nature adopts a particular method for the construction of one part of an animal, she pursues faithfully the same method in the formation of all the parts. Thus it appears that the works of nature are formed according to *plans*. Anything which is a plan has been thought out. The plans of nature are the expressions of mind.

XXXIII. The King Crab's Grandfather and Other Grandfathers.

CAMBRIAN FOSSILS.

The King Crab.

One who strolls along the coast of New England or the contiguous islands will notice many things "cast up by the sea," but one of the most interesting is the King Crab, *Lim'-u-lus Pol-y-phe-mus*. It seems to be essentially a wide basin with a small and spike-like handle. It is in fact employed by the fisherman for removing water from his boat. The same objects are strewn along the beach all the way to Charleston. A few years ago, Professor A. S. Packard determined to make the acquaintance of the King Crab's family and study his pedigree. He studied the King Crab's eggs. He studied them seriously and thoroughly by the aid of microscopes. More strictly speaking, he studied the progressive development of the embryo within the egg. He believed—for many others so believe—that the several embryonic stages are pictures of the ancestors of the animal. He believed that the first trace of an embryonic form would be a picture of the remotest ancestor—either in its embryonic or adult stage ; and that the phases presented by

Its embryology.

the later stages of the embryo would be pictures of later ancestors.

Professor Packard discovered that the earlier embryo of the King Crab shows a striking resemblance to the early stages of soft-shelled shrimps and low fresh water crustaceans now living; and that in a later stage, the embryo of the King Crab was strikingly like certain *Tril′obites* found fossil in the Cambrian strata. There are at least three genera of such Trilobites—*Ag-nos′-tus* and *Sa′-o* from the bottom of the Cambrian, and *Tri-nu′-cle-us* from the Upper Cambrian. Now, the meaning of this is, according to some, that our King Crab is descended from the same primeval stock as these Trilobites; and that all the Trilobites were descended from that stock. This, in fact, means evolution, and that all the crustacea have descended from the same primitive stock.

Individual embryology repeats race history.

But what are *Crustaceans?* Aquatic animals covered by a crust which is composed of a series of segments or rings joined by their edges; and having more than eight feet. Of these, Lobsters and Crawfishes are examples. And what are those Trilobites? They are crustaceans in which the body is divided lengthwise by two grooves, into three lobes—the axis running along the middle, and a lateral lobe each side. The Trilobites were very ancient animals. I say "were," because the last of them perished millions of years ago, during the progress of the Carboniferous Age. Here are the tombs of their remotest ancestors. Here lie their forms imbedded in these primordial sandstones and slates.

Crustacea.

Trilobites.

Let me explain about these sandstones and slates. At Potsdam, in northern New York, and throughout

Potsdam Sandstone. that vicinity, a gray sandstone lies at the surface—the same as referred to in Talk XIX. It stretches across the St. Lawrence River, and northeastward along its valley. It encircles the Adirondack highlands. This is the Potsdam Sandstone. Westward it stretches through Canada to the Sault Ste. Marie, and along the south shore of Lake Superior to Keweenaw Point. The "Pictured Rocks" are part of it. Southward from this shore it disappears under the Trenton Limestone. It is the Potsdam Sandstone

Its fossils. which forms the lower portion of the high cliffs along the Upper Mississippi River. It is in this sandstone that multitudes of these ancestral Trilobites lie packed away.

Trilobites. They have had a hard time however. They are all in pieces, and it is difficult to get sufficient pieces together to describe any one of the species. The sands from which this sandstone was formed must have beaten to and fro in shallow water, or along some beach for many years. These Trilobites are but a few inches in length.

Besides Trilobites, we find in the Potsdam Sandstone, many remains of little bivalve shells called

Lingula. *Lin′gula.* This is a genus of Brachiopods. The name signifies a "little tongue," referring to the shape. This is a remarkable genus, for it has been in existence on the earth from the epoch of the Potsdam Sandstone to the present. In every formation are some species of *Lingula;* and living species may be found along our Atlantic coast, clinging by their fleshy peduncles to the wharves and other supports. Another remarkable fact about *Lingula* is this: Its shell is composed largely of *bony* substance—phosphate of lime—while the shells of ordinary mollusks are composed of *stony* substance—carbonate of lime; and this peculiarity of constitution has clung to this little type through all the ages.

Symmetry and non-symmetry in bivalve shells.

It is a peculiarity of Brachiopods to have the two valves unequal; one is more convex than the other. The more convex valve has also the more projecting beak. But each is symmetrical taken by itself. That is, if you lay it down on the side, you see the beak in the middle, and on each side of it, the outline of the valve presents the same shape and curve. Now, the clam and river mussel are quite different. In these, the two valves are equally convex; and, if you consider one valve by itself, it is *not* symmetrical. That is, if you lay a valve down on its side, you find the beak nearer one end; and the slope of the shell-outline is *not* the same on each side of the beak. Shells of this sort belong to the class *La-mel'-li-branchs.* All the difference in the forms of these two classes arises from the position of the animal in the shell. In the Lamellibranchs, one valve is on the right side and the other on the left. So the principle of *bilateral symmetry* makes one valve the counterpart of the other. In the Brachiopods, one valve is on the back and the other over the abdomen. So the principle of bilateral symmetry does not operate between the two valves; but the right and left sides of each valve separately are symmetrically developed. By bilateral symmetry we mean the law or principle which causes every feature of the right side of an animal to have a corresponding feature on the left side. This principle runs through the whole animal kingdom. Even among the starfishes, crinoids, corals, or other so-called "radiate" animals, we can draw a line which will separate right and left sides. Try it in a starfish.

Other Cambrian rocks:

The Potsdam Sandstone from northern New York to Minnesota appears to be the lowest formation above the Eozoic crystalline rocks. The copper-bearing rocks are older, but it is not yet decided whether we should regard them as embraced in the Palæozoic System or not. There is also, in Wisconsin and Minnesota, a massive quartzite formation underneath the Potsdam Sandstone; but as it is not fully proved to contain any fossils, we are not certain whether to call it Eozoic or not. But in Vermont, in eastern Massachusetts, and in New Brunswick are slates which underlie the Potsdam and contain fossils. ("Acadian" or "St. John" Group.) Some of these were Trilobites ten to twenty inches long.

their fossils.

Cambrian life varied and well developed.

Down in these lowest Palæozoic strata we find also, other remains of animal types. Here, for instance, are "chambered shells"—the grandfathers of those described in the last Talk. We find here *Or-thoc′-e-ras*, as well as some marked deviations from it. Here are the oldest examples known of this type. Here, we might say, was its first introduction to the world; and we might begin to query how it came here. We should be inclined to think it was an *abrupt* introduction, without predecessors, gradually more and more simple as we should trace them into remote ages. If an abrupt introduction, it was *not* an evolution from some older form, because evolution proceeds by gradual transitions. Such is the conclusion of some scientific men; and if we were obliged to form a conclusion on the whole question from the facts connected with the first appearance of chambered shells, I think we should all say they did not appear according to the method of evolution. We must be candid, however, and consider all the circumstances. We only wish to ascertain how the facts were—not to make ourselves think them different from the reality. Now we know full well that the rocks older than the Cambrian have been subjected to such actions since they were deposited as ocean-sediments, that their aspect is totally transformed. We may feel confident that if any shells or corals had been originally inclosed in the sediments, they would have been destroyed. Especially would carbonate of lime have disappeared. Therefore, we are not certain that no chambered shells existed before the Cambrian. They may have existed. They may have been so formed and constituted as to show that the Cambrian species were *not* suddenly introduced, but made their appearance in such graduated succession as evolution implies. Here, at least, is a possibility which prevents us from feeling confident that the Cambrian Orthocer′atites were introduced by a sudden creation.

Does it disprove evolution?

In these lowest Cambrian strata are, also, still other forms. Here we find *Gas′-ter-o-pods*—univalve shells coiled up. These, too, are well advanced from any humble beginning of Gasteropods—in case they began in a humble way. The same queries arise as in the case of chambered shells. Now, to recapitulate, we find in these lowest, fossil-bearing strata, remains of several types of animals appearing to our knowledge for the first time, but all well advanced beyond the lowest grades of the orders to which they belong. Here, in the very lowest strata, are Trilobites; *Lin-*

Cambrian life types.

Gasteropods,

Crustacea,

Brachiopods, etc.

gula and some related genera of Brachiopods, as well as *Or′-this*, quite a different genus, and perhaps Worms. At the very dawn of the Cambrian Age numerous types well advanced in rank, suddenly appeared. You will notice, however, that several important types of animals were absent. Here were no corals, no crinoids, no Bryozoans, no Lamellibranchs.

Rocks of upper Cambrian and lowest Silurian.

So far we have confined our attention to the lowest group of the Cambrian rocks, composed of the Acadian or St. John formation and the Potsdam Sandstones. Next above the Potsdam is the Calciferous formation. It is very conspicuous along the bluffs of the Upper Mississippi, where it forms generally the upper half. Like the Potsdam Sandstone it is buffish in color, and disposed to crumble to pieces. In the northwest it is known as the Lower Magnesian Limestone. It contains the lead mines of Missouri (Talk XXI.). Above this comes the St. Peters Sandstone, white, clean, and destitute of fossils; but this is not known at the east. Next is the Trenton Group, which contains the great Trenton Limestone. Like the other great central limestone masses (Niagara, Corniferous, Lower Carboniferous) this forms a conspicuous landmark across the country, and constitutes the rich repository of the remains of the animals which dwelt in the Upper Cambrian ocean. This limestone mass forms the bluffs at St. Paul and Minneapolis; comes up on the north side of the Manitoulin Islands; stretches westward across Ste. Mary's River, and running through the Upper Peninsula of Michigan, goes down along the west side of Green Bay, into southern Wisconsin, northern Illinois, and northeastern Iowa, holding the lead

Calciferous formation or Lower Magnesian Limestone.

St. Peters Sandstone.

Trenton Limestone.

mines in these three states; outcrops over a large area about Cincinnati, extending to Madison and Richmond, Indiana, and Frankfort and Lexington, Kentucky; outcrops again at Nashville and surrounding region; stretches through central New York to Watertown, and across the St. Lawrence to Georgian Bay, stretching along its eastern shore and emerging again at the Manitoulin Islands. Everywhere, this group of limestones and shaly limestones is wonderfully rich in the remains of creatures which swarmed in the seas of the twilight ages of the world.

XXXIV. Earth's Deepest Graves.

THE EOZOIC ANIMAL.

We are down now, on the bottom rocks of the earth's crust. This is the home of the vitrified and crystalline bowlders which overstrew the surface. There are fifty thousand feet of later strata resting above these rocks in regions where the series is complete. But here, and over extensive regions, the deep Eozoic beds have been arched up to the surface, and no newer rocks have ever formed over them; or if they were, have subsequently been worn away. Let us see what has been found out.

Eozoic rocks were at first sediments.

In the first place, deep as we have ever penetrated into these Eozoic rocks, they all retain some traces of stratification. In most cases, the stratification is very obscure; in many cases, it is quite obliterated, but rocks of this sort furnish some evidence of their original bedding. Sometimes we can trace them into continuity with stratified rocks. In all cases the crystals which they contain, and the crystalline condition of the rocks indicate solidification from a state of solution or softening which requires the presence of water. Grant us water and heat, and the present condition would be produced from ordinary ocean sediments. We must look upon all these rocks as ocean-born.[1] Hard and crystalline as they now are, we must think of them as at one time in the condition of ocean-slime. These rocky beds have been successively ocean-bottom. These rocks too, have successively rested as sediments upon an ocean-bottom preëxisting. There must have been an ocean-bottom for the very first sediments to rest on. Let us remember this.

Kinds of rocks.

In the next place, the very oldest rocks known are granites, syenites, gneisses, and hornblendic schists. Not having seen the bottom of this series, we cannot state its thickness. At a higher level, have been found, in the northwest, conglomerates, quartzites, and marble, all together attaining a thickness of one thousand to six thousand feet. Then come various schistose rocks and diorites; and about here occur great beds of hæmatite or iron ore. This series is four thousand or five thousand feet thick. Next above are black slates and schists, often ferruginous, and other diorites, making about twenty-six hundred feet more. Next, are five thousand feet of mica schists, and finally, several hundred feet of granite and gneiss and kindred rocks. These rocks altogether aggregate a thickness not exceeding twenty-five thousand

[1] The rocks here called Eozoic are now a subject of much study, and re-classification of many appears necessary and new views are arising as to their origin. F. S.

feet. But this may not embrace all. In Canada, Sir William Logan computed the Eozoic rocks as fifty thousand feet thick, and that estimate is generally adopted. The thing of chief importance here, is to know that the thickness is great, and the rocks are all crystalline.

Why fossils are absent or rare.

Now, we explore these old rocks from bottom to top, and scarcely find a trace of organic remains. Who could expect fossil shells or corals imbedded in hard rocks consisting of fragments of crystals and grains of quartz, feldspar, mica, and hornblende? The nature of the rock proclaims changes in constitution which must have dissolved or destroyed all relics of the hard parts of animals. Here must be some lost chapters of the history of life—the first chapters in the volume. It is like the loss of the Alexandrian Library. Could the records of those earliest ages be restored, how many outstanding doubts and irresolvable problems would be disposed of! But since the records are wanting we must proceed—not as if they never existed, but by some rational process to reproduce them. From the bottom of the Cambrian up, we have learned well the general tenor of the history of life. We must project that tenor backward toward a lost beginning.

The discovery of *Eozoon.*

But thanks to the Canadian geologists, the first chapters are *not completely* lost. We have a fragment of a page; and we know about where in the book it belonged. In the lower part of this vast series of rocks are in Canada three great beds of marble or crystalline limestone. In the third, or upper one, occur some forms which appear to be organic. These were brought to the notice of the scientific world in 1856. They have been studied by mineralogists, palæontologists, and chemists. They have been subjected to most searching microscopic study. The general opinion is that they are organic remains; and they have by general consent been referred to a group of organisms of low grade called *Fo-ram-i-nif′-e-ra*—the same as that to which Globigeri′na belongs (Talk X.). A few mineralogists regard them as inorganic.[1] These forms have been obtained at several localities in Canada, as also, in New York, near Troy, in Ireland, in Bohemia, and elsewhere. They contain certain features which, in my opinion, could not be regarded as of mineral origin. On the contrary, they closely resemble some structures found in certain Foraminifera.

Structure of *Eozoon.*

In the mass, we notice a concentric or laminated structure, as if the organism were formed of numerous layers wrapped, one about another. These layers, in most cases, consist alternately of serpentine and carbonate of lime. The serpentine, as is believed, occupies the place of the fleshy part of the animal, while the carbonate of lime is its skeleton; and we may speak of it as coral, for in many respects it was like coral, though produced by an animal much lower in rank than the polyps which secrete true coral. When we prepare extremely thin slices of this skeleton, some minute structures are seen under the microscope, which convince us of their animal nature. The name of this creature is *E-o-zo′-on can-a-den′-se* or the "Dawn Animal of Canada."

Now, if we understand correctly the nature of this

[1] The number of opponents to the organic nature of Eozoön increases. F. S.

animal, it was related to *A-mœ'-ba*, a minute soft creature often found in stagnant fresh waters. Those who use the microscope to search for animalcules may sometimes discover in the field of view, a little shapeless lump which seems like a particle of dirt, except that it is partially transparent. While wishing it out of the way, it is seen to move. On one side is extended a little arm or tentacle; this is then withdrawn. But suddenly one or two others are protruded; and we find that the creature generally keeps two or three tentacles extended. But one or all may be very capriciously withdrawn; and when withdrawn, it is impossible to trace any outline of them. The tentacles melt into the general substance of the body. In the interior can be seen what is called a "nucleus" and a "contractile vesicle."

Nature of *Eozoon*.

Attending carefully to the movements of *Amœba*, we discover that they have an end in view. The tentacles are extended in search of food. See! its arm is wound about a minute animalcule; it holds it, but now, it does not convey it to the mouth. Where is the mouth? In truth, there is none. The arm is absorbed—animalcule and all. It disappears in the common mass of jelly, and the animalcule is seen within it. So this creature feeds. It gets around its food successfully; but it simply pours itself over it. What an amazing simplicity of structure is here! Indeed, there is no structure. Whenever the animal takes breakfast, it extemporizes an arm for seizing it. Whenever it eats, a mouth is extemporized for admission of food, and a stomach is extemporized for receiving and digesting it. From all the ailments of hands, mouth, teeth, and stomach this animal is happily free. Exempt from headache, sore eyes, ringing ears, and heart-flutterings, it still exercises all the functions requisite to make it an animal.

And this modern creature is the representative of *Eozoön*. But *Eozoön* could not be placed defenseless in the sea. A little lump of jelly would be swept into annihilation by the force of the waves. *Eozoön*, however planted, held fast to its support, and immediately secreted a strong roof over him for protection. A thousand little holes through the roof allowed threads of its gelatinous substance to be protruded. These coalesced in a common film which spread over the roof like a coating of tar. This was unprotected, and a second and higher roof was built. The structure was now two stories high. Through the upper roof innumerable minute perforations allowed the jelly of the second story to be protruded in fine threads, and these in turn coalesced, and a third roof was secreted. Thus the process continued, and the structure became many stories high. Meantime other individuals were planted by this, or near this, and by and by, they were so enlarged that they grew together, and grew as one animal. So hundreds and thousands of animals grew together and continued to grow and enlarge the structure during, probably a thousand years.

As time passed on, this organism grew old and effete. The life-time of its species was drawing to a close. It was destined to be replaced by something better suited to the improved circumstances of the world. All the time, however, the sediments had been gathering about the bases of the rising reefmass. The eozoönal reef-structures were buried and forgotten—buried thousands of feet deep—buried in sea-sediments which became stone. Then the æons of the world continued to roll by. In the Age of Mind, a marble edifice was demanded to meet some want of civilization. The primeval tomb was opened by the quarryman, and there rested the relics of the first inhabitant of our globe. It is *that* of which we have been speaking.

XXXV. An Earlier Beginning.

INTIMATIONS OF A FIERY ÆON.

We are searching for a beginning. We have followed down the succession of formations to what seems a foundation; but we perceive this must rest on something which already existed; it can not be the beginning. It is an ocean-born mass of sediments. The ocean preceded the sediments. Something for the ocean to rest on preceded the ocean; what was that? Not something born of ocean. What existed before ocean and ocean sediments?

How sediments were changed into Eozoic rocks.

You have just seen (Talk XXXIV.) that the deepest rocks are hard and crystalline. We have concluded that their condition has probably resulted largely from the action of water and heat. Water alone would not dissolve the substances of which these crystals are composed; but heated water would be much more efficient. Moreover, the addition of alkali to the heated water would enable it to dissolve nearly all the substances in these lower rocks. However mud-like or sandy the sediments originally were, Hot alkaline waters probably an agent.

heated alkaline waters would dissolve them; and then, if the solution were allowed to cool, the various constituents would enter into such combinations as suited their several affinities for each other. So the resulting state of the materials would be extremely different from that of the original sediments.

Source of the heat.

But in this connection, the important point is the evidence of ancient heat universally extended. I do not suppose the metamorphism of the rocks has taken place at the surface. The heat engaged seems to have been interior heat. It was shut in and retained for ages by overlying masses of strata. And yet I doubt if all metamorphic regions now exposed have been formerly covered. Much yet remains to be learned about metamorphism.

The wastage of heat from a cooling earth.

That the heat was internal is evinced by many proofs of the continued existence of internal heat. You will recall the facts cited in Talk XVII. You will recall the phenomena of geysers and hot springs (Talk XIV.). You will remember that lavas from volcanoes come up from some heated interior (Talk XV.). Your thoughts will again glance over the thousands of square miles of surface covered by lavas which issued through fissures in the age preceding the present (Talk XVI.). You will be vividly impressed with the conviction that intense, fusing heat exists within the earth; and since all heat tends to waste away, you will conclude that the earth's surface temperature was much higher some millions of years ago than it is at present. The wastage of the earth's heat is proved by actual observation. Science has measured the amount of heat which comes to the earth annually—that is, the amount on each square yard—and has also measured the amount which escapes annually; and it is thus shown that the wastage exceeds the receipts. The earth is growing cold. This great fact is established by experiment, by observation on the escape of heat from within, and by the records of an ancient higher temperature than now exists at the surface.

Trace backward the history of a cooling globe.

Cooling off! That disclosure puts our minds in a new attitude toward the world's history. We have to contemplate the earth as a *cooling globe*. That points our thoughts backward, along a *progress of cooling*. Not the slightest evidence exists that the laws of heat are different under our observation, from the laws which controlled the cooling of the ancient world. We know what they are, and what they were. It is as safe to base backward calculations on them as to base forward calculations on the planetary movements which bring conjunctions and eclipses.

An oceanless globe;

This is the way reasoning leads us:—Following the course of cooling backward, we arrive at a time such that water could not have existed on the earth. All the water of the earth must have been vapor or gas suspended in the atmosphere. At a time when no ocean had existed, no ocean-sediments had been deposited, all those rocks which have resulted from marine sedimentation were yet non-existent. The earth had probably a solid surface of some kind; but to emit heat sufficient to hold all the water of the world in an uncondensed state, the temperature of the surface must have been high—perhaps a glowing temperature.

A molten world;

But even here we are in the midst of a cooling process. Why not? Who can affirm that the world began to exist as a red-hot body? You know that red-hot matter may be made white-hot; and then by increase of heat, may be rendered liquid. We must trace this history back to a *molten* world.

A world of vapor.

Is there now any ground for refusing to trace the history farther back? This is a *cooling* process. There is no certain beginning for a cooling process except in a temperature so high that the heated matter exists as a mere vapor, or perhaps gas. There is no known remoter *condition* of matter, though we may conceive the temperature indefinitely high. It is, let us say, the remotest *condition* which we seek. Now all terrestrial substances are capable not only of fusion, but of volatilization. Iron and the other metals have been reduced to vapor. So, by reversing conditions, all gases may be liquefied and then consolidated. Carbonic acid, oxygen, nitrogen, chlorine, have been made solid. The form under which matter exists is a circumstance depending on temperature and pressure. There is no inherent improbability that all the matter of the world was once so heated as to exist in the form of vapor, or even of gas. Before our eyes worlds are existing in those states.

We should distinguish between vapor and gas. Gas is dry, like atmospheric air—like steam in the boiler; vapor is composed of minute liquid particles floating in a gaseous medium—like the cloud of steam condensed in the air after escaping from the boiler. There may be mineral vapors as well as igneous vapors. Most mineral vapors must be intensely

Fire-mist.

heated. We may call such a vapor "fire-mist." If the earth were vaporized by heat, to what limits in space would the vapor extend? We must think of that. If the earth was ever a fire-mist globe its dimensions were vastly greater than at present.

There is another thought to be mentioned here. The earth is only one of a system of worlds, and there is good reason for believing that any remote origin which we can establish for the earth must represent the remote origin of the other planets. In saying they are one system, I refer to their common motions about one sun; to the common elliptic form of their orbits; to the fact that all move from west to east; that all revolve nearly in one plane; that, so far as ascertained, they all rotate on their axes; and all rotate from west to east; that the forms and movements of all, and of all the satellites, are conformed to one set of laws, and that all we know of other planets, points to a fundamental correspondence and identity between them.

The solar system.

This conclusion vastly enlarges our field. We must think of each of the planets heated up to a fire-mist condition. It is easier to think the sun also heated to such condition, since he is at present not so far removed from it as the planets. Now, when all these bodies were in that heated condition which maintained them in a fire-mist state, the whole space of the solar system must have been filled with fire-mist. Notice, that I do not say it was fire-mist of any specified density. The density of vapor depends on the proximity of the liquid floating particles, to each other. There may have been a diffused very thin gas also, in which the liquid particles floated. Still, I do not conceive such gas necessary. These particles —some of which may even have been solid—would

The planets once fire-mist.

have weight smaller than imagination can conceive. They were not particles like those of our clouds, influenced by the powerful attraction of a vast globe of matter not half a dozen miles distant, and hence needing some buoyant support. These fire-mist, and perhaps solid, particles were attracted only by each other, and by the great common aggregation of particles. For the particles in the neighborhood of the center of the aggregation, the attraction would be nearly equal in all directions. For particles millions of miles away, an excess of attraction toward the center would be felt; but the force would be inconceivably small. So the mist particles were practically suspended in space and required no gaseous support. The cooling history can be traced no farther back. Such, probably, was its beginning. But I do not assume that the matter of our system was originated in this state. We may be able to trace out some remoter antecedents; but if that can not be done, I am perfectly prepared to admit that matter may have entered existence as a fire-mist.

Now, another thought is in every reader's mind. This point has been reached as a beginning of a history of cooling.

Natural evolution of the physical world need not abolish—

From this point a *natural* process of cooling brings to pass all the events in our system's physical history —all the events in our world's history. We are proposing to show this, and trace the evolution in its general outlines.

Suppose we call the fire-mist the absolute beginning; there are certainly three things which are *not* fire-mist, and require explanation infinitely more than a fire-mist condition of matter. Without these three things, there would never be a cooling history. These things are: 1. MATTER—regardless of its condition. 2. FORCE—and that in its various forms. 3. METHOD—or every thing would be plunged in chaos, and forever remain there. These things imply Power, Intelligence, Self-determination. Where self-determination is present, there is Personality. While the origination of Matter, Force, and Method remains, there is still need of a Creator

Matter, Force, Method.

XXXVI. GATHERING WORLD STUFF.

WANDERING GERMS OF WORLDS.

Comets.

COMETS are facts of observation; there is no mistake as to the real existence of such bodies, whatever they be. They always excite our admiration. They are full of wonder. They come from the unsearchable depths of space, and after shining in our heavens a few weeks disappear in the unsearchable depths. What is their origin? What their end? Think of the approach of one of these mysterious messengers from the infinite. Before discernible to unaided eyes, the astronomer with his instrument detects it as a faint luminosity just appeared. For weeks he watches its changes. Nightly it grows brighter. It is approaching; it will arrive. Like the head-light of a locomotive seen at first as a luminous point in the far distance, over some miles of track, gradually growing brighter—so comes the head-light of a train of cosmical matter; so grows its luminosity; with such a stunning demonstration of physical power it rushes past us, and sinks into infinite distance in another quarter of the heavens. I confess it is impossible to contemplate all this without a feeling of awe.

Would that the mystery of the comet were once unfolded to us! It tantalizes us by its near approach and its undiminished inscrutableness. But, thanks to intelligence — thanks to the spirit of science— thanks to that beneficent constitution of the universe by which it gives up its secrets one by one, to the demands of intelligent inquiry, we have found out something. We have seen comets torn to pieces by the power of attraction—without a collision—by the attractions of the satellites of Jupiter. This was Bi-e′-la's [Be-a′la] comet, and each fragment thenceforward pursued its separate path. We have seen comets so shattered and disintegrated by the pulls and strains to which they were subjected in our system—in making their circuit about our sun, in getting through the entanglements of Jupiter's and Saturn's attractions, that they appeared literally to be going to pieces and dividing up their remains among the planetary masses of the system.

Comets are trains of meteors.

The comet, in short, appears to be essentially a train of stones flying with three thousand times the velocity of the railroad "express." The smaller stones more resisted than the larger ones, by other matter disseminated through space, slacken their motion slightly, and are struck by the larger stones with velocities exceeding that of a cannon ball. Light is disengaged, as when the cannon ball strikes the iron target, and thus the whole cometary train is lighted up. The nearer it approaches the powerfully attractive bodies of our system, the greater these disturbances become—the intenser the luminosity—the more extended and the more widened the train of finer materials. But do not think this train of stones is the so-called luminous "tail" of the comet. The tail always turns away from the sun; the dark train follows in the path of the comet. The cause of the tail is yet a mystery. It may be a smoke of luminous particles driven off by the intense heat of the sun.

Courses of comets. The comets all have to make a journey around the sun. Some of them remain in our system and subject themselves to the laws of the planetary family; but others can not be induced to stay; they rush onward with such velocity that all the power of the sun and planets is not sufficient to stop them. They launch out from our remotest shore, on the limitless ocean of space which stretches to the shores of other systems, and stretches beyond, farther than imagination can picture. But the comet which becomes domiciled in our system seems gradually to undergo disintegration, and by and by its borders are spread so far as to brush the atmosphere of some planet when passing near it. Our atmosphere has been thus pierced by the outlying constituents of certain cometary trains. Sometimes countless thousands of them shoot through the air. These missiles move with a velocity as high as twenty to forty miles a second, and the friction and condensation resulting develop sufficient heat to render the missile luminous.

Meteors. We call it a meteor. We had not contemplated the meteor as a burning fragment of an old decayed comet. But some of our most splendid meteoric displays have resulted from clouds of meteoroidal bodies which have been quite certainly identified with recognized comets. At certain regular intervals, on or about the sixteenth of November, occurs a celebrated meteoric shower which comes from a meteoroidal train or cloud that has been identified with Tempel's comet—the first one observed in 1866. Another meteoric shower occurring annually about the tenth of August has been identified with the third comet of 1862. Also, the shower which occurs on the twenty-seventh of November, and was particularly conspicuous in 1885, has been connected with Biela's comet, first observed in 1826. This is the comet which was parted. The fragments have not appeared to view during several revolutions; and there is reason to think nothing remains but dark trains of stones.

Radiant points.

So much is pretty well settled. There are numerous other trains of meteoroidal matters which we have reason to regard as worn out comets. In fact, since we have meteoric displays on nearly every night of the year, must there not be as many meteoroidal trains as there are distinct radiant points from which the meteors shoot? One train, you understand, might touch our atmosphere on one side and another on a different side. To our eyes, the motions of the ignited meteors would be in all directions from the region of contact. That region would be projected on some constellation, and would remain fixed there though the earth rotated. So each radiant point would imply a different contact—a different swarm; and accordingly there must be a hundred swarms or more which touch our atmosphere.

But reflect now, that a meteoroidal swarm is describing an orbit about the sun, and we learn of its existence simply because it happens to pass very near the orbit of the earth, and happens to pass at the time when the earth is there. If it passed at a little greater distance, or passed always when the earth was absent, we should know nothing of the swarm—save possibly as a comet, if not yet too much disintegrated to emit light. How many chances against this favorable concurrence of positions! How many more swarms there must be which never reveal to us their existence! When we reflect that we are brushed by say a hundred of them annually, must we not conclude that there are thousands which sweep through space unnoticed? I think the spaces around us must be full of their motions. Were our vision perfect, we should see the heavens clouded by swarming meteoroids darting in every conceivable direction —like the clouds of home-returning swallows in the dusk of a summer evening. These particles of cosmical matters—these clouds of cosmic dust intervene between us and the sun, and must shut out a large proportion of the solar light and heat. We are told by Professor J. P. Langley that not more than half the sun's radiant force reaches the earth. They tell us the remainder is "absorbed" by the atmosphere and the dust which floats there; but much of the absorption must be accomplished by the cosmic matter which exists beyond the atmosphere. The absorption thus effected would be still greater to the inhabitants of Venus and Mercury, if inhabited; since cosmic matter must be more accumulated in the nearer neighborhood of the sun. Thus the temperature on those planets would be lower than their

Multitudes of meteor swarms.

Their effect on sun's radiant heat and light.

proximity to the sun would lead us to suppose. On the same principle, the solar emanations at Mars or Saturn would be greater than their distances from the sun would lead us to suppose.

Meteoric dust.

We have seen the meteor ignited in the upper air. We have seen its bright streak vanish while we gazed. The little body was melted—it was vaporized. While passing through the space measured by its line, it changed from a cold stone to shining dust, and then a darkened dust left floating in the upper strata of the atmosphere. But though unseen, the meteoric dust still exists. It now belongs to the earth. It will be wafted to and fro by the winds; it will come down, after some months, and contribute some new material to the earth. Some of these atoms will fall on the ocean; most of them will fall there; and after other months they will settle to the bottom and mingle with the ooze which is there accumulating. You will remember our walk under the sea (Talk X.), and the comet-dust which we found.

Summary.

The point which we have reached reveals the boundless space around us well stocked with material particles. They are not uniformly distributed; by their mutual attractions they are gathered into swarms. The swarms are not motionless; they are drawn toward every attracting body in the universe. They are not changeless; by degrees each swarm grows as long as it has a separate existence, by the accession of other swarms. As these swarms sail majestically through the ocean of immensity, some are brought under the control of distant suns, and start on long journeys to pay their flying visits. They approach now as comets. If they are induced to circle perpetually about given suns, they finally go to pieces again, and the parts are either drawn to their central suns, or distributed among the planets. If they escape from the systems entered, they steady themselves across the gulfs of space which separate systems, and in the progress of centuries, float into other ports and new excitements.

But some of these swarms remain floating in the depths of extra-firmamental space, and gather to themselves, by their increasing power of attraction, all other swarms and particles from their region of immensity. They become *Nebulæ.* They are luminous because pounded by the fall of other swarms, and lighted by the collisions of their internal parts. They are composed of matters solid, liquid, and gaseous. They rotate. Poised in space, the impacts of gathering matters have started them on their axes of motion. There they are before our eyes. The background of the heavens is phosphorescent with the glow of these distant fields of world-stuff. Each is a living picture of that primordial state in which we fancy the matter of the solar system existed when that history of cooling began which we endeavored to trace to a starting point. Nebulæ.

XXXVII. The Whirling Fire-mist.

NEBULAR THEORY OF WORLD ORIGIN.

Behold the matter of a solar system in the form of a nebula. Poised in the midst of space, it tends to a globular form ; but the attraction of its own center is so distant as to be feebly felt at the remote The solar system once a nebula.

periphery of so tenuous a mass. The late accessions of nebulous stuff have left superficial irregularities—like those in the clouds which float in our atmosphere. They subside with comparative slowness; but yet they tend to disappear. This vast empire of world-stuff rotates, but a million of years may flee away before one revolution is completed. With eternity at command all finite intervals of time are zero. I cannot answer the question whether a gaseous constitution pervaded all parts of this nebula. I think it probable that portions of the included space were filled with gas. I think such portions may have been bounded by the sphere on which the elasticity of the gas was equalized by opposing attractions. There was already fire-mist—fine liquid particles suspended in gases or poised between counter attractions. There were probably stones and concretions of iron hanging suspended through the mass. It is not at all supposable that the entire space within the periphery of the nebula was occupied. There may have been spaces hundreds or thousands of miles wide, not filled with anything but the all-pervasive ether—if that exists. I do not conceive a continuous medium so unimaginably thin as would result from the expansion of the matter of the solar system uniformly through a sphere bounded by the orbit of Neptune.

Structure.

Contraction

If this mass is heated, it radiates heat into surrounding space, and the heated parts contract. If the parts are still gathering themselves nearer to the distant center of gravity, the whole mass contracts. If the time ever arrives when the parts gathering toward the center of gravity are balanced by mutual resistances, or by reaction of heat, then further loss of heat will result in contraction of the whole mass. In either event, the mass contracts. If a rotating body contracts, its rate of rotation is accelerated. This is one of the necessary laws of matter. A rotating sphere of tenuous matter undergoes some flattening at the poles; as the velocity of rotation increases, the polar flattening increases; the equatorial protuberance increases. The earth is equatorially protuberant because it rotates.

and rotation.

When a body rotates on its axis, the parts around the equator experience a tendency to fly off, which is greater than such tendency on other parts of the surface. If the earth were to rotate seventeen times as rapidly as it does, bodies at the equator would have no weight. In the rotating nebula which we are considering, the centrifugal tendency of the equatorial parts diminishes their weight, and the undiminished weight of the polar parts presses the equatorial out in a bulge.

Increasing contraction and rotation.

Meantime the nebula contracts and the rate of rotation continues to be accelerated. Evidently the time will arrive when parts on the equator will have acquired a tendency to fly off just equal to the attraction by which they had been held in their places. If contraction still continues, as it must in a cooling mass, the peripheral parts, balanced between equal centrifugal and centripetal forces, will not move either toward the center or from the center. What should make them? Those parts will remain where they are, and the parts within will withdraw from the equatorial parts. That is, a ring will be disengaged—not thrown off. The ring will retain the ro-

Formation of a ring.

tation which it had, and the residual mass will continue to cool and accelerate its rotation within the ring.

Ring ruptures and becomes spheroidal.

What will happen to the ring? Perhaps you have seen the ring of white smoke resulting from the explosion of a soap bubble inflated with phosphureted hydrogen; what happened to that? It floated as a ring till external disturbances caused its rupture, when the smoke became a simple cloud. The cosmic ring will experience the same fate. This nebula is not hanging in the universe alone. All space is animated by moving masses and groups of masses. Comets are darting to and fro. Distant suns are tugging steadily, even if feebly, on the parts of this ring. Somehow, in the course of ages, the balance of the ring will be destroyed. An excess of matter will be drawn to one side; and, as a consequence, all the matter will be drawn to that side. Or, perchance, the unequal attraction may set up a wabbling rotation of the ring. Then, by the laws of matter, the wabbling will increase until the ring is ruptured. That will cause all the matter to gather to the unbroken side.

Motions of this spheroid.

Thus, from one cause or another, the ring of nebulous matter must become a sphere of nebulous matter. Its distance from the original center is the distance of the ring. This sphere moves in an orbit occupying nearly the place of the ring. This sphere rotates on an axis, and the direction of the rotation will be determined largely by the width of the ring from which it was formed, and relative velocities of the outer and inner circumferences of the ring. In most cases, the direction of the rotation would be the same as the direction of the mass in its orbit; but if the diameter of the orbit is relatively very great, the direction of rotation may be the reverse of the motion in the orbit.

Continuation of the process upon the central body.

This resultant spheroid is to become a planet. The residual mass continues its history as begun. By and by, another ring is detached, and in the course of ages, this also becomes a spheroid destined to become another planet. Meantime, as the disengagement of a new ring diminishes the mass of the central body, the centripetal force exerted on the first planet is diminished. The centrifugal force therefore increases its distance from the common center. This diminishes its angular velocity, and therefore the centrifugal force, and thus the centripetal and centrifugal forces become equal again—both diminished.

The resulting planets vary.

Thus two planetary masses come into existence. By repetitions of the same process, a complete series of planetary masses becomes scattered over the distance between the original periphery and the center; and at each occasion of planetary birth, all the older planets recede a certain distance farther from the center, and undergo a certain retardation in their orbital velocities. The different planetary masses, however, do not possess equal densities; they are not composed of such ingredients as to furnish, on cooling to a given temperature, the same proportion of solid, liquid, and gaseous constituents. Before planet making began, we may suppose the heavier constituents of the general mass had gravitated to the central regions; while the lighter constituents remained nearer the periphery. If so, the first planets separated would contain more of the substances which, at temperatures familiar to us, make gases and water. Similarly, the later planets disengaged would acquire a larger proportion of the substances which form solid rocks. In the case of the earth we may suppose the greater part was rock-making material, since the earth's specific gravity is so high; but watery stuff in sufficient amount to provide oceans and rains, went off with the rock material, and with these, the lighter stuff for an atmosphere. But in the case of Venus, most of the stuff was rock-material, if not the whole of it; while with Mercury it seems probable that little water-stuff was included. In the opposite direction, Saturn, Uranus, and Neptune must have received a large excess of water and atmospheric stuff. It is rational to suppose that their oceans have always covered the whole land, as ours does more than half. In fact, these bodies must be composed chiefly of water and atmosphere; as their specific gravities are low as water and cork.

Each pursues an independent course.

So, in the history of our system, the work went on as long as the conditions existing permitted the central mass to detach rings. Meanwhile, the planetary masses entered severally on their separate careers. Each career was, in effect, a history of cooling. They did not proceed with equal pace, since some, with larger mass than others, had more heat to radiate, and the power to radiate was not in proportion to the mass but to the surface. Hence, some of the older planets are less advanced than the earth, because so much larger; while Mars, I imagine, is more advanced, both because smaller in mass and older. Now, during the habitable stage of the earth, the sun remains the residual mass of the ancient nebula.

The sun is a relic of the primordial fire-mist. The sun is historian of a mighty past. He is more to us than a source of bodily comfort. He sustains relations to our intelligence. He proclaims and exemplifies our material origin. He responds to our anxious inquiry concerning long histories which were enacted in the ages unnumbered; before man existed.

The sun a relic.

XXXVIII. The Primeval Storm.

ORIGIN OF THE OCEAN.

Let us now attempt to trace the physical history of that planetary mass which was destined to become the earth. We contemplate it in a state of fire-mist. Here are no water, no atmosphere, no rocks, no organic forms. In this fire-mist, however, were the elements of all the forms of matter which were to exist in or upon the earth, in the long progress of its history. The moon, on what seems to me the most probable view, had already been separated, but was still much nearer the earth than at present, and performed its revolution in a shorter period. The earth's axial rotation was correspondingly more rapid. Earth and moon mutually exerted powerful tidal actions. Each changed the form of the other from the simple oblate spheroid shaped by rotation, to a prolate modification of this. That is, each by its attraction drew the other into a form slightly elongated. The elongation was a "deformative tide" or "bodily tide." Of course, the moon was much more deformed than the earth. The tidal elevation

The history of the cooling earth to be traced.

An earth of fire-mist.

on the moon, at its present distance, is one hundred and thirty-four times that on the earth. Those tidal interactions have always existed, and still exist.

Fiery precipitation.

I can not affirm that the matter of the earth was now all fire-mist suspended in a continuous gas. There must always have been, since fire-mist first began to form, a tendency of the liquid particles to coalesce, and this tendency would increase with the progress of cooling. A time would arrive when drops thus formed would begin to descend by gravity toward the center of the fire-mist sphere. They are not to be conceived as dropping with accelerated velocity, like bodies falling through space, since within the sphere, the central attraction continually diminishes as the distance from the center diminishes. At the center the attraction is equal in all directions. But the molten liquid began finally to accumulate at the center. It shaped itself in a globe which grew as the fiery precipitation continued. In the course of time, the greater part of the fire-mist had rained down, and a molten earth stood forth in space, glowing with a white heat, and enveloped in a hot and heterogeneous atmosphere which contained all the substances vaporized at the temperature then existing.

A molten globe.

This earth as a sun.

This self-luminous earth was a sun in reference to the moon. The moon had already advanced to a stage corresponding with that called habitable, and the light afforded its conceivable inhabitants was twelve times as intense as that received from the sun —assuming the distances the same as at present. The earth was a star, and had long been a star, to the inhabitants, if any, of remote orbs. Perhaps they had descried it with their instruments; perhaps it had been noted in their catalogues, with latitude and longitude thus and so. The sun was now shedding its superfluous light and heat on a planet which was yet itself a sun.

The forming crust. The molten earth continued to waste its heat. The exposed surface materials, as fast as chilled, sank into the interior by their superior density, and hotter materials rose to the surface. There was a circulation between the surface and interior. This prevented any extreme difference in temperature. But some greater reduction was always experienced at the surface. It was at the surface, therefore, that the first solidification took place. At this juncture, the sinking of the coolest portions ceased. Rock-materials, like all others which crystallize on solidifying, undergo a slight enlargement in the act of becoming solid. A crust, therefore, began to form over the liquid planet. Like ice on the lake, it floated. If you go to the crater of Kil-au-e′-a, in Hawaii, you will find a vast lake of molten rock, the surface of which has frozen into a crust like that which formed over the earth's surface. There is no mistake in the opinion that the cooling crust would float.

Tidal action in the crust. The tidal protuberance caused by the moon never ceased. The side toward the moon was always uplifted. As the earth turned on its axis, a different part of the terrestrial surface was raised at each moment. The great tidal swell swept past every point of the surface at every revolution of the planet. Thus the forming crust was alternately uplifted and depressed. Much fracturing of the crust must have resulted. The crushing and grinding of the fragments displaced them; great lateral pressures tilted them on edge and piled them up in enormous hummocks. The scene must have been analogous to those in Baffin's Bay and the Arctic Ocean, of which explorers bring us exciting accounts. The surface of the earth assumed the rugged character of a vast "floe."

Continued cooling allows at last the precipitation of water.

I imagine this floe was still luminous, except in the projecting crags. Over this still glowing terrestrial surface, sunlight was still shed. Who can calculate the length of the æons which passed while such a scene of desolation reigned? All the time, the process of cooling went forward. While the white-hot crust subsided to a red-hot temperature, the atmosphere became less parched. While the shadows of a darkening crust tipped the most salient crags, the upper air grew continually freer from the terrific heat which had swept outward from the terrestrial surface. As the temperature of the air subsided, there were precipitations of various substances which could maintain their gaseous condition no longer. At length it came the turn of water to begin to condense. It had long, already existed as an invisible gas. Now, with an upper air temperature passing below 212°, the invisible steam began to become visible vapor.

I have often wished I might have beheld the scene. I think, could I have been present, I should have witnessed something like this: The forming vapor in the upper air reveals its presence in a thin and gauzy haze, like that which overspread the sky when the ashes of Kra-kat′-o-a were floated round the world. The veil grows thicker from age to age. It is now a "cirrus" sheet of cloudy vapor like that which the anti-trades drive up from our southwestern horizon. The contour of the round sun is blurred; the intensity of his ancient ray is softened. Indeed, his light is dimmed; the haze is becoming a cloud. A twilight approaches; the shade deepens. The world is enveloped in a cloudy pall; the lurid light of the decaying fires of the crust reddens the overarching canopy. The sun is quenched; the world hangs in shadow which forms the first night which ever visited its surface. "In the beginning" there was "light"; now "darkness is upon the face of the deep," and a denser darkness impends.

Battle between fire and water.

The burdened clouds drop rain. The o'erburdened clouds discharge a storm of rain. The drops descend into the lower and heated strata of the atmosphere, and are dissipated into vapor which rises to the clouds to be again condensed. Continual rains descend; but the hot air dries them up and sends them back to the bosom of the clouds. There is a battle in mid-air between the powers of water marshaled above, and the powers of heat intrenched behind the rocky ramparts below. But the powers of water are destined to prevail.

Meantime the equilibrium of the electricities is disturbed. The friction of ascending vapors and descending rains develops electrical phenomena. Here, in this storm of the ages, the dazzling glare of ten thousand lightning gleams sheds an infernal tinge over the murky world; and the responsive voices of ten thousand thunders split the welkin with their detonations. While this fury and chaos reign, the line of battle sinks to the hot surface of the earth, and all at once the attacking waters are volatilized in ten thousand explosions, which rend the elements.

The culmination of the great æonic storm is passed. The powers of fire are vanquished; the waters gather over the heated crust. They are furious with effervescence and ebullition, but they hold possession. On all sides rise columns of steam from a boiling ocean. The atmosphere, once so arid, is now soaked with vapor. The skies still drip with rains, but the gloom is not so dense. There seems to be a daybreak on the scene. The exhaustion of the clouds proceeds; and now behold, it is dawn. A new cosmic day is rising on the flooded world. The volume of the ocean swells; it has no shore. The clouds, fed by the vapors of a heated ocean, are not dispersed; but a brightening glow heralds promises of a new age. The years speed on, and the alternations of night and day are discernible. The years speed on, and expectation waits for some glorious dénouement. Behold, it arrives. The sun, in his daily circuit about the world so long lost to him, rose one day in the eastern sky, and a broad rift in the clouds let in a golden beam of sunlight, direct upon the waters which enwrapped the earth.

A universal ocean.

How changed the scene since last those rays fell useless on the scorched and glowing crust. Then the self-luminous earth cast no shadow, and there was no night. Now, one hemisphere is in darkness and the other is in sunlight. Now for the first time, as the earth rolls on its axis, the succession of night and day becomes possible. Now, for the first time, the sun becomes "the ruler of the day" and the moon of the night.

XXXIX. The War in the Ocean.

THE EARLIEST STRATA.

The chemistry of the primeval sea.

A SHORELESS ocean now enwrapped the world. It was not a placid summer expanse overhung by bright skies and swarming with happy sentient creatures. The rains which supplied the ocean had washed from the atmosphere certain acid gases—especially sulphuric, chlorhydric, and carbonic—and these pervaded the water now resting over the earth. The fire-formed crust, however, on which the ocean rested, was composed chiefly of silicates of somewhat complex constitution, but largely silicates of alumina, potash, soda, lime, and magnesia. Now when the hot acid waters came in contact with these silicates, certain reactions immediately began. The silicates were decomposed; the alkaline bases, potash, lime, and so forth, were taken up by the free acids, forming chlorides of potassium, calcium, sodium, magnesium; as also sulphates and carbonates of potash, soda, magnesia, and lime. Now some of these resulting compounds were soluble, and remained dissolved in the sea-water. Such were the chlorides and sulphates, and the carbonates of potash and soda. Thus the water of the primitive ocean became charged with sulphate of soda, or Glauber's salt; sulphate of lime, or gypsum; sulphate of magnesia, or Epsom salts; also with chloride of sodium, or common salt; and the other chlorides, which are the bitter impurities in the sea.

Soluble contents.

Precipitates.

But others of the resulting compounds were but little soluble, and were therefore *precipitated to the bottom;* what were they? Carbonate of lime and carbonate of magnesia. The first is *limestone*, and the second is generally mixed with the first, forming *dolomite.* That is, a layer of calcareous material was spread over the sea-bottom. It was a chemical precipitate, not a sediment in the geological sense. Two other constituents were added to the material spread over the bottom. I stated above that the primitive crust contained silica and alumina; what became of these when the original partners had to sunder connections? Potash, soda, lime, magnesia we have traced to their destinations; but silica and alumina are left outstanding. Now, probably, these concluded to form a partnership for themselves; and so silicate of alumina resulted. This being insoluble must have fallen to the bottom. It may have mingled, in some places, with the calcareous precipitates and it may in other places have been bedded by itself. In the latter case, beds of *argillite* would result. With the silica and alumina some potash may in other cases, have combined; and thus would be formed a mineral known as *potash feldspar*, or common feldspar. If soda or lime, instead of potash, united with the silica and alumina, the result was simply another species of feldspar. The feldspars are very abundant in the oldest rocks.

But perhaps, again, some of the outstanding silica and alumina concluded not to combine together. Then the alumina would simply remain free alumina, to mix with any of the other compounds produced, or form by itself a bed of pure clay; and the silica would, in a similar way, mix with other substances or form by itself beds of pure quartz.

The oldest rocks known are not such, but derivable from them.

We may inspect, now, the oldest rocks accessible to investigation, and see if they are the kinds which should be expected, according to the above reasoning. Yes, in a general way they are. Feldspars are everywhere disseminated in the bottom rocks. There are great beds of crystalline limestone, and of argillites. There are micas, hornblende, and augite, all of which, like the feldspars, are essentially silicates of alumina and other bases. But here, also, are conglomerates, composed of rounded or angular fragments of *older* rocks. Here, indeed, are vast formations of *quartzites*, but they are formed of grains, instead of being those purely vitreous masses which would result from the precipitation of free silica. But each separate grain is such vitreous quartz, and it appears as a fragment of some rock in which the whole mass was purely vitreous. At some time then, earlier than the formation of these granular quartzites, there *were* formed quartzites *not* composed of grains, but continuous like a mass of glass. We have to conclude that the oldest rocks accessible are *not* remnants of the primeval precipitates. This is the conclusion pointed out also by the presence of conglomerates.

Let us trace further the necessary succession of events. The chemical war is now settled by treaty of peace; but the rains of a geologic spring-time are still frequent and copious. The tides and waves stir up the fine particles resting on the bottom, and these float off to the deeper situations, where they subside as sediments — fragmental sediments. This consequence of unequal depth in different parts of the shallow ocean is augmented in course of time, by the formation of wrinkles in the crust. These resulted, as explained in Talk XX., from the lateral pressure due to the contraction of the earth within the crust. This was an incident of cooling. The wrinkles did not, at first, rise above the surface of the sea; but they formed bars and shallows, while between them were the depths. Over these bars the tides and waves stirred up sediments which settled in the deeper water not far remote.

Life appears.

Graphite made from plant-remains.

I find no improbability in the supposition that plant life was now in existence. The fronds of fucoids could be rooted on bottoms within reach of the aërating agency of the atmosphere; and though full sunlight was not yet revealed there was a twilight sufficient to meet the requirements of the humblest forms of vegetal life. Whence this life originated, science is unable to declare. Yesterday there was no life yet, on all the planet. To-day it is here—positive organic life. The inductive evidences supporting this deduction are found in the beds of graphite included in the older rocks, though I do not imagine these to have been formed till many ages after the first advent of marine plants.

Land appears.

The time arrived when some of the ever-growing wrinkles rose dripping above the ocean level. They were not, to any great extent, domes and ridges of granite and granitic rocks. They were arches of the primeval fire-formed crust. The mineral constituents of granitoid rocks had indeed been formed as already stated—quartz, feldspar, mica hornblende, augite, and they probably overspread these upheavals—but I believe these minerals must have existed under different aspects, and I think the minerals which compose the granitoid rocks have resulted from metamorphism of plain sediments, as I shall explain. We can not, therefore, look upon our oldest "granite domes" as examples of the earliest crust, nor of the earliest precipitated beds. They are later. Let us see.

There were long, low ridges of barren rock now emergent. I can not state where they lay; but it seems probable they occupied nearly the places of later ridges which were to rise as the germs of the continents. Old ocean now seemed envious of his loss, for he immediately began pounding and devouring the slender land, and taking it back into his possession. The work of *erosion* was inaugurated, from which old ocean has never desisted to this day. Nothing escaped from his domain without a conflict; and many a patch of land and many a continent has thus been reclaimed for his possession, as we shall see.

Ocean erosion begun.

I wish to emphasize here a doctrine which has been very generally overlooked. Ocean sedimentation has been carried on only around the continental slopes. The products of erosion have been laid down in waters comparatively shallow, and not in the distant abysses of the ocean. The deep remote sea-bottom remains to our times, with only a shallow covering over the primitive crust. In our walk under the sea, we found no continental sediments in the deep sea. We found there a state of changelessness and stagnation. We found no evidence of fragmental rocks. We found, on the contrary, in the abyssal

Sedimentation takes place near coast line

islands, rocks of igneous origin—samples of the old fire-formed crust, as I suspect.

and the thickened crust leads to fusion of the older rocks below

The accumulation of sediments over any portion of the ocean's bed would constitute a thickening of the crust. But the thickness of the crust was already adjusted to the intensity of the heat within. It was of such thickness that the heat within could not escape with rapidity sufficient to melt the lower surface, and thin the crust. It was of such thinness that the internal heat escaped with rapidity sufficient to prevent a lowering of the temperature of the different zones of crust, and thus produce a thickening of the crust. But, if by sedimentation the crust were made thicker, this balance would be destroyed; the escape of internal heat would be retarded, and it would therefore, re-fuse the inner surface of the crust, and restore the thickness, and with it, the balance of actions. Thus, wherever the original crust has been supplemented by sediments, more or less of the original crust has been lost from the under side. Who can say how much has been lost? Undoubtedly, an amount approximating the entire thickness of the overlying sediments. It is generally admitted that the Eozoic strata are 50,000 feet thick. There must have been, consequently, 50,000 feet of the primitive crust melted away. This leaves crust thickening due to progressive cooling, to be supplied by sediments above the Eozoic. If the Eozoic beds extend down 30 miles, then 30 miles of primitive crust are lost. If that crust was less than thirty miles thick, then some part of the 30 miles melted away must have been sedimentary rocks.

I wish to make one more point in this connection, and that, I believe, is new. If sediments accumulated only along the continental slopes, then not only did all formations grow finer and thinner in receding from the shore, but they must be found to disappear at great distances from the shore—except in shallow water. Thus, we are not at liberty to suppose the Eozoic beds extended under all the oceans, so as to be literally universal. Wherever they now exist, the land was then not far distant. Thus also, in general, it should result that *all formations grow thinner and less fragmental as they pass under newer formations.*

Sediments thin out seaward.

Eozoic beds did not extend under all oceans.

So it appears that by due reflection, it becomes possible to reproduce the important features of the ocean's primitive history. The earliest outcrops of sea-bottom were entirely consumed by erosion. We find traces of those lost lands in the grains of vitreous quartz, which must have been a product of early precipitation. We find other traces in the conglomerates embraced in the old Eozoic rocks. We even find traces in the slaty character of many of the pebbles, since much alumina and silicate of alumina must have been liberated in the progress of the chemical conflict, as already explained. So when, at the end of the Eozoic Æon, vast beds were upraised which stand to our times, they were not the first land, but only the first land which has survived to the human era.

XL. The World Without a Backbone.

REIGN OF INVERTEBRATES.

The Eozoic world.

UPLIFT, erosion, sedimentation, are the key-words to the physical history of the world; and these all express mere sequences of a more fundamental action, COOLING. We are now contemplating the world as it existed during the æon designated Eozoic. Even then some areas of sea-bottom had been upraised to serve as sources for the clearly fragmental materials laid down to become Eozoic rocks. Where those crumbling lands were located, we can not well conjecture. It was a reign of the physical forces alone. The wide sea was without a tenant, there were no bleached shells strewn along the beach. No shrub contended with the surf for the possession of the sandy foothold; and no tree, however humble, held safer possession of the sparse soil gathered in the chinks of the knotted cliffs. There was no form of living creature seeking the ends of its being over all the stretch of the herbless land, and no wing of bird or insect agitated the fervid air. It was in the progress of this reign of physical forces that I expressed the opinion that vegetal life may have made its advent in the sea.

How the Eozoic rocks—granites, gneiss, etc.—were made.

The æons of the earth's infancy rolled on; the first low presages of coming continents had been ground to sediment; the only upraised examples of the primitive chemical precipitates had been broken up and returned to the sea. Over the ocean's floor was accumulating a mud which, in a later age, should be baked to granite and gneiss—those granites and gneisses which in our times, have become forms so familiar. We have before us the evidence that at least fifty to a hundred thousand feet of such sediments accumulated. The sea-bottom bent down under its load. The downward protuberance reached into an intenser heat than could be endured. Besides that, the very thickening of the crust permitted the interior heat to make encroachments upward, as already explained. The water which saturated the strata of simple fragmental sediments became intensely heated under a high pressure. Alkaline substances were dissolved by the heated water, and the hot alkaline solution acted powerfully on the rock-materials. They were partly dissolved—even silica was dissolved; they were partly softened; they were brought to such a state that the atoms were free to arrange themselves according to their affinities in their new situation. The old substances were therefore made over into minerals which did not exist in the sediments before. These minerals were formed in juxtaposition to each other; and when, in a later age, the temperature subsided, the mineral mixtures which constitute Eozoic rocks of the various kinds were at hand. They formed granites, syenites, diorites, and similar rocks, in which the metamorphosis was so complete that the lines of original bedding were obliterated. They formed gneisses and schists in which the metamorphism was less complete.

Life of the Eozoic sea.

The end of the Eozoic Æon approached at last. Life had appeared in the form of humble seaweeds; and life had throbbed into conscious being in the forms of the humble Eozoön which I have before described. I can not admit that no other forms of life found fitting home in the Eozoic sea; but no demonstration of it has been discovered. We know, however, that a vast thickness of rock-sediment was accumulated, and that now very considerable areas were upraised to constitute the beginnings of those lands destined to endure to our time. Very likely the upheaval was accomplished through many partial upheavals widely separated in time. But we can only contemplate the total result. When the Eozoic Æon was ended, and the Palæozoic Æon begun, there existed on the American side of the world, the following outcrops: 1. The Great Northern Land, lying north of the St. Lawrence and the Great Lakes, stretching in one direction to the coast of Labrador, and in the other, over the region between Hudson's Bay and the Mackenzie River to the Arctic Ocean. This sent a tongue across the St. Lawrence, at the Thousand Islands, and extended into the Adirondack Highlands. 2. The Seaboard Land, lying east of the present Appalachians, and reaching on the north to New England and on the south to Alabama. 3. The Cordilleran Land, covering a large part of the region west of the Great Plains—stretching from the crests of the eastern ranges of the Rocky Mountains into California. Of its northern and southern extent we remain in ignorance. Possibly this Cordilleran Land was more of the nature of an archipelago than a continent. There were smaller exposures of land, but we need not speak of them particularly. The rocks forming these continental nuclei are all metamorphic. Between them and the rocks

The continent of North America begun.

immediately overlying is an abrupt contrast. Why the process of metamorphism has been thus limited upward, has not yet been explained.

Some of the lands then made have disappeared.

These lands were outstanding at the beginning of the Palæozoic Æon. All else was sea. I am quite ready to believe, however, that other lands existed, since consumed by the erosions which sought to lay the foundations of newer formations. On the remoter side of this upheaval was an ocean barren, if we can believe it, of all forms of animal life. On this side was an ocean which suddenly teemed with the shapes of sensitive creatures already of high rank, and diversified in nature, but strange and archaic in their structures and aspects. This sudden advent of hordes of creatures of diversified types of life has been relied on as evidence that the Cambrian fauna did not originate by descent from any older fauna. But you will easily infer that I take another view of the facts.

Did the Cambrian fauna appear suddenly?

Life of the Cambrian.

Let us glance over these populations. There are first in order and highest of all, the Trilobites, which I have already described. With them, in the very dawn of this Æon were Brachiopods—few and feeble, but in *Lingula* as strong and numerous as in any later age. Here grew also, calcareous sponges—not corals, but forerunners of corals—not plants, though rooted and fixed—poor, humble creatures pinned helplessly to the sea-mud, appointed to an age when the work of nature was still crude and unfinished, yet sensitive, capable, undoubtedly, of suffering, and capable of enjoying life. Death, certainly, was there, and pain. The Trilobite, in the very attitude in which existence ended, reveals conscious suffering and apprehension. We often find their forms closely rolled together, as if shrinking from the felt approach of death. The little trilobite, in his final repose, proclaims suffering and death in the world before "sin entered."

Life of the Silurian.

Glancing down to the next epoch, we find other creatures. Ah, this glance overleaps a million years or more. It is an easy step for thought, but who can realize the slow rolling years? Here are trilobites still, and brachiopods and sponges; and here are those huge orthoceratites of which I spoke—long and slimy tentacles projecting at the open end; fierce, huge eyes looking out for some other creature on which to feed; strong, lance-shaped teeth with which to seize and tear him. From this grim presence all other creatures fled away—save those, alas, which nature fixed in the soil and doomed to serve as food for these monster mollusks. Here were meadows of crinoidal forms which have already been described. Raising their sculptured urns on gently waving stems, they spread their jointed arms and fingers in search of their own aliment, and were nipped for supper by some ravaging *Orthoceras.* Here were banks of polyp corals—each little creature planted in his cup and expanding his petal-like tentacles in the life-giving sunlight. Over this slope of animated stone crawled lazy sea-snails grazing on the tentacled growths then beginning a work of coral-building which the Florida reefs witness still in progress.

The cycles of Cambrian and Silurian time swept on and came to an end. The history of life showed no departure from the fundamental types with which that history was inaugurated. There were new species, new genera, some new families, scarcely a new order or class. The changes were so slow that the world seemed finished, and finished for these happy creatures that held possession of it. Yet an occasional visitor from another world would have noted changes. The Cordilleran Land had sunken step by step, and was even now reduced to an archipelago. The Great Northern Land, on the contrary, had risen step by step, till its southern limits extended from Albany to Syracuse and Buffalo, and thence to Detroit, Mackinac, Milwaukee, and Chicago. North of this line lay the continental surface. A great island stretched perhaps, from Sandusky to central Kentucky. These lands were the empire of silence and desolation. Populous as were the waters, here was no motion or sound of animated creature. Sparse, dwarf tree-growths fringed the bleak horizon, but flower and fruit, grass and herb, were yet unknown. The sea, always jealous of the conquests made from his domain, continued to growl around the borders of the land, and pursued industriously the work of reclamation of his ancient slime.

Changes in geography during the Cambrian and Silurian.

XLI. THE DYNASTY OF FISHES.

DEVONIAN AND CARBONIFEROUS TIMES.

WHEN the morning of the Devonian Age dawned, a new form was seen moving in the populous sea. It was a vertebrate form. Without a bony skeleton, its cartilaginous framework and general plan embodied a new conception. Among vertebrates its or-

Vertebrate life introduced.

ganization was decidedly low; but it was not a fish in any ordinary acceptation of the term, though we shall have to call it a fish. There were other vertebrate forms more clearly fish-like, but all widely separated from modern fishes. One could easily distinguish three types of these archaic vertebrates. They are known among us as *E-las′-mo-branchs*, *Plac′-o-derms*, and *Gan′-oids*. The Elasmobranchs are a group which still survives. They are all shark-like. The kinds which lived in the Devonian were true sharks (*Sel′-a-choids*) of the peculiar *Ces-trac′-i-on* family, the best known species of which ranges from Japan to New Zealand. *Cestracion*, the Port Jackson Shark, has spines in front of both the dorsal fins; the nostrils unite in the cavity of the mouth, and the upper lip is divided into seven lobes. The teeth along the middle of the mouth are small. External to these are large flat teeth twice as broad as long, arranged in oblique series so as to form a sort of tesselated crushing surface.

Three types of Devonian fishes.

Elasmobranchs.

Among the very earliest American fishes were some of these spine-bearing sharks. The spines are flattened, two-edged like a bayonet, and curved as if one had belonged to the right side and the other to the left. The external surface was covered with a thin coating of enamel, sometimes smooth, sometimes ornamented. These spines are not attached by a joint, but inserted in a mass of cartilage imbedded in the flesh. They were perhaps the front rays of the pectoral fins. Some of them were more than a foot in length. Being two-edged and very sharp, they must have been very powerful weapons, offensive or defensive. These cestracionts were numerous during the Corniferous period. Their smooth, brown spines are very often found in the Corniferous Limestone of New York, Canada, Ohio and Michigan. If you wish the name, here it is: "*Machær″-a-can′-thus*" or "Dagger-spine."

Plated Ganoids.

Another type among the earliest American fishes was (*Rhyn′-cho-dus* or "Beak-tooth") a form related to the *Chi-mæ′-ra*, which also resembles sharks. It has, however, a long, whip-like tail; its gill-slits are covered by a flap of skin, and the skull is blended with the jaws. The teeth consist of minute denticles firmly massed together into large tabular plates which are inseparably blended with the jaws. It has a long and powerful spine in front of each dorsal fin. The only known specimens of *Rhyn′chodus* are found in the Corniferous Limestone of Ohio; but it must have had a much wider range.

Another of the most common and most striking fishes of the same age appears to have been a relative of the modern sturgeons — a family of plated Ganoids. Our American geologists have almost buried it under a pile of nomenclature, which they have finished in the following shape: *Mac-ro-pet-al-ich′-thys* or "Big-plated fish." These fishes were of large size. The cranium was composed of large polygonal plates, united by double sutures which are nearly concealed by the tubercled enameled surface; the tubercles are stellate; the surface is ornamented by double rows of pores and single thread lines, forming a pattern which does not correspond with the plates below. These large, geometrically formed plates often attract the attention of quarrymen, since they are sometimes fifteen inches in length.

Ganoids. In this assemblage of old American fishes, we have to mention one more. This is a ganoid by the name of *O-nych′-o-dus* or "Hook-tooth." It was of large size. The cranium was composed of a large number of bony plates covered with an enameled and tubercled surface. The borders of the jaws were set with a row of conical, acute, more or less recurved, teeth; and, in the middle of the lower jaw in front, was a single series of large, curved, conical teeth, presenting a striking appearance, and often found imbedded in the Corniferous Limestone. The body of the fish was covered with rounded, overlapping, bony scales, nearly circular in outline, and about an inch in diameter.

Please notice that these old American fishes, dating from the Corniferous period, are Elasmobranchs and Ganoids. Of the former, there were two types, Cestracionts and Chimæroids. Of the latter, also two types—related to sturgeons and gar-pikes.

First fishes Silurian. In the Upper Ludlow rocks of England, which form the upper part of the Silurian, is a "bone-bed" composed almost entirely of the remains of fishes, much triturated and matted together. From this bed spines of *On′-chus* have been obtained—a fish apparently belonging to the Cestraciont type of sharks. In the Upper Ludlow have been found, also, portions of *Ceph-al-as′-pis*, or "Shield-head," having the head covered by a broad plate. This fish was intermediate between Placoderms and Ganoids. Still lower down in the "Lower Ludlow," relics of a similar fish called *Pter-as′-pis* or "Wing-shield" have been found. So we say the oldest fishes of Great Britain lived in the Silurian Age. We know also,

Europe.

that very similar fishes dwelt contemporaneously in the waters which covered Russia and Bohemia.

America.

I have next to inform you that this record is beaten by America. It has very recently been announced by Professor Claypole that the Corniferous Period was *not* the earliest date of American fishes. He finds remains of fishes in the lower and upper portions of the Salina Group of Pennsylvania. They appear to be related to Placoderms and Ganoids, and he has bestowed on them the name *Pal-œ-as′pis* or "Ancient Shield." Still lower than this he reports some fish remains which he thinks may be referred to the genus *On′-chus.* These are at the bottom of the Clinton Group, which in Pennsylvania is fifteen hundred feet below the Corniferous Limestone, and is two formations lower than the oldest fish remains of Europe.

What were the ancestors of these fishes?

We have now stirred up all the old bones—the oldest bones buried on our planet—so far as we know. But I do not think we have found the first fishes yet. There must have been some forms still less like fishes than these. Perhaps if we could carry the line back, we should find fish-like creatures approximating more and more to crustacean creatures. There was *Pter-y-go′-tus* in the Old World and America, and *Eu-ryp′-te-rus* plentiful in America, with its extended pair of arms reminding one forcibly of the *Pter-ich′-thys* or "Winged-fish" of the Old Red Sandstone. There was *Cephalaspis*, with its broad head-shield exceedingly similar to the shield of the modern King Crab and some of the old trilobites. Other intimations exist of a possible near relationship between these half completed vertebrates and the dying-out forms of Crustaceans.

The later history of the oldest fish types. These relations enable us to contemplate with new interest, some of the despised fishes which live in our times. Our sturgeons, gar-pikes, and sharks are the sparse representatives of those ancient families which once sustained alone, the dignity of the vertebrate type. Of these ancient families, the placoderm was destined to disappear with the Devonian, and without a successor. The sturgeon-type has survived in a slender line of representatives, to the human epoch. The cestraciont sharks were probably differentiated into the various better known families of modern sharks, but continue to our times, to exemplify the probable nature of old *Onchus*, patriarch of sharks. The bony scaled ganoids—more fish-like than any of the others, both in form and scaly covering—were well represented by *Onych'odus*. The power and numbers of their family continued to increase through Carboniferous and Mesozoic times; but then they dwindled away. In modern times, our familiar bony-scaled gar-pike haunts the freshened waters of river and lake—the poor degenerate descendant of ancestors which once dominated over the world. Venerable relic of a mighty empire!

The lesson of the gar-pike, sturgeon, and shark. Why have these creatures been preserved in existence so long? These forms are misplaced in the modern world. They constitute an anachronism, which is either an absurdity, or a phenomenon too full of meaning for ordinary comprehension. The gar-pike destroys our game-fish and our market-fish —as he ravaged neighboring kingdoms while he ruled an empire of his own. He tangles and tears the nets of the fishermen, who visit their execrations upon him. His flesh is unpalatable for food. The mud-loving sturgeon, less destructive in his nature, brings no utility into the modern world. The fierce shark, equally unfit for food, is the freebooter of the ocean. Other fishes furnish aliment to man. But these archaic types linger from a time when human wants had as yet no existence, when human food was not demanded. They were never intended for food, since they made food of every other creature. These useless and destructive beings are out of joint with the world and with history. Why are they here?

Why? They come to import ideas into the modern world. They bring down to us living illustrations of faunas passed away. The plates of *Cephalaspis* and the spines of *Machœracanthus* quarried from the rock might pique our curiosity and distress us by their mystery; but they would not instruct. It was intended that the intelligence of the being which always stood as the finality of organic improvement should grasp the conception of the world, and reproduce the grand history of departed cycles. Why? It was an act of beneficence which saved these relics of ancient dynasties from total destruction. There was purpose, not accident, in the failure of their complete extinction, and the assignment of the world exclusively to more modern creatures. These are precious examples preserved in a museum. These are caskets filled with documents from an olden time. The gar-pike and the sturgeon and the shark are missionaries from the past to the present. Hear them. They are preaching to man's intelligence. They are unfolding the plans of Infinite Wisdom. "He that hath ears to hear, let him hear."

XLII. Scenes from the Coal Period.

HOW THE COAL BEDS WERE FORMED.

A new age dawns.

While the monsters of the ancient deep were luxuriating in empire and blood, the premonitions of progress were felt. Behold, the tide bears out into the sea a floating log. Its exterior is marked by peculiar and significant impressions. They reveal the crest of a dynasty in the vegetal world. They are the seal of a *Sigilla′ria*, or the scars of a *Lepidoden′dron.* It has floated from the shore of a low-lying and silent continent.

The Sub-carboniferous.

It was the beginning of the Carboniferous Age. The tremors incident to the upthrow of a new belt of land had strewn the submerged continental slope with the sandy ruins of older lands, and left the bed to mark the beginning of a new system of strata. We know these hardened sands as Waverly Sandstone and Marshall Sandstone. They were not outspread in a day. Through another age still, the impending events, heralded by the floating log, were destined to be delayed. Meantime the waters deepened, and nature seemed to have forgotten her announcement. She had promised land and green forests; she gave deep sea and an expansion of the empire of bony-scaled ganoids. She gave larger development to Brach′iopods; she dallied with the chambered shells, and gave the world an improved type, which we have named *Go-ni-a-ti′-tes.* She lingered lovingly over one of her ancient conceptions

Abundant sea life.

Brachiopods.

Goniatites.

which we style crinoidal. She had had it in her repertory of beautiful thoughts since early Cambrian times—the pretty little stone lily. She had taken it up in every age, and had turned off some improvements and some new decorations. But now, during this waiting period, she seems to have returned with true devotion to one of her first ideas. She gave great attention to diversifying it, decorating it, and filling the sea with its delicate and graceful forms. All for the Age—not for perpetuity.

Crinoids.

This dream of placid waters and teeming populations was broken by a jar. Some stay of the long pressed crust of the earth was broken by the accumulated strain, and the mud of the sea was stirred from its prolonged repose, and floated over the fields where stone-lilies had flourished, generation after generation. Tenants of the sea alarmed, retreated to deeper waters or perished in their homes, and received a Pompeiian burial. The ocean-bottom had been lifted to a higher level. The scene was totally changed. The summer sea became a stormy and turbid shore; and a broad belt was given to the land. The torn beach, crumbling before the waves, contributed coarse rubble for the foundations of new land in some future age. The vegetation promised for the impending epoch was crowding into possession of the ground. It flung its fragments into the deep. These chips from the by-standing forest were buried in the sands which loaded the sea-bottom.

Growth of the continent.

Now came the first charge in the conflict destined to alternate during an age; another collapse of some of the stays and supports of the rigid crust. The land uprose by another notch; the bottom of the sea was lifted to the surface. The great "Carboniferous Conglomerate" was now first bathed in air and sunlight. The continent of North America received an annexation of territory which stretched from the Seaboard Land east of the Appalachians, to the Great Plains. The new territory included all the regions which had been selected as the sites of the capacious coal repositories, for the use of civilization. It was not a dry upland. It was a broad and mighty marsh. Michigan was not included in the common continental marsh, but stood apart for a special destiny.

Great swamps abound.

A forest growth arises.

Now, over all this breadth of bog and swale sprang up vegetable growths—trees and herbs, ferns and rushes. Whence these forms? Some, as I said, had been nursed on the older and contiguous land, and now entered upon a new possession because it was fit. Some sprang from germs fresh planted by some unseen hand. What mean all these transformations? This luxuriant crop is sustained by the carbonic acid of the atmosphere. This, as is generally supposed, was in excess. It made the air irrespirable; no terrestrial creature could live. But terrestrial animals must constitute the next step of progress. The march of improvement had now gone as far as possible with water-breathing populations. The highest type of animals had been reached and its aquatic class had lived a striking career. Nature had now paused for the purification of the air for the next class.

The atmosphere full of carbonic acid.

The Power which had called matter and force into existence, could have made other disposition of this difficulty. The carbonic acid could have been combined with lime and fixed in limestones. It could have been banished from the planet. But carbon is precious. It is the basis of all our combustion. It warms and blazes in coal and petroleum, peat and gas. The carbon must be preserved for future use. Man would discover its utilities, though the age then passing had no use for it. Man was yet far off; but man was anticipated; man was involved in the plans of the world; man was prophesied in these preparations.

In life the vegetation cleared the air

So vegetation was appointed to do the work and conserve the material. This explains the presence of coal-making trees upon the shores of the preceding epoch. They came by appointment, they were to fulfill a plan; they stood waiting by the border of a domain which had been promised them for a possession. Unlimited supplies of aliment pervaded the atmosphere. The marshy situation exhaled the abundant vapor in which vegetation delights. The earth, in its comparative newness, retained the warmth to stimulate at the root. So tree-fern and herbaceous fern, calamite and sigillaria, begin work. Atom by atom, they selected the poison from the atmosphere, and, returning the oxygen, fixed the carbon in their tissues. Frond, stem, and root treasured up the fuel impelled by the force of sunlight; every pound of vegetable answered to a given amount of solar force.

and in death packed away fuel for the future.

The work was begun. Generations of plants succeeding each other fell prostrate at last, and added their substance to the growing bed of peat. Standing water protected the peat from decomposition. Now the skies again were lowering and forebodings of change trembled through the continent. A cataclysm was at hand. The wide expanse of marshy land again went down. Old ocean, which had roared and frothed in rage around the borders of the territory of which he had been dispossessed, came careering back to his old haunts. He brought a freight of mud and sand, and spread it over the whole vast peat-bed. Beds of clay and sand shut out from the atmosphere the sheet of peaty matter which was to lie and consolidate to coal.

Alternating sea-bottom and forest swamp.

The dominion of the ocean was temporary. Again the reeking sea-bottom came up to sunlight, and another scene of bright verdure was spread where late, old ocean had celebrated a jubilee. It looked as if the former forest had undergone a resurrection. Here stood again *Lepidodendron* and *Sigillaria* and the other established forms. But they were other species; and with them was an occasional newcomer among the vegetable types. They resumed the work of selecting the impurity from the air. Already, some adventurous and hardy types of air-breathers had colonized the jungle. They were sluggish and slimy creatures, with whom life passed slowly, and respiration was a matter of comparative indifference. Yet they enjoyed existence. They grazed on the humble herb; they seized the dragon-fly, alighted to rest his wing; they violated the home retreats of the passive snails. They crawled out and sunned themselves on the ferny bank. There were grosser and heavier forms, mail-clad and vociferous; haunting the bayou; paddling for some eligible fishing station; bellowing like oxen, when excited in pursuit; stirring up the mire of the stagnant bay; resting their chins on the

Life in these jungles.

reeking bank to absorb the slanting sun-warmth of the early morning, or lolling under the noonday shade of some wide-spreading and umbrageous *Lepidodendron.*

Formation of cannel coal.

At the entrance of the bay was an exposed headland. From this the high beach stretched away for miles; and already the older coal deposits were exposed along the eroded cliffs. Here the waves pounded up beds of sandstone, shale, and coal. The sands were deposited along the beach which faced the open sea. The finer and lighter materials were floated off in search of a quieter nook. In the bay they found a retreat from wind and waves, and there laid themselves down in a mixture of comminuted coal and clay. In a later age, the deposit was a bed of cannel coal.

The close of the Palæozoic.

The land continued to oscillate as long as the purification of the air was incomplete. Again and again, the forest resumed its work, and bed after bed was stored away beneath ocean sediments, to await the end. When the beneficent work had been accomplished, the tired forces, that had endured with trembling and vibrations, the enormous strain that had been accumulating under the prolonged contraction of the interior, yielded with a tremendous collapse which jarred the hemisphere. Huge folds of the massive crust uprose, and were mashed together till their crests pierced the clouds. This was the birth of the Appalachians. It was the end of the long Palæozoic Æon. Only the stumps of those folds remain to-day. Though crumbling, they stand as monuments of the mighty throes through which the world was prepared for man and civilization.

XLIII. The Reptile Monarchies.

MESOZOIC EVENTS.

A new world.

The storm is cleared, and a new sky overhangs the scene. We seem to be in another world. We glance over the territory lately covered by luxuriant coal-vegetation, and Cycads and Voltzias now hold possession. The Cycads are palmetto-like in form, fern-like in foliage, and pine-like in affinities; the Voltzia seems a progenitor of the cypress. No *Lepidodendron* or *Sigillaria* raises its green crown in all the wooded landscape. The reeking marsh has disappeared, and an undulating upland occupies the continent. We glance over the place of the great flat which had stretched from New England to Alabama, and dark-wooded ranges of mountains frown down on us. We search for the old shore-line which had set the bounds to the empire of the sea, and it is removed. Far southward it lies, within two hundred miles of the Gulf-border of the human epoch—so much more of the ocean's domain has been wrested from his possession.

Flora.

Fauna.

We range over this new bright landscape. All the old Palæozoic forms of animal life are displaced. Strange tenants have moved in. Instead of the feeble, lizard-shaped Amphibians which housed themselves in a hollow stump, we find great quadruped-like Labyrin′thodonts crawling like enormous toads under shelter of a fringe of forest. Their ponderous bulk impresses deep footprints in the sand

Amphibians.

along the beach—four-toed and hand-like—destined to remain and become a wonder of the human age. (See also Talk XXX.)

But the Amphibians have yielded empire to another dynasty. Great was *Archegosaurus*, but *Deinosaur* was greater. An extraordinary and amazing figure reveals itself stalking along over the beach. Evidently this monster, tall, scale-covered, erect, with diminutive head, swollen abdomen, and massive, trailing tail, is a representative of the ruling family. He reveals massiveness without elegance; strength, without grace. He marches on two feet and leaves a footprint three-toed like that of a bird. His jaws are armed with strong, sharp-edged, and pointed teeth. His long bones are hollow like those of birds; the pelvis, as well as the foot, is bird-like; the sacrum has four vertebræ like that of a mammal; the neck-vertebræ are concavo-convex as in mammals, and his lower jaw has lateral motion for triturating food, as in the ox. Shape like a frog; head, tail, and scales like a lizard; feet like a bird; sacrum like a mammal—what shall we call the creature?

Reptiles.

Deinosaurs.

We watch him through his sea-side promenade, and follow him to the dank and peaty jungle where he finds his home. We see him browse from the lower tufts of foliage, and grind the fibrous twigs with the jaw-movements of a herbivore, wearing away and blunting the crowns of his teeth. But he meets his enemy—another Deinosaur of bloodthirsty disposition, a flesh-eater, and armed with sharp and lacerating teeth. Between the two a bitter feud exists, and they have, at former times, clenched in the struggle for prowess. The herbivore recognizes his superior; but unwillingly subject, fierce anger flashes from his dark eye, and with a defiant growl, he makes room for carnivore to pass.

Sea-saurians.

There are others of the ruling dynasty which disport themselves in the waves; but these sea-saurians (Enaliosaurs) are only the forerunners of an army which may be expected in the morning of another age. There are also others. We walk in the twilight of a Mesozoic day, along the reedy shore of a gloomy estuary, and the crocodiles are crawling out on the land for midnight prowling. A broad crocodilian grin reveals an array of cruel, conical teeth set in the jaws; and their lazy forms are encased in a jointed bony cuirass, which fits them for defensive warfare. When *Bel′odon* moves through the jungle, even the Deinosaur is startled from his security.

Crocodilians.

Estuary conditions of the Triassic Period.

Within the limits of that recess of the continent destined to be named New England, is a deep and narrow bay, which projects far northward from the future shore of Long Island Sound. We stand upon the gneissic slope of the western shore, and survey the shining expanse. The tide is out, and the smooth sand beach is laid bare. Over its surface lie squirming and crawling and shrinking from exposure, the sundry forms of marine life which the last tide brought up. This is the opportunity for the land-marauders. Now they hurry to the scene in search of a meal. There, most conspicuously, strides the tall uncouth *Bron-to-zo′-um*, a three-toed Deinosaur, standing fourteen feet high. Its foot is twenty-four inches long. At times it drops on four feet to seize a dainty morsel of a crab, and leaves, for a space, the footprints of a quadruped. But the forward feet are comparatively diminutive in size. In the distance, *Oto-zo'-um* paces along the beach—another bipedal Deinosaur, but with four toes behind. With foot twenty inches in length, he has a stride of three feet, in a leisurely gait. *Otozo'um* is partaking of his meal. Now and then he picks up a stranded fish. Among these gigantic figures more humble Deinosaurs are seen mingling. One of these leaves a footprint but three inches; and we notice one wee pet of a reptile which makes a track but a quarter of an inch in length. They are all engaged in refreshing themselves.

How footprints in sand are preserved.

Let us wait here for the tide to come in. It is coming, and announces itself by its roar. The tide of the open sea is here augmented by the limits of the narrowing bay, and it swells into a terror-striking "bore." The Deinosaurs and Labyrinthodons hear the sound, raise higher their heads in listening attitudes, and scurry away to their retreats. The tide lingers awhile, dallying with the sands, and then retires. Where now, are the footprints of those gigantic saurians? Has the dallying tide erased them? No. It has covered them with a soft film of fine sand. They are not destroyed; they are preserved. The table is spread again with squirming viands, and the saurians recognize another call to refreshments. Again they range along the sand, and impress their tracks in the soft surface. Unconsciously, these creatures are inscribing their autographs on the pages of the world's history. The tide returns and spreads its conservative sands again over the well-inscribed beaches. And so the tide rolls in and out, and the saurians write their daily chapters of history. By and by the tides will cease; this bay will be uplifted beyond their reach; these sands will become a solid brown sandstone; quarrymen will ply their avocation along the slopes where *Otozo'um* breakfasted; the stony slabs will be split apart, and there will be found, in all their details, the same footprints made in this opening epoch of the Middle Ages of the continent's history.

Mesozoic coal-beds.

So the years rolled on; and meantime the vegetable kingdom was performing its part in the drama of the world. There must have been lowlands where water-loving trees stood and bathed their feet—swamps, where fallen foliage and worn-out tree trunks gathered themselves in beds of peat that hardened into coal. One of those tracts is a few miles west of Richmond, Virginia; and two others are in the Deep River and Dan River regions of North Carolina. Good coal was formed, quite similar to the bituminous coal of the Carboniferous Age.

Conditions at the close of the Triassic.

The Triassic Age came to a close through movements of a nature similar to those which closed the Carboniferous, but less pronounced in violence. The sandy beds were disturbed and tilted, all the way from Nova Scotia to North Carolina. The strains which they suffered caused great fractures which intersected the formation in straight lines; and from below came molten mineral matter which filled the fissures. The matter was of a basaltic character, and in places where it overflowed on an extensive scale, it assumed a columnar structure. We note especially four regions of Triassic sandstones and Triassic eruptions: Western Nova Scotia, the Connecticut Valley, the Palisade region, extending through New

Jersey and Pennsylvania, four others in Virginia, and two in North Carolina. The coarse Potomac marble is from the lower part of the Trias.

It is now the middle part of the Mesozoic Æon. We are in the midst of the reign of reptiles. This dynasty is even more pronounced than was the reign of fishes. Down by the sea-shore Mesozoic saurians amuse themselves in the surf. The Ich′-thy-o-saur, with thick and fish-like form and alligator head, pursues the fated fish into the deeper water, guided by a pair of enormous eyes which gather in the feeble light. The swan-like neck and head of the Ple′-si-o-saur rise above the surface, while the short, thick body is propelled beneath by a pair of long, flat, many-fingered and many-jointed paddles. There too, winds the progenitor of the sea-serpent—a real sea-serpent, whatever fable may connect itself with the modern one. This is the Mos′-a-saur, attaining sometimes a length of eighty feet. The body is covered with small, overlapping bony plates. The paddles are five-fingered and resemble those of whales.

The hey-day of the Age of Reptiles.

Ichthyosaur.

Plesiosaur.

Mosasaur.

Contemporary with the sea-saurians are those of the estuary and the river. Turtles and tortoises sun themselves on the naked slopes. Real lizards scamper over the cliffs, or skulk among the *dêbris* of the forest. But most conspicuous of all move the gigantic Deinosaurs. Some swim in the sea; some crawl on the land; some scud among the branches of the trees, and other forms standing erect, walk in reptilian majesty among their humble subjects.

Chelonians.

Lizards.

Here is the Had′-ro-saur, whose province is limited to the Atlantic border. His near relative, the *Ig-uan′-o-don*, holds some provinces in the Old

Hadrosaur.

World. These are vegetable eaters. But here is

Lælaps. their traditional enemy the carnivore. *Læ′-laps* disputes supremacy with the Hadrosaur, as in the Old World, Megalosaur rivals Iguan′odon. Strangest of

Pterosaur. all, for a reptilian modification, the Pter′-o-saur sails over our heads and shadows us with his broad leathery wing. The Pterosaur is a ground disputed between reptiles and birds. In aspect, bird-like, he is, however, essentially a saurian. In structure he is less bird-like than the Deinosaur.

Reptiles everywhere.

What a range of adaptations is this; sea, river, shore, upland, forest, jungle, and atmosphere—all populated by fit modifications of a single type of vertebrates! But we stand still more amazed. Before we make our exit from this wonderful Mesozoic time, behold a real bird on the wing. Clothed with proper feathers and constituted a bird, it is yet reptilian. Its long and lizard-like tail, vertebrated to the extremity, is furnished with proper quills, but cannot conceal its kinship with the reptiles. It comes out of the empire of reptiles and brings reminiscences of the reptiles with it.

A higher type is now standing at the threshold of being. A knell is sounding the funeral of the reptilian dynasty. The saurian hordes shrink away before the approach of a superior being. After a splendid reign, the dynasty of reptiles crumbles to the ground, and we know it only from the history written in its ruins.

XLIV. Mammalian Rule.

CÆNOZOIC TIMES.

The striking figures which appealed to our wonder during our walk through the Mesozoic Æon, diverted attention from some very humble but very suggestive creatures which managed to elude the dangers threatening them under a rule which knew only cruelty and extermination. These creatures were little mammals. The first species found to have existed in America was found by Professor Emmons in the red sandstone of North Carolina. The lower jaw is armed with a series of teeth somewhat like those of the common mole. It seems, therefore, to have been insectivorous. Its nearest relative among living mammals is the *Banded Anteater* of Australia, a small animal with a fox-like appearance. We call it *Drom-a-the′-ri-um*, or "Running-beast." It is singular that a very similar mammal lived in the same age in the Old World. Some of its remains have been found at Würtemberg, and others, at Frome, England. Another Triassic mammal has recently been described by Professor Owen from South Africa, as large as a gray fox, and remarkably specialized. All these mammals are most distinctly mammalian. Whatever the origin of these little forerunners of a noble type, it can not be supposed they had no companions. There must have been hundreds, if not thousands, of individuals of each of these species, but they are wholly lost to knowledge. Where we are sure of the disappearance of so many remains,

The first mammals known date from the Triassic.

Their character.

how easy to believe the remains of different creatures —of lower mammals—have also disappeared.

Altho' mammals lived in the Jura-Triassic, they are almost unknown in the Cretaceous.

Mammals once in existence, we are compelled to believe that they continued uninterruptedly in existence until our own times. We cannot admit that the type was lost to the world, and then the same identical conception reintroduced. But where did mammals live; where did they perish; where lie their bones? Save one or two thin bone beds, we search in vain the depth and breadth of Jurassic and Cretaceous strata for evidences of the existence of mammals. In a bone bed of the Stonesfield Slate of the English Jurassic, the teeth and jaws of several species of mammals have been found. These are mostly near relatives of the Triassic mammals. In the Middle Purbeck of the Upper Jurassic, occur other remains. We know in Europe, all together, not much over fourteen species, and they are probably all marsupial; and a majority are insectivores. In the Jurassic of America, Professor Marsh has brought to light at least 17 species; and these all closely resemble the Old World remains. In all the vast thickness of the Cretaceous strata, but a single species is known, and of this so far as I am informed, but a single individual, and this very imperfectly preserved. It comes from Dakota, and was described in 1884 by Professor Cope, who bestowed on it the name *Men-is-co-es′-sus.* This also, is similar to the Old World forms.

Thus all the intimations show that while the mammalian type had already made great advance in the Mesozoic Æon—almost equally advanced at the beginning and end—it was still but meagerly developed. Its affinities, even to the end of the Mesozoic, were with the lower division of mammals, the Marsupials. With so little progress between the Triassic and the end of the Cretaceous, we are reminded again, that a long interval of mammalian existence must have passed, before the Triassic *Dromatherium* took its place in the world.

But early in Cænozoic mammalian life is abundant and diverse.

With the opening of Cænozoic time all is changed. The transition reminds us of that from the Eozoic to the Palæozoic. The world is now astir with mammalian life of considerable development in rank and diversification of type. When was this advance effected? Probably during the Cretaceous. Then we must admit that the sole Cretaceous mammal known fails to represent the average of the Cretaceous. But a glance over the assemblage of early Tertiary mammals at once shows them stamped with inferior characteristics. They are all greatly *generalized*—that is, some characters of two, three, or more of our modern orders are blended in one individual. This principle is exemplified in the early representatives of every group of animals. In the next place, they possessed small brains. If we compare one of them with its nearest relative in any later age, and especially with a modern mammal, the disparity in brain is striking. Enlargement of brain is a strong mark of advancement. Another circumstance is the generally pentadactyl character of these mammals. To have five toes on each foot may be thought a mark of superiority, since man has five. But five is the typical or fundamental number. This is possessed by many reptiles and by most of the lowest mammals. Advance has been marked by modifica-

Generalized types.

tions, and these, as a fact, have involved, in most cases, a reduction in the number of digits. The extremities of man may, therefore, be regarded as more primitive than those of the dog with four digits, the ox, with two digits, and the horse with one. This at least is the prevailing scientific opinion; but I venture to contest it. Finally, most of the early Tertiary mammals were plantigrade; that is, they walked on the whole length of the foot, with the heel on the ground; while most mammals walk on the toes with the heel elevated—the "hock" being the heel. This also may be thought a mark of superiority, since man is a plantigrade; but digitigrade walking sustains the same relation as pentadactylism, to progressive advance.

Eocene types.

Coryphodon.

One of the first figures to greet us on our entering Cænozoic times is *Co-ryph′-o-don*, one of the best examples of a generalized type. As large as a Malayan tapir, with similar short legs, it had no other characters of the tapir, or of other hoofed quadrupeds (Ungulates). It had the full number of the different sorts of teeth; five toes on each foot; nose not adapted for work as in the tapir, hog, and elephant; canine teeth prominent as in hogs and Carnivores. The feet were somewhat elephant-like, and the head, anterior to the eyes, was long, as in the horse, and the whole range of incisors was horse-like. Here, also was *Hy-rach′-y-us*, more tapir-like, with four toes in front and three behind. Here further, were two forms more related to the horse, but only as large as a fox—*Eo-hip′-pus* (Dawn-horse) and *O-ro-hip′-pus* (Mountain-horse). They had four perfect toes in front and three behind; but in spite of the number

Hyrachyus.

Eohippus.

Orohippus.

of toes, they showed their affinities with the horse in several particulars of structure of the leg and foot-bones and in the teeth.

A little later, the forms of huge and curious mammals crowd on our view. *Til-lo-the′-ri-um* (Biting-beast) had enormous, long incisors, two in number, much like the beaver; but it was not a real Rodent, or gnawer. *Di-noc′-e-ras* (Fearful-horn) was like an elephant in size. It had short legs and perhaps three pairs of horns—one on the snout, one on the cheeks, and one on the forehead. These must have given the creature a grotesque and fierce aspect. Its habits appear to have been like those of the rhinoceros. It was five toed, like *Coryph′odon*, and in other respects was related—widely different as it was nevertheless. The *Dinoc′eras* had for relatives *U-in-ta-the′rium* (Beast of the Uintas) and *Ti-noc′e-ras* (Avenging-horn). This must have been the ruling family of beasts during the Eocene, or earlier Tertiary. Only a few mammals related to the fox, wolf, cat, bat, and squirrel had yet appeared on the scene. There was a marked tendency toward the tapir type, the rhinoceros type, and the horse type. Some even-toed Ungulates came at last—*Par-a-me′-ryx* (Ruminant-like) which had relations to camels and stags—and were really the precursors of the true Ruminants (Cud-chewers).

Tillotherium. *Dinoceras.* *Uintatherium.* *Tinoceras.* *Parameryx.*

In the Miocene or Middle Tertiary, the tapir, rhinoceros, and horse tendencies continued. The Ruminant tendency also continued. But there was developed, also, a tendency to the hog and the sheep. In fact, the hog and sheep were somewhat united in *O-re′-o-don* (Mixed-tooth), for which

Miocene types. *Oreodon.*

Menodus. reason Leidy styles it "a ruminating hog." *Men′-o-dus* (strong-tooth) was intermediate between *Dinoc′-eras* and Tapir. It was large as an elephant. *Bronto-therium.* *Bron-to-the′-ri-um* (Thunder-beast) was of similar bulk, and had a pair of horns. Now came, also, the increase of Carnivores. *Machærodus.* *Ma-chær-o-dus* (Saber-tooth) was as large as a lion, with fearful, tearing canines. *Hyænodon.* *Hy-æn′-o-don* (Hyæna-tooth) was as big as a black bear. Insectivores existed, and now appeared the earliest of the beavers.

Pliocene types. In the Pliocene or late Tertiary, we witness a marked approximation to modern genera. Now the equine type had become almost a horse. Here were camels, rhinoceroses, tapirs. Here the first elephants came upon the scene, though elephantine characters had been in the world through the whole Tertiary. Mastodons were perhaps earlier. The lowest monkeys (Lemurs) had existed from the Eocene; and proper tailed monkeys from the Miocene. But in all this teeming procession of mammals we notice no sign of man—save only the prophecy of man.

XLV. Anticipation and Retrospect in Life Plans.

COMPREHENSIVE TYPES.

Definition of *comprehensive types.* What I wish now to set forth is a principle of very profound significance. It is a general truth in the nature of the succession of organic types; and I will endeavor to make it plain by citing some of the striking illustrations of it. From the working of this principle, it results that the creatures of any age often unite in themselves some characters of a group actually existing, with characters of a group not yet in existence. This is *anticipation.* Such a union forms a "prophetic type," as Agassiz used to express it. It is also a *comprehensive* type. Also, from the working of this principle, it results that the creatures of any age often unite in themselves some characters of a group actually existing, with characters of a group which was dominant in a former age —whether still existing or not. Such a union forms a *retrospective* type. This is also *comprehensive.* But in some comprehensive types we find a union of characters none of which belong to any fairly circumscribed existing group. They are all prophetic or anticipatory of groups which are destined to be defined in the future.

Examples. Ganoids.

Take first the early Ganoids for a good example. Their vertebræ were generally concavo-convex. This is a reptilian character. Nearly all reptiles, living and extinct, possess such vertebræ, while all typical proper fishes possess biconcave vertebræ. Now the early Ganoids were not reptiles, and had no claim to concavo-convex vertebræ. There had never been a reptile in existence when these Ganoids first lived—when *O-nych'-o-dus* of Ohio, for instance, flourished. If we may attribute to the ancient Ganoids certain other characters which belong to modern Ganoids, like the gar-pike, we should say they possessed an opening or glottis in the back part of the mouth, and that a passage existed from this to the air bladder; and that the latter organ was coarsely vesicular, giving a rough imitation of a lung. The gar-pike too, is capable of a vertical motion of the head; that is, unlike all other modern fishes, it has a neck, and can raise the head, like a reptile. The ancient Ganoids were certainly not less reptilian than the modern ones. The possession of bony armor is also a reptilian prerogative; and it may be added, that the teeth of the ancient Ganoids were truly reptilian. Those of *Onychodus* were strikingly so. As in reptiles, too, the vertebral column continued to the end of the tail. Thus the ancient Ganoids possessed several reptilian characters; while in general form, they were fish-like; in aquatic respiration, in many rayed fins, in cranial and general skeletal structure they were fishes. Thus the ancient Ganoids, and to a similar extent, the modern ones, were a comprehensive type. They anticipated reptiles; they were prophetic of reptiles. Later the ganoid type was *resolved*. The ichthyic characters were retained in one organism, and the reptilian were gathered together in a different organism. How did it occur that an animal on the whole a fish, should incorporate in its structure features of a class which was yet far in the future?

Amphibians. The Amphibians are a comprehensive type. Structurally they partake of the natures of fishes and of reptiles. They are fish-like in branchial respiration during early life. They are fish-like in the possession of biconcave vertebræ; in having two occipital condyls, and in other less conspicuous characters of the skull; in the organs which serve as kidneys; and among Batrachians (frog-like) in the double septum which divides the orbits—which is a ganoid character. They are reptilian in breathing air in adult life; in the possession of appendages for locomotion on land, and in the undivided ventricle of the heart. The nervous system is intermediate between fishes and reptiles. The extinct Labyrinthodont, while possessing many distinct batrachian affinities, was reptilian in its crocodile-like skull, and the protective bony plates upon the thorax and flanks. In the teeth is found, however, the peculiar labyrinthine structure seen in some Placoderm fishes; and the sculptured plates of the *Ganocephala* furnish a resemblance to bony scaled Ganoids. The structure of Amphibians is on the whole, so reptilian that they were, for many years, merged in the reptile-class. Now Amphibians existed, as far as we know, before the reptile-type had been introduced. All their reptilian characters, therefore, were prophetic of a class which was yet non-existent. On the contrary, they appeared when the reign of fishes was passing away. All their ichthyic characters, therefore, were retrospective.

The ancient Reptiles.

Take next, the wide-ranging class of Reptiles. During the age of its dominance, various ordinal divisions exemplified various relations to the future and the past. While the concavo-convex vertebra was proper to reptiles, the sea-saurians had biconcave vertebræ—a reminiscence of fishes. Other reptiles had the teeth soldered to the jaws as in fishes. Some reptiles with socketed teeth, however, had biconcave vertebræ. The Ichthyosaur with fish-like vertebræ and jaws, had crocodilian teeth and whale-like paddles. It looked forward toward the mammalian type. Some of the Deinosaurs, also, were prophetic of land-mammals in their short, compact bodies, while their bipedal attitude anticipated both mammals and birds. A more explicit anticipation of birds was revealed in the composition of the digits and the structures of the tarsus and pelvis. The Pterosaurs were prophetic of bats in their leathery wings supported by elongated digits. They foreshadowed birds, not alone in the flying function, but in their bird-like scapula, coracoid, and other structures. In one genus the tips of the mandibles were without teeth; and in the American Pterosaurs, the mandibles were completely destitute of teeth, while the tail, also, is reduced to a few vertebræ, and the head is distinctly bird-like.

The gradation of reptiles towards birds brings us to facts still more remarkable. In the Jurassic slates of Solenhofen in Bavaria, which have yielded specimens of Pterodactyls retaining the impression of the leathery wing, have been found, also, remains of a bird which had a long vertebrated tail, like a lizard, with a pair of quills standing out from each vertebra. It had also, saurian teeth inserted in sockets. It had a true bird-foot, except that the metacarpals were separate. This wonderful compound of bird and reptile, after causing much discussion, was finally assigned a place among birds and named

The first Birds.

Ar-chæ-op′-ter-yx or "old-flyer." Very recently, however, other specimens have been found, and Carl Vogt of Geneva, after careful examination, declares that the creature was a *feathered lizard*, and not a bird. There are two conical teeth in the upper jaw; eight neck-vertebræ, with five pairs of ribs directed backwards; ten dorsal vertebræ without spinous processes, and supporting ribs without uncinate processes; five sternal ribs and very minute sternum.

The fore-limb, he maintains, is not a proper wing, and there are three digits resembling those of a clawed lizard; the feathers are attached to the side of the arm, hand, body, legs, and tail. If the feathers had not been preserved, no one would have thought this Old-flyer a bird, or capable of flight. Now what can we say of a creature having the bird and reptile so mixed that the best judges are unable to decide whether it is one or the other?

The Cretaceous Age in America produced still other mongrel forms, which have been published to the world by Professor Marsh. These seem to lean unmistakably toward the side of birds; but they possessed saurian teeth, and are known as *O-dont-or′-ni-thes* or "Toothed-birds." There are two genera. *Ich-thy-or′-nis* or "Fish-bird," had strong wings, biconcave (fish-like) vertebræ, and teeth inserted in sockets. *Hes-per-or′-nis* or "Western-bird" had feeble wings, and teeth inserted in grooves along the crests of the jaws.

Comprehensive types become specialized.

From such examples as have been cited, it will be understood that the principle of comprehensive types results in gradational relations. That is, organic forms, recent or fossil, may be arranged in series according to structural relationships. The forms more or less bird-like, for instance, may be ranged in a column beginning with most highly developed birds, and ending with characteristic saurians. We find, indeed, two series, and may arrange them as follows:

I. From Running-Birds Back to Reptiles.

1. *Struthious Birds*, ostrich-like, feeble wings, runners.
2. *Brontozo′üm*, bipedal, three-toed, with phalanges bird-like.

From reptiles to running birds.

3. *Laosau'rus*, bird-like in head, ischiac and post-pubic bones and toes.
4. *Compsog'nathus*, bird-like in head, consolidated astragalus and tibia.
5. *Anomœ'pus*, four toes before, three bird-like toes behind.
6. *Hadrosau'rus*, weak fore-legs, attitude bipedal.
7. *Rhynchosau'rus*, saurian, with toothless mandibles, bipedal.
8. *Iguan'odon*, tips of premaxillaries toothless, obliquely bipedal.

II. From Carinate Birds Back to Reptiles.

From reptiles to flying birds.

1. *Carinate Birds*, sternum keeled, flying birds.
2. *Hesperor'nis*, with poor wings, teeth in grooves.
3. *Ichthyor'nis*, with good wings, socketed teeth, biconcave vertebræ.
4. *Archœop'teryx*, bird or lizard, tail long, teeth socketed, metacarpals separate.
5. *Pteran'odon*, winged reptile, short tail, no teeth, bird-like head.
6. *Ramphorhyn'chus*, winged reptile, distant, sharp and curved teeth, horny tips of mandibles, long tail.
7. *Pterodac'tylus*, winged reptile, bird-like scapula and coracoid.
8. *Thec'odont Saurians*, typical saurians with socketed teeth.

Here are two lines of gradation from reptiles to birds, arranged out of extinct forms. It must be stated, however, that their order of succession in time does not correspond with their relative position in the gradation. But we know, as yet, so little about the complete fauna of different ages, that it would be rash to conclude that the actual order of appearance was not accordant with their order in rank.

Let me now present a gradation of forms which corresponds strictly with their order of appearance.

From *Eohippus* to the horse.

1. *Equus*, late Pliocene. Common horse, feet reduced to central series of bones (middle finger and toe), a pair of "splints" to represent second and fourth digits.
2. *Pliohip'pus*, middle Pliocene. Smaller, central digital series more slender; splints more elongated; crown of upper molars shorter, and crescentic areas simpler.
3. *Protohip'pus*, early Pliocene. Size of ass; central digital series still more slender; splints terminated by dangling hooflets; ulna long as arm, but slender; fibula rudimentary; crowns of molars much shorter.
4. *Miohip'pus*, of late Miocene. Size of sheep; three functional toes before and three behind; small splint of fifth digit, before; ulna distinct, long as radius, but very slender at lower end; fibula coossified with tibia at lower end; molar crowns decidedly short; enamel folds much simpler than in horse.
5. *Mesohip'pus*, of oldest Miocene. Size of sheep; three functional toes before and three behind, but more nearly equal than in *Miohippus;* large splint of fifth digit, before; radius and ulna distinct, and also tibia and fibula.
6. *Orohip'pus*, of middle Eocene, of Wyoming and Utah. Size of fox; four functional toes before and three behind; ulna complete and distinct from radius; tibia and fibula also distinct; molar crowns exceedingly short; enamel pattern simple.
7. *Eohip'pus*, of oldest Eocene, of New Mexico. Size of fox; four functional toes before and three behind; rudiments of outer or fifth toe behind, and hence, probably, of first digit before; hoofs mere thick, broad and blunt claws; molars less specialized than in *Orohippus*, without cement.

The affinities, gradations, and successions thus indicated are facts of observation; they depend on no theory of organic history. They simply show that each type of the past possessed characters which related it to organisms yet future. There was retrospect; there was anticipation. The past was bound to the present; the present, to the future. History was a constant unfolding of that which was contained in the past. Progress was a perpetual fulfillment of prophecy.

XLVI. The Throes of the Continent.

HOW THE LAND GREW.

The continent a growth.

While the great plan of organic life was unfolding itself, the continental theater of its exhibition underwent a process of expansion which no less reveals a plan, and no less awakens our interest and admiration. By what stages the region east of the Great Plains acquired its form and dimensions, has long been understood; but the method of the building of the western half has only been brought to light through the recent researches of Hayden and Meek, King and Wheeler, Powell and Dutton, Gilbert and Hague, Whitney and Gabb, and their compeers and collaborators.

The continent at the end of the Eozoic.

East of the Great Plains, rose first a long, hook-shaped ridge, with its longer branch stretching from the north shores of the Upper Lakes to the Arctic Ocean, in the region between Hudson's Bay and McKenzie's River; while the shorter branch extended northeastward as far as the coast of Labrador.

Not improbably this branch stretched across the North Atlantic to the British Islands and Scandinavia. This primitive area I have styled the *Great Northern Land.* It is also known as the Laurentian area—a name which applies properly only to the portion sustaining some contiguity to the St. Lawrence.

Along the low seaboard region east of the Appalachians, stretches, from Maine to Alabama, the stump of an ancient mountain range which appears to have been of the same age. The stump only, I say, for the tooth of time has gnawed it nearly level with the sea, and the old material has been rebuilt in the foundations of later lands. This was the great *Seaboard Land.*

West of the Great Plains, as we now understand, stretched another long belt of land, which was destined eventually to be consolidated with the eastern lands, to form the continent. In width, it extended originally—that is, at the beginning of the Palæozoic Æon, from the eastern bases of the Rocky Mountains to western Nevada—probably seven hundred and fifty miles ; in length, it stretched far northward and southward, to distances not yet ascertained. This was the *Great Cordilleran Land.* There were probably other small land areas, rising like islands from the universal ocean ; and there may have been other areas of moderate continental extent ; but so far as our probable knowledge goes, the three continental expanses mentioned were the chief beginnings of North America.

The Cordilleran Land was a great mountain system, displaying lofty ranges made of crumpled strata ; enormous precipices, the result of mechanical dislocation; and finally, a type of mountain sculpture, of such broad, smooth forms as to warrant the belief that subaërial erosion had never carved and furrowed the mountain flanks with the sharp ravines characteristic of modern mountain topography. This massive belt of Eozoic cordilleras determined the limits of the modern cordilleras, and very much of the details of their fundamental structure.

Such was America in the twilight of its history. There must have been, however, as I have argued in Talk XXXIX., some lands which had now disappeared. These surviving germinal nuclei are composed of stratified rocks. Older rocks had been reduced to sediment in supplying material for the building of the lands which are the oldest now remaining. Let us see what vicissitudes these lands were destined to undergo.

Geography of the Cambrian.

The first æon of the ocean's history was past. With the opening of the second, nearly the whole of the Cordilleran Land began to subside. It sank until only the mountain masses rose as rugged islands above the sea-level. Only the western border held its position. This remnant of the Cordilleran Land stretched along western Nevada and eastern California. The continent eastward became an archipelago. Cambrian sediments were deposited over all its scarred and broken surface. One ocean stretched from western Nevada to New England. Whether the Atlantic Seaboard Land rose or subsided, we are unable to say. Probably it sank, and its original extent became concealed by overlapping Cambrian sediments. The Great Northern Land, however, began a slow upward movement, which was destined to continue through all Palæozoic time.

Of the remainder of Palæozoic time.

In the progress of the Palæozoic ages, the tenor of continental history was an almost continuous emergence of the Laurentian portion of the Northern Land, and a continuous sinking of the Cordilleran Land. The Laurentian, accordingly, continued to broaden its base as the remnants of the Cordilleran continued to grow less. The Cordilleran subsidence was greatest toward the shore of the Nevada continent, which was undergoing vast wastage in supplying the sediments which overspread the surface of the sunken Cordilleran region. Coarse and thick toward the west, they became finer and thiner eastward. By the close of Palæozoic time, the sediments accumulated over the Cordilleran Land were one thousand feet thick in the Rocky Mountains, thirty-two thousand feet in the Wahsatch region, and forty thousand feet at the extreme western Palæozoic limit, longitude 117° 30′ west. Only a few granitic islands interrupted the continuity of the uppermost Carboniferous sheets, from Nevada to the Great Plains. The ancient Eozoic topography was buried irretrievably out of sight — save where, in later times, local uplifts brought it again up to observation. The Appalachian region, meanwhile, underwent a similar subsidence. There are some reasons for supposing this region was, at the beginning of Palæozoic time, annexed to the western border of the Seaboard land. If so, the conditions here were a sinking land loaded with sediments derived from a wasting stationary land on the east ; as in the west, the situation was the same, but with the wasting land on the west. West and east the fixed and wasting land was oceanward from the sinking area.

Great changes now took place. The Nevada continent, which had yielded thousands of cubic miles of Palæozoic sediments, now, in its turn, went down, and a broad region eastward, as far as the Wahsatch Mountains, came up. The Cordilleran continent was now located in the region at present known as the "Basin Province," embracing Great Salt Lake, Pyramid Lake, and others. Only the foundations of the Sierra Nevada had been laid. The Basin continent on the east was to be ground up to supply the masonry for a new structure; just as the Nevadan foundation itself was the mere stump of a land pulverized to supply materials for the Basin Land. So nature's method is to build, demolish, and rebuild. As in the successions of life, so in the successions of continents.

But while this continental see-saw was in progress west of the Wahsatch, all remained quiet to the east, as far as the Great Plains. In the Appalachian region, however, a similar see-saw occurred. The loaded Appalachian belt came up in a series of mountain folds fifteen thousand feet high, while the Seaboard Land, that had been wasted in supplying the load, went down—most of it, like the old Nevadan continent, below sea-level. Simultaneously, the whole breadth of the country westward to the Great Plains, was finally annexed to the eastern limb of North America.

North America during the Mesozoic.

It was now the beginning of the geologic Middle Ages. East of western Kansas, the land was completed, save the Atlantic and Gulf border. West of the same meridian stretched a broad ocean—over the region of the Great Plains; across the belt of the Rocky Mountains, where it was interrupted by the meridionally disposed Colorado, Medicine Bow, and Park Ranges; across the broad Plateau region of the present, to the base of the newly uplifted Basin Land —which was now melting away under the sedimentary demands for Mesozoic materials on the east and the west. To the south, this ocean extended to the Gulf of Mexico. Northward, it joined the Arctic Ocean. West of the Basin continent, the sediments of the Triassic and Jurassic formations were laid down unconformably on the eroded Eozoic surface which had sunken. East of the Basin continent, the new sediments were spread conformably on the last Carboniferous sheets. At the close of the Jurassic Age, these sediments had attained on the west, a thickness of twenty thousand feet. On the east, they were less than four thousand feet.

Now rose the vast crumpled folds of the Sierra Nevada,[1] adding two hundred miles to the Basin continent on the west, and stretching southward at least to the thirty-sixth parallel, and northward to Alaska. East of the Wahsatch, however, everything still remained quiet—save that the great orographic event of the west sent its rock-fragments, pebbles, and sands eastward over the ocean's floor as far as Kansas, forming the conglomeritic Dakota Group at the base of the Cretaceous.

No further orographic disturbances took place until the close of the Cretaceous. To this epoch, the sedi-

1 The reader is recommended to make a table of North American mountain ranges in the order of their formation. F. S.

mentary sheets had been laid down in conformable positions continuously from the Cambrian upward. Now, however, came the turn of the region at present known as the "Plateau Province." Upward and undulatory movements were experienced from the region of the Great Plains to the base of the Wahsatch. Now rose the broad, flat, east-and-west anticlinal known as the Uinta Mountains; and the whole mass on the east was further upraised, of which the Rocky Mountains are the salient ridges. The broad shallow basin of the Colorado River was now defined. On the Pacific coast, this disturbance was felt only in the defining of the position of the Coast Ranges.

The great feature of this post-Cretaceous movement was the re-emergence of that part of the ancient Cordilleran area, now called the Plateau Province. It had sunken, with the whole breadth of the Cordilleran Land, at the end of the Eozoic Æon. Now the two limbs of the American continent were joined together. From Middle California to Boston Bay was a continuous land connection. Only a narrow border remained to be added around the Atlantic, Pacific, and Gulf coasts. Remnants, however, of the ancient Mediterranean Sea remained in the interior, forming lakes as large as Superior. These in the succeeding ages were at times enlarged, at times contracted, through the orographic movements taking place, and finally filled or drained (see Talks XVIII. and XLIV.). During the Miocene epoch a great lake covered the region of the Great Plains, as far as the Gulf of Mexico—a region which appears to have been mostly land during the Eocene. Meantime,

America during the Cænozoic.

vast volcanic eruptions were taking place along the Pacific border, burying thousands of square miles under lava, and supplying ashes which filled some of the western lakes four thousand feet deep.

The interior lake history continued of similar tenor till the close of the Pliocene, when the grand movements occurred which impressed on the broad Cordilleran region its present surface features. The rocky sheets of the Great Plains were tilted into a position which secured drainage of the great lake which had covered them. In the far west, the Sierra Nevada and the Wahsatch were rent longitudinally by great faults along their crests, and the continental mass between the faults sank down one or two thousand feet, forming the Great Basin, and returning it to the depressed condition which it had held through the whole of Palæozoic time. On its eastern and western borders gathered two lakes, each as large as Huron, the eastern of which has shrunken to Great Salt Lake, Utah, and Sevier; while the western exists only in the remnants known as Pyramid, Winnemuca, Carson, Walker, and Humboldt lakes. Later mountain ranges have risen here and there in the Basin, and volcanic outbursts have contributed to diversify the topography. These final disturbances, followed probably by some later ones—all embraced within the Quaternary period—shattered the Plateau Province to a destructive extent. Great fractures ran through it from end to end. On one side of each, the rocky sheet is generally upraised, and on the other, depressed. Volcanic mountains have been built up here and there, and earthquakes have shattered the blocks shaped by the meridional faults.

Simultaneously, surface erosions have perpetually changed the configuration of the surface. Rivers have cut their way through mountains, through lava plains, through the later strata, and in some cases, a thousand feet into the long-buried formations of the primitive Cordilleran Land.

XLVII. The Reign of Ice.

CONTINENTAL GLACIATION.

Teleological argument regarding the Glacial Period.

The gradual advancement of organic improvement had now reached a stage where the next step must bring man upon the theater of life. Even the animals which man was destined to domesticate were already on the earth, and awaiting the advent of their master. The forests too, had assumed the aspect which was to become familiar to man, and seemed to stand expectant of the being so long promised.

But nature must yet pause. The continents intended for civilized man lack something yet to fit them for his advent. Throughout Asia, Europe, and North America, the continental surface had become deteriorated by erosions and wastage taking place during the reign of mammals. The land had been set apart for the use and convenience of this dynasty, and in their service it had been exhausted. Each of the great dominant dynasties in succession, had the continents for their use, and in their behoof they were worn out. For each new dynasty a renovation was demanded. At the present juncture, the soils had been reduced through wastage, to the condition

GLACIALLY FACETED AND SCRATCHED PEBBLE,
Two sides of which are shown. This specimen bears eighteen facets. They indicate successive positions of the pebble in the ice, in which it was set like a diamond.

which we plainly see approaching again under the actions exerted during the human reign. The rivers, long confined to the same channels, had excavated deep gorges. Retired in these their evaporation was checked, the clouds were starved, and the soils were robbed of their rains. Every tributary had scored a ravine which split the land. The streams were inaccessible and dwarfed, and their availability for human uses seriously impaired. There must be a general repair of the surface before it would meet the demands of a being of such enterprise and resources as man was destined to be.

The end so necessary was accomplished without departure from the fundamental method of all the previous history of the continents. Uplift and subsidence accomplished the glacial renovation which now approached. We have already studied many indications of glacier action. We have concluded (Talk III., which should now be reviewed) from the inductive evidence, that a continental glacier has some time, brooded over the land, and we have made some observations on actual glaciers (Talk IV.).

Gradual lowering of temperature.

The mild climate of the middle and later Tertiary time which had prevailed as far north as Disco, on the coast of Greenland, and Melville and Bennett Islands in the Arctic Ocean, had already been succeeded by a colder one. The cause of the change remains an unsolved problem. The later invasion of severe cold throughout the northern temperate zone is generally ascribed to northern elevation ; but there is much reason to suppose it the result of certain astronomical changes, and to hold, also, that this was but one of a succession of glacial visitations. What-

Causes of glaciation: (*a*) geographical, (*b*) astronomical.

ever the cause, the reality of the glacier period can not be questioned. The area of perpetual snow had extended its limits from the arctic zone into northern America. In the middle latitudes, an unwonted chill was already experienced in the atmosphere. Successive winters grew more and more severe, and the snow lingered always later in the spring. There were deep ravines where it survived the summer. With continued depression of mean temperature, the winter snows still further delayed their departure. The forest was changed. One by one, the species suited to a milder climate perished; and frost began to brown foliage in a zone which had witnessed a state of perpetual verdure. Year by year, the line of permanent snow extended itself southward. Probably the volume of snowy precipitation was increased, and thus the march of the reign of snow was accelerated.

Permanent snow-sheet extended.

The sheet of perpetual snow, to whatever limit it reached, was divided into two areas by an isothermal line. Had the sun never exerted a thawing influence—had no thawing ever taken place in any portion of the snow, it would have remained a soft and fleecy covering. But wherever incipient thawing was felt, the snow crystals began to resolve themselves into grains of ice. Down to the latitude where this change was unable to proceed farther, the condition of the snow remained granular, as it now does in the Alps. If, however, the melting influence proceeded farther, the granular snow-mass resolved itself into solid ice. These changes can be traced in the snow which falls upon our streets. Thus all the southern portion of the snow-field became a true

Its passage into glacier ice.

glacier; north of that was a zone of *névé;* and possibly a zone of soft snow covered the area still nearer the pole. All this, of course, supposes precipitation to have taken place. If in any region precipitation was wanting or scant, the snowy or icy covering did not appear.

Movement of the ice-sheet.

On its northern border, the glacier was fixed to the mass of ice or *névé* beyond; and very probably it was fixed to the earth. The glacier, like all glaciers, must move; and the motion would be developed along the free border. The glacier, therefore, traveled southward. Consider the consequences of the motion. The soft snow had filled the gorges and the river valleys. It had settled around cliff and crag, and when it became ice, it held them in its firm grasp. The motion of the glacier wrenched fragments from their fastenings and moved them southward. The rock fragments, like diamonds in a setting, marked and scored the underlying surface. The loose materials, the accumulation of a previous geologic æon, were plowed to the bed-rock. The bed-rock was scored and striated by the tremendous power of the glacier.

Its development southward.

Every year, the great ice-sheet encroached a little farther on the unglaciated area. This resulted partly from the southward growth of the glacier, and partly from its southward motion. In its motion, it prostrated the standing forest, and the ruins were mingled with the rock-ruin which the ice-mass stirred and transported. The march of the glacier's southern border continued until it reached New York, Louisville, St. Louis, and Topeka. It passed over Long Island Sound and reached the ocean shore. West-

GLACIER STRIATIONS IN TWO DIRECTIONS.

From a photograph of a limestone slab in the educational series of the United States Geological Survey. Procured by E. E. Howell at Rochester, N. Y. The older set of striations is shown by the "drag lines" on their lee sides.

ward, over the Great Plains, its footmarks are not traced. Perhaps the precipitation there was insufficient to enable the snow to outlast the summer heat. Further west, the glaciation seems to have been restricted to mountain ranges. But glaciation was far from unknown, even to the Pacific slope. Northward, the extent of the glaciation increased, as far as Alaska.

An "open" spell.

Inter-glacial period.

Recurrence of cold.

Now the geologic winter was marked by an "open" spell. It probably lasted for centuries. The ice dissolved, and the border of the glacier retreated perhaps, to the latitude of Marquette. Over the uncovered area, it was a new spring time. Vegetation sprang into existence, and a fresh soil accumulated. Then came a recurrence of cold. The old glacier resumed its southward movement. In saying it was a "continental" glacier, it is not meant that an ice-field continent-wide moved with a consentaneous movement. The ice-sheet felt the influence of the underlying topography. Its motion tended everywhere to the lower level and warmer situation. Seldom was that direction precisely south. In the valley of the Connecticut, the movement was south. In the valley of the Mohawk it was eastward. Through the valley now occupied by Lakes Ontario and Erie, it was southwest as far as Indianapolis, and south as far as Columbus. Another glacier stream flowed through the valley destined to be the basins of Lake Huron and Saginaw Bay. Its southern border joined the Lake Erie glacier; and the long broken chain of sand and bowlder hills passing through Ann Arbor, shows where the joint rubbish of the two glaciers was left. Another glacier stream passed

The border of the glacier lobate.

GLACIAL FLUTING FROM NORTH QUARRY, KELLY'S ISLAND, LAKE ERIE.

Specimen now in the National Museum, donated by Mrs. E. K. Huntington. It illustrates both simple and compound grooves. These glacier fluted surfaces are found beneath the loam of the island, and the work of quarrying is rapidly causing their disappearance.

along the valley of Lake Michigan ; another down the valley of Green Bay and its continuation to Madison. Still others streamed from Keweenaw Point and Duluth into central Wisconsin and Minnesota. Wherever these local ice-streams terminated, they left moraines to mark the extent of their advance. This was the "second glacial period." The entire continent north of an irregular line passing through New York, Fort Wayne, Madison, Minneapolis, and Yankton, lay, like the soil of Greenland in our time, buried beneath a bed of ice and snow some thousands of feet thick. The summits of the Adirondacks, the Catskills, and the White Mountains barely emerged above the desolate, featureless waste.

The fate of the mammoth in Siberia.

During this reign of ice, the snows fell which overtook the long-haired elephant of Siberia and Alaska (Talk XXVII.), and buried them in herds. They had been browsing for many generations on that northern slope. I know not to how severe a climate their natures fitted them ; but clearly it had not been a climate which brought perpetual snow. Now they experienced a new chill in the atmosphere. Now the snows descended and they crowded themselves together in ravines for warmth and mutual protection. Their instincts taught them this mode of self-preservation. They had often outlived a snow-burial during winters preceding. But their last burial finally arrived. Now no thaw succeeded the overwhelming storm. No spring-time returned to release them from their chilly retreat. Spring only turned the snowy blanket to ice. Other winters buried the mammoth beneath added beds of ice. In such a tomb, they lay unchanged until the age of man and slowly returning warmth brought their lifeless carcasses to a dumb resurrection.

The accumulation of five thousand feet of ice over a portion of the earth's surface required some new adjustments of equilibrium. If the ice-bed covered the entire north, and the terrestrial crust remained rigid, the added weight transferred the earth's center of gravity toward the north, and with it flowed the ocean northward. With a flooding of all the northern shores there was a corresponding emergence of the antarctic. If the weight of ice depressed the terrestrial crust, the position of the center of gravity may not have been changed; but the shores depressed would be flooded by the ocean, as before. Farther, the displaced fluid matter beneath sought escape, through fissures, to the surface. If the enormous ice-pressure was felt by the regions east of the Great Plains and north of the Snake River, the depression of the glaciated regions caused the fluid internal substances to react beneath regions farther west and south; and in many cases, to develop fractures through which molten outflows took place. In this view, the great post-pliocene lava floods of the west were the counterpart of the great ice-burdens of the east and north.

Results of the weight of glacial ice: flooding. vulcanism.

XLVIII. A Geologic Spring Time.

INCIDENTS OF THE CHAMPLAIN EPOCH.

THE rigor of the long winter began to relent. We can not certainly state what physical conditions

Evidence of subsidence: elevated sea beaches.

brought about the change; but if elevation brought the cold, then probably, the return of warmth resulted from restoring the ancient level. We are certain, on good evidence, that a subsidence took place. At some time after the advent of general glaciation, the eastern United States and Canada were inundated by the ocean. The depth of the submergence was 470 feet at Montreal; and it diminished gradually southward. At Lewiston, Maine, the sea-beach is two hundred feet above present tide-level; near Boston, one hundred feet; on Nantucket, eighty-five feet. Northward, on the contrary, the submergence increased in depth. On the coast of Labrador, it was five hundred feet; in Barrows' Strait it was over one thousand feet. The usual opinion is that this submergence occurred *after* the dissolution of the glacier; but I incline to the conviction that it was coincident with the glacier. I have already suggested, following Croll and general opinion, that a load of northern ice would very probably cause submergence of northern shores—though I think it resulted from depression of the crust, rather than a shifting of the center of gravity. Such submergence would be greatest northward. The facts observed seem to show that it was a submergence of the glacial epoch, instead of the post-glacial. If the sunken shores were already buried in ice, the temperature of the sea would dissolve it, and the sea-bottom would be of the usual character of a submerged beach.

The depths of submergence just mentioned are far less than would have taken place, if the crust of earth had yielded readily to the pressure of five thousand feet of ice. To have influenced the temperature, there must have been a much greater subsidence from the point of maximum elevation. It is reasonable to conclude that the action which caused the original elevation was now reversed, and much greater subsidence took place than was due to the load of ice.

The melting of the glacier.

Whatever the amount of subsidence; whatever its cause; whatever the cause of the climatic amelioration, there is no question about the return of a geological spring. The glacier began to waste more than its annual growth. A steady recession began along its southern margin. A series of morainic loops was left to mark its farthest advance. They were composed of bowlders and sand. The materials were accumulated in hills and ridges, with intervening "pot-holes" and valleys. The dissolution of the ice-field proceeded with rapidity. Lively rills flowed over the surface of the ice, and turbid streams sprang from the foot of the glacier—such streams as make the Aar (Talk VIII.) and the Arve (Talk IV.). The moraine deposits were partially washed away. The moraine of the first glacial epoch, farther south, was now subjected to the action of a second flood. It suffered greater erosion than the second moraine, and hence remains to us a less conspicuous feature than the second.

Terminal moraines.

The outer moraine affected.

Material transported by torrents beyond area of glaciation.

The ice-sheet had laid down an unstratified bed of "till"—a compact mass of clay, pebbles, and bowlders; the glacial flood transported vast quantities of materials, and left them in a state of torrential stratification overspreading the till. There is much reason to believe that the materials thus transported were borne beyond the limits reached by the glacier.

In this way, the action of the glacial expedient for renovating the surface of the north was extended to the southern states. There has certainly been a southward transportation of pebbles and sand throughout all the Gulf States. It was an event synchronous with the dissolution of the great glacier. But we must bear in mind that the south had not been visited by an agency which plowed up the disintegrated rocks accumulated during preglacial ages. The flooding of the south exerted only a surface action.

Present drainage systems established. Between the glacier and the floods, the surface of the whole country east of the Great Plains—with the exception of a few small isolated areas—underwent a process of thorough repair. The sharp river gorges were filled—even an ancient gorge of the Niagara River—and a fresh bed of subsoil materials was spread over the land. The larger rivers sought out the drainage valleys which they had occupied before the invasion of glaciers. The fundamental features of the drainage were everywhere determined by the underlying rocky structure. But many of the smaller streams which now sprang into existence, selected for the first time their winding channels among the inequalities of the Drift-covered surface. From that epoch to the present, all the streams have employed themselves in effecting an ever deepening erosion. Of the greater arteries of the continental drainage, the ancient preglacial bounding walls may sometimes still be traced. The high cliffs of the Upper Mississippi show where the great river was bounded throughout all Cænozoic and Mesozoic time. There was an epoch when the excavation of this gorge began. The great tide swept along at the high level of the land. But the stream has also scored deeper than at present. The rocky bottom of its channel is everywhere many feet below the present bed of sediment. The country stood higher once than now; the descent to the sea was sharper, and the erosion more profound.

Flooded rivers left terraces.

Of course, during the melting epoch of the great glacier, all the streams were flooded. Not only did the dissolving ice supply enormous quantities of water; evaporation must have been increased by the extension of evaporating surface, and condensation must have been promoted by the large amount of ice-cold surface. It was an epoch of rains and floods. All the rivers have left records of their ancient altitudes. These are the terraces. On the Connecticut we find them from one hundred and eighty to two hundred feet above present flood level; on the Hudson and Mohawk, three hundred and thirty feet; on the Genesee, two hundred and thirty-five feet; on the lower Ohio, fifty to one hundred and eighty feet; on the Missouri, two hundred and fifty feet; and so throughout North America, all the rivers at this epoch were flooded.

The Niagara gorge and the Glacial Period.

The Niagara River had been at work on a vast gorge ever since the Devonian Age. Probably none of the Great Lakes except Superior, then existed. From Lake Superior sprang a river which flowed along a valley in which the basins of Lake Huron and Lake Erie have since been excavated. At a point west of the present mouth of the Niagara, it made a fall, and flowed as a river along the Ontario valley, and thus to the sea. In the course of ages, the stream excavated a gorge as far as the whirlpool

—perhaps even farther. On the re-establishment of the river, it did not find its ancient gorge, but precipitated itself over the escarpment at Lewiston. Here it began a new gorge, and dug back four miles, when it struck the old gorge. Of course the falls now continued their recession rapidly as far back as the head of the old gorge. Since that was reached, the work has been continued in solid rock, and is now proceeding at the rate of three feet a year.

Question of the basins of the Great Lakes.

The question has been much discussed whether the basins of the Great Lakes were excavated by the action of the continental glacier. By Ramsay, lake basins have been generally attributed to such action. By others, the doctrine is held in light esteem, since we have evidence, in some cases, that glaciers have moved over sheets of clay without plowing them up. I incline to agree in part with both. The positions of the terminal and lateral moraines show that glaciers moved along the beds of Lakes Erie, Huron, and Michigan, and Saginaw and Green Bays. What directed ice-streams to these positions? A pre-existing valley. What caused the valley? The erosion of the great river which had been flowing out of Lake Superior during Mesozoic and Cænozoic ages. The valley may have been a mile, or five miles, wide, and bounded by precipitous rocky walls. When the glacier commenced its movement along such a valley, it exerted powerful erosion along the steep bounding walls, and wore them down to the gentle slopes which now form part of the bed of the lake. The basins of the lakes are demonstrably works of erosion. Why the great glaciers worked there more than elsewhere, was because the great river had inaugurated the work and invited the glacier. A glacier also moved out of the western end of Lake Superior. A valley already existed—indeed a lake basin existed, shaped by the ancient upheaval of rocks along the northern and southern shores.

Glacial lakes of Maine, Michigan, Minnesota, etc.

In regions where returning spring-time found the general surface nearly level, and locally indented with basin-like depressions, the Champlain floods formed large numbers of lakes and lakelets. Such depressions might arise from the rocky configuration of the country—especially the larger depressions. More generally they were mere intervals inclosed by hills and ridges of Drift. Thus arose the numerous lakes of Maine, Michigan, and Minnesota. Whenever a lakelet found an outlet, the process of erosion began; the lakelet was continually lowered, and in many cases, it has been completely drained. In all cases, the filling of the lakelets has gone forward in the manner described in Talk VIII. Nature is finishing the world before our eyes.

The making of the prairies.

It was during the spring-time empire of water, that the Great Lakes stood at the high levels described in Talk VII. To this inundation of Illinois, the prairies of the Mississippi owe their origin. The prairie formation is a stratified deposit of fine clay, sand, and alluvial matter. It is a fresh-water deposit. It was laid down on the top of the Drift. The topographical and geological facts point to the great lacustrine flood as the occasion. When, in the course of time, the high waters subsided, the lake bottom was left exposed. It lay a barren waste until the seeds of vegetation were distributed over it by natural means. Birds and winds were the principal agents; but these agents transport only the lighter seeds—the seeds of grasses and herbs. The forest was standing thrifty and green around the border of the ancient lake, but its seeds found little opportunity to gain foothold on the old lake-bottom. The Indian was here. He had paddled his canoe in the waters above the soil which was now a prairie. When the grasses and herbs had been browned by the first frosts of Autumn, the Indian's torch set them ablaze. The air was filled with smoke during the dry and sunny days which follow the killing frosts. The west wind wafted the smoke to New England, and our ancestors said, "The Indian Summer is here." But the burning killed the shoots of the young trees without injuring the roots of the grasses and sedges. So when May covered the surface again with green, the grasses were there, but the woody shoot was dead. Thus the prairies remained treeless. When the emigrant discovered the Indian at his annual burning, he said, "That is the explanation of the treelessness." But he never explained why the region was treeless enough in the beginning to allow the surface to come into possession of the grasses, and furnish the Indian occasion for the burning.

For recent studies and fuller statements regarding the glacial period, see Professor Chamberlin's papers in recent United States Geological Reports and Professor Wright's *Ice Age in America* and *Man and the Glacial Period.* F. S.

XLIX. The Earth Receives Her King.

THE ADVENT OF MAN.

At some juncture in the progress of these later events, man made his first appearance on the earth.

He was not present during Tertiary periods, in any portion of the world which has been subjected to research. There appears to have been no European Tertiary man, and no American Tertiary man. This conclusion is now almost universally accepted.

Man during the Glacial Epoch.

But both in America and Europe, man seems to have been present during a portion of the Glacial Epoch. American man dwelt in California. Along the Pacific coast, as I stated in Talk XLVII., a milder climate prevented the prevalence of universal glaciers. The situation, therefore, may have been as favorable for human occupation as that in our day, at the foot of the glaciated valleys of Switzerland. The human remains of California, however, are found in situations which at first excite our wonder; for they lie in the deep placers underneath great tables of ancient lava (Talk XVI., end). These lava-sheets, in the judgment of Professor J. D. Whitney, were erupted in the latter part of the Pliocene Epoch; and if so, man was a Tertiary resident on the Pacific coast. This opinion, I have myself been disposed, heretofore, to adopt. (*Preadamites*, pp. 426–428.) Everything depends on the epoch of the lava eruption. That would be given, if the other fossil remains of the deep placers afforded unquestionable criteria of age. Professor Whitney thinks they do. In his report on California, he says: "The beds which were deposited prior to the great volcanic disturbance and consequent overflow of lava throughout the Sierra, inclose a peculiar fauna which we refer to the Pliocene Epoch, and which appears to have some analogy with the group of the same age occuring on the Niobrara and White Rivers and in their vicinity,

Remains in California.

Age of these remains?

to the east of the Rocky Mountain chain." "Among the animals of the Pliocene of California, or the group which preceded the epoch of volcanic activity, we recognize the rhinoceros, an animal allied to the hippopotamus, an extinct species of horse, and a species allied to the camel and resembling the *Meg-a-lo-me′-ryx* of Leidy; all these species, so far as we know, are peculiar to the deposits under the lava." As to the plant remains found in the same beds, Dr. Newberry reports that they are not older than the Miocene, and most resemble species found in the later European Tertiaries. For myself, I hardly think this evidence is fully conclusive on the Pliocene age of the deep placer gravels with human relics. I feel persuaded that the great lava eruption was connected with the enormous load of ice which once covered the regions farther north and east; and if so, they occurred probably while the Glacial Epoch was at its meridian. Mr. Boyd Dawkins thinks the evidence of Pliocene man in California is "unsatisfactory," because almost no species of Pliocene mammals have survived to the present, and the strong presumption is afforded that man is not an exception.

But in any event, American man existed in the Glacial Epoch—not, of course, in the midst of a continental glacier; but in some favorable region which glaciation did not reach. Much of the "far west" was suitable for human occupation at the time. Great lakes existed in Oregon, in Utah, and Nevada; and they were populated by a molluscan fauna not less exacting in its requirements than the types accompanying man in the present epoch. In eastern America, also, some human relics have been found which, as is thought, argue the presence of man in the Glacial Epoch. Dr. C. C. Abbot has described some stone implements in ancient gravel near Trenton, New Jersey,[1] and the announcement of Glacial man has been proclaimed; but I agree with Mr. H. C. Lewis, that these gravels are post-glacial. Stratified gravels of the Drift belong to the epoch of the Champlain floods. The deposits of the Glacial Epoch, with local exceptions, are unstratified, and in the nature of "till." The Trenton gravel appears to be a river-drift deposited during the flooded stage of the Delaware.

Remains from Trenton gravels.

Human implements in river-drift gravels are widely known in Europe. They occur especially along the valleys of the Somme, the Seine, the Thames—but also, in many other regions. They have been the subject of voluminous discussion. In Brazil, stone implements have recently been described in large numbers from the gravels of the province Rio Gran-de do Sul. From caverns many relics have been obtained, which throw much light on the condition and associations of primitive men. Numerous other facts have been yielded from the bottoms of European lakes. It appears that the early inhabitants constructed their habitations on piles in the lakes, and communication with the shore was effected by a bridge which could be readily removed. Some of these piles still remain. Naturally, many articles used by the dwellers in these abodes were lost in the water and never recovered. Many thousands have been dredged up in recent times. Another

Relics from river gravels of Europe;

of Brazil.

Later relics from Swiss lakes and

[1] A vigorous controversy is in progress regarding the antiquity of these relics. F. S.

source of light on primitive man is found in the seaside accumulations of kitchen-refuse—piles of shells and bones and organic *dêbris* reaching several yards in length, and sometimes eight or ten feet high. These are the refuse of fishing villages. They contain implements, domestic utensils, and personal ornaments once belonging to the inhabitants. The peat bogs of Denmark and other countries give us other relics. From the mounds and other burial places much further information is obtained.

from Danish bogs.

Character of relics found.

Among the relics of these early settlers in Europe, we find many stone axes—some rough and others laboriously polished. Flint arrow-heads and lance-heads are very common. Fish-hooks and other articles of bone occur in the lakes and the shell-mounds. Very numerous articles of bronze used for ornament are dredged from the lakes—brooches, bracelets, pins. Fragments of pottery occur in the lakes and shell-mounds. Woven cloth has been exhumed from some of the oldest deposits; and jars of dried apples and wheat, and even cakes, have been yielded from the pile-habitations. The older relics are rudest, as might be expected, and consist exclusively of stone and bone. Later, bronze came into use, and the workmanship was finer. Lastly iron became known. Archæologists accordingly divide prehistoric time into three ages: 1. The AGE OF STONE; which was subdivided into the *Palæolithic* or rough-stone epoch, and the *Neolithic* or polished-stone epoch; 2. The AGE OF BRONZE; and 3, the AGE OF IRON. Within certain geographical limits these three ages in the progress of culture are consecutive. But it must not be supposed that they

The "ages" of prehistoric archæology.

mark periods in the history of man at large. The Age of Stone is long past in Europe; but it prevailed still in the Hawaiian Islands when discovered by Captain Cook; and still prevails among some Indians of America.

Man in Europe was contemporary of extinct mammals.

Gathering together the numerous facts which supply information concerning the primeval inhabitants of Europe, we are able to set the following inferences in order: When man first made his advent in Europe, that continent was still the abode of quadrupeds now long extinct. The caverns were shared with man by the Cave Bear, the Cave Hyæna, and the Cave Lion. These gradually gave place to gigantic Herbivores—the Hairy Mammoth, the Hairy Rhinoceros, and the Reindeer. The Mammoth roamed in herds over the whole of Europe, Northern Asia, and North America (Talk XXVII.). The Hairy, or Two-horned Rhinoceros, in company with another two-horned species, thundered through the forests or wallowed in the jungles and swamps. The rivers and lakes of Southern Europe were tenanted by the hippopotamus and the beaver. Three kinds of wild oxen, two of which were of colossal strength, and one of these was "maned and villous like the Bonassus," grazed with the marmot and wild goat and chamois upon the hills and plains which skirt the Mediterranean. The musk-ox and the reindeer browsed in the meadows of Perigord, in the south of France, while a gigantic elk ranged from Ireland to the borders of Italy.

Also in America.

From similar evidences, we learn that primitive man in America was also the contemporary of quadrupeds now long extinct. Beneath the lava of California, the bones of the mammoth and mastodon and the broad-faced ox lie mingled with the bones and implements of man. East of the Rocky Mountains, the relics of the ancient proboscidians have often been discovered in such association with human relics as to afford strong evidence of contemporaneity. On the banks of the Ashley River in South Carolina, human bones, arrow-heads, hatchets and potsherds are found mingled with bones of the hog, the horse, the mastodon, and extinct gigantic lizards. In the same epoch lived the wide-faced bison, the shrub-loving tapir and a gigantic beaver, and a number of gigantic Edentates—wanderers from South America.

The character of primitive man as shown by relics.

If, from the monuments which these primitive people have left behind, we attempt to form an estimate of their physical, intellectual, and moral characteristics, we become at once convinced that in their cranial characters they were equal in rank to the average races of modern times. Beyond all question, they were no connecting links between man and lower animals. The evidences of their intelligence place them as high as the Esquimaux. In mechanical skill they were equal to the manufacture of a large assortment of implements of stone and bone. Before the close of the Stone Age, they produced many evidences of an æsthetic faculty. They polished their stone axes, and worked their arrow and lance heads after more elaborate and artistic patterns. Their pottery began to receive some crude decorations. They carved the bone and horn handles of some of their weapons. They engraved on slate, ivory, and bone the figures of familiar animals ; and among these portraits are sketches of the hairy elephant, furnishing further evidence of their contemporaneous possession of the forest and the plain. These men, also, possessed a religious nature. There are certain emblems and objects which, by general admission, must receive a religious interpretation. The care bestowed on the dead evinces a belief that even after death they retained relations of love and recognition. They sent them on their mysterious journey with such offerings and supplies as should meet their necessities. They felt the notion of a Supreme Divinity stirring within them. A little later they erected altars and built rude temples. The Stone Folk of Europe were every way MEN.

Who were they? And whence did they come? Where did the first men appear? Who was Adam? Are these peoples descended from Adam? These are interesting questions which strike us at this point, and are worthy of study; but I do not regard it expedient to enter upon them at the present time. The reader who may desire to see what can be said about them, may consult "Preadamites; or, a Demonstration of the Existence of Men before Adam"—a work which is essentially a commentary on portions of Genesis and a vindication of Biblical ethnography.

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