FIRST BOOK OF PHYSICAL GEOGRAPHY

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FRONTISPIECE.

Granite peaks in the Yosemite.

FIRST BOOK

OF

PHYSICAL GEOGRAPHY

BY

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PREFACE

In preparing my Elementary Physical Geography, I attempted to present the subject in such a way as to put it forward in its more modern aspect, and particularly to include the new physiography, or science of land form. An effort was made to cover the entire ground in a very elementary way; but at once the difficulty arose that the field was so large, that even to present the subject in an elementary manner would require a good-sized book. To avoid this there were two things possible: one to omit some parts and curtail others; the other to commence the consideration of some subjects with the assumption that either the scholars knew the preliminary points, or that the teacher could explain them. Both of these methods of shortening the book were followed, but even then it grew to a size entirely too large for those schools in which the subject has a minor place.

The result has been, that although this book has met with a success wholly unexpected, many teachers who wish to give instruction in the *new physical geography*, are unable to make use of it. It is partly in the hope of meeting the needs of these, that I have undertaken the preparation of this smaller book, from which still other subjects are omitted, but in which the attempt is made to start from the beginning, and make every topic thoroughly clear, assuming no more than is absolutely necessary in a subject which is based in part upon certain well-known principles of other sciences, notably physics and geology.

If I have been successful in this effort, the other object that I have in mind may also be accomplished. Now, in many of the better schools, geography is taught first as a home study of observation, and this is followed by general geography, and this by physical geography. But the latter subject, as treated in most geographies, is entirely inadequate, and ought to be supplemented, or better still be entirely replaced, by a real study of physical geography in the upper grade of the grammar school. Since the great majority of our youth never go further than the grammar school, I believe that they ought not to be allowed to go out into life without a genuine knowledge of the main principles of air and earth sciences. I feel this strongly, not merely because of the information which they gain, but also because of the discipline and culture which these sciences can impart.

In reality, it is for the last object that I chiefly seek, for I believe that with this information and training, the student, if he enters the high school, will then be able to go on with much greater profit with a more thorough study of the earth sciences, geology and physiography. Indeed, I would urge, that where the general study of physical geography as a whole can be put into the grammar schools, the high schools should take up, *not* a more thorough study of the same subject, on the "concentric" plan, but a fuller study of a part, or better still, several parts, like meteorology, physiography, and geology.

Although having in mind the use of this book in the high school, I would frankly say that I have no sympathy with the conditions which seem to demand it. Modern education should rise above fourteen-week courses, and it is better to omit physical geography, giving its place to a more thorough study of some other science, than to keep it on that plane. By peculiar merits of its own it demands fuller study. It is my hope, therefore, that where this book may be used in high schools in which conditions have made necessary a short course, it may help to create a demand for better and fuller instruction in the subject.

Much of the value of the new physical geography, — indeed I might almost say its whole value, aside from the information which it imparts, — depends upon the way in which it is taught. To assign certain pages to be memorized, and to stop there, whether this is done in the grammar or the high school, is to fail to obtain the full results which can be gained from the study. Simple class-room experiments; laboratory study of specimens, maps and photographs; observations made by students independently, and discussed in the class; practice in grouping facts which logically lead to conclusions; and collective study out-of-doors, should take the place of much of the time-honored recitation. No specific suggestions are made here, but teachers will find some in my earlier book. No school is so unfavorably situated that opportunities for such study cannot be found in abundance; no genuine teacher will fail to find pleasure from the results of such study; and no student will fail to gain great profit from it.

Much good comes in any study when the desire is created for fuller information; and still more benefit arises when to satisfy this desire, students are taught that there are places in which to look, and are given instruction how to find them. To make these benefits possible, I appended at the close of each chapter of my Elementary Physical

Geography, a list of books of reference selected from the best. It is not worth while to repeat these here; but at the end of this book there are a few supplementary references, chiefly to works which have appeared since the former book was published.

This book follows approximately the same order as that of my Elementary Physical Geography, because I believe that this is the best. Still some will be found who prefer a different order, and there is no reason why a teacher who prefers to commence with the land may not do so. As in my Elementary Physical Geography and Elementary Geology, I have introduced illustrations profusely, because it is my belief that next to nature itself, such illustrations are of most value. More can be told in the space occupied by them than in several times that much space in type, and it can be told more clearly. Moreover, some of them can be made to serve as a basis for observation study. A considerable majority of the illustrations are original, but some are copied, and some are reproduced from photographs taken by others. To those who have kindly allowed me to use these I return especial thanks.

RALPH S. TARR.

ITHACA, N. Y., June 1, 1897.

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ACKNOWLEDGMENT OF ILLUSTRATIONS

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OHIO SUPPLEMENT.

Geology and Topography. — The rocks of Ohio are all sedimentary (p. 228), having been deposited in the sea at a time when there was a great ocean extending over the Central States. This was during the Paleozoic time (p. 239), and the strata belong to the Silurian, Devonian, and Carboniferous periods. In this sea, where now the state of Ohio stands, great sheets of shale, limestone, and sandstone were spread out over the ocean bottom (p. 233).

In many of these rocks proof of this ocean origin may be found in the fossils (p. 238) that are entombed in them. Each fossil represents the remnants of an animal or plant which lived in this sea, and, settling to the bottom, became buried in the sandy, muddy, or limy beds. By the deposit of cement (p. 230) these soft beds have become consolidated to form hard rock, and the fossils have been preserved in them.

These layers of stratified rock were laid down horizontally, and, now that they are raised above the sea, they are still in a nearly horizontal position. You can see that this is so in any ledge or quarry in the state. The first part of this sea bottom to be raised above the surface was a broad tract in the southwestern part of Ohio. It was left as a great and low dome extending across the boundary of Ohio into Kentucky and Indiana, and has been called the Cincinnati Arch. For a long time it stood as a low island in the Paleozoic sea.

Then, toward the close of the Paleozoic, in the Carboniferous period, the depth of the sea in the eastern part became less, and a great shallow sea extended from this part of the state to the very base of the Appalachian Mountains in West Virginia and Pennsylvania. Indeed, it was then that the Appalachians were being formed; and, as they rose in great folds of rock (p. 336), the region to the west of them, where Ohio now stands, was lifted also, but, in this part, without any folding or crumpling of the rocks, such as occurred where the mountains rose.

Sometimes this shallow sea bottom was lifted above the water, and great swampy plains, perhaps somewhat like those of Florida (p. 333), were formed. On these swamps the coal plants grew and built beds of swamp muck, which were later buried beneath layers of clay and sand, and slowly changed to the coal which is so valuable to the states of Ohio, Pennsylvania, and West Virginia.

Finally Ohio became dry land, and so it has remained nearly, if not all of the time since. This all happened so long ago that there has been much chance for change. While the state has been standing weathering in the air, as a dry land part of the continent, and rivers have been slowly carrying the rocks away. The streams have cut down through the sheets of sedimentary rock and carried a great deal off to the sea, including many hundreds of thousands of tons of coal. These rivers have been so long at work that they now occupy mature valleys (p. 270), excepting in those places where they have been locally changed or *rejuvenated* (p. 274) by the glacial deposit to be described later.

The topography of Ohio is therefore that of a plain, underlaid by nearly horizontal rocks, and cut by many deep and broad valleys with gently sloping sides. Standing in the bottom of some of these valleys, such as the Ohio, with the hills rising from 400 to 700 feet above the valley bottom, one might not recognize the scenery as that of a plain; but if one should go to the top of a high hill, he would find that many other hills rise to nearly the same level, and that they all form a part of a dissected plain. In fact, if one could look down upon Ohio from above, he would see that it was really one great plain, higher along the Ohio divide, which extends in a northeast and southwest direction across the state, and where some of the highest hills are 1200 to 1500 feet above the sea level. Moreover, this extensive plain is but a small part of a much larger one extending from the Appalachians to the Rockies, and rising higher still near the base of these mountains. This plain is really a broad plateau near the base of the Rockies, and also near the base of the Appalachians, and its lowest part is near the middle, where the Mississippi River flows.

Through this dissected plain many streams extend, most of them entering the Ohio, either directly or through the Wabash, but some passing into the St. Lawrence drainage through Lake Erie. The drainage lines of the state may be studied on any good map of Ohio.

Effects of the Glacial Period. — In the period just preceding the present, that is, during the Pleistocene (p. 239), there came down over this region of plains the great continental glacier (pp. 305–312), and this changed the physical geography of Ohio in a most important manner. The glacier did not cover all of the state, but left the southeastern corner uncovered (Fig. 199). In other parts of Ohio proof that the ice visited the region may often be found, for there are pebbles frequently scratched (Fig. 162) and quite different from the rocks near by; and, where the bare rock has been recently uncovered, glacial striæ (Fig. 167) may be found, showing where the glacier has ploughed over the bed rock.

These striæ tell the direction from which the ice came, and the arrows on the map (Fig. 199) show that this direction was mainly from the north and northeast. But in different parts of the state there were currents moving in various directions, as will be seen by studying the map (Fig. 199).

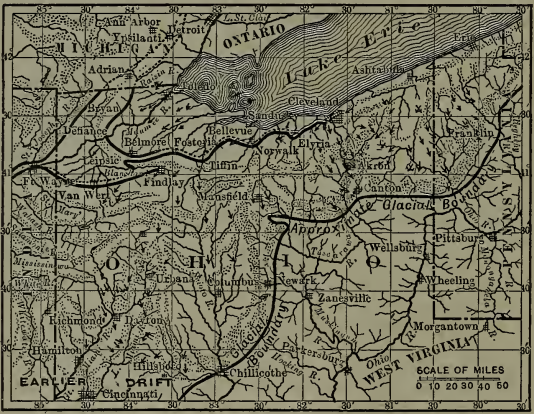

FIG. 199.

Map showing moraines of Ohio by dots; direction of ice movement by arrows; and beach lines by heavy and dotted lines southwest of Lake Erie. After Leverett.

Along the margin of the glacier a terminal moraine (p. 308) was built, and when the glacier slowly melted away, so that its front stood at different points north of this terminal moraine, other morainal deposits, known as moraines of recession, were built. The dotted spaces on Fig. 199 show where these moraines of recession were built, and each line represents a halt in the withdrawal of the ice. Many of the small drift hills of Ohio are parts of this moraine, and perhaps some of them are so near that you yourself may see them.

Not only were moraines built at the margin, but a sheet of till (p. 306) was deposited wherever the ice stood. This till forms the soil of much of the glaciated portion of the state, and in some places, particularly in the western part of Ohio, it is very thick. Some of the wells that have been bored for oil have passed through 200, 300, 400, and even 500 feet of glacial drift. In many places this sheet of glacial deposit is so deep that the river valleys have been made shallower, and some entirely buried beneath the drift. As a result, there are buried valleys in places where no one would know about it, if wells had not been sunk there, showing hills and valley bottoms beneath the glacial deposits. The Cuyahoga valley is one of those that is deeply filled with drift.

Fig. 200.

Till plain near Columbus, Ohio.

The moraines and the till sheet have been laid down irregularly, so that little lake basins have been formed; and the many ponds and tiny lakes, found here and there in the state, have been caused in this way. Many of the swamps and peat bogs are ponds of this kind that have been filled by the aid of vegetation (p. 292). Even Lake Erie itself has been partly caused by deposits of glacial drift which have choked up the valley that, before the glacial period, was occupied by a river where Lake Erie is now situated. Probably, also, glacial erosion (p. 312) has helped to deepen the basin of Lake Erie, by scooping out some of the rock as the ice passed along the Erie valley.

By the deposit of all this drift, many other changes were made in the drainage. The gorges and waterfalls that occur in the state are the result of some of these. Where these young portions of rivers are found, it may be assumed that the streams are not flowing in their old preglacial valleys, but that they have cut out new valleys since the glacial period.

FIG. 201.

Present drainage lines of Upper Ohio. Chamberlin and Leverett.

One of the most important effects of the glacier was to rob the St. Lawrence system of many of its tributaries and give them to the Ohio. In Fig. 201 we have a sketch map showing the present drainage, and in Fig. 202 a similar map showing the *probable* course of the streams before the glacial period. By comparing these maps, it is seen that the entire upper headwaters of the Ohio were apparently given to it during the glacial period. What a vast difference it would have made to the state had this not been done! The Ohio would have been so much smaller than now that it could not have been nearly so useful as it is.

One of the reasons why it is believed that all these changes occurred is that in some places (as near the mouth of the Grand River) the old valleys are deeply filled with drift. A second reason is that the Ohio narrows up near North Martinsville so that this seems to be a divide, over which the water poured when the ice was here, and cut the valley so low that, after the ice had gone, the drainage was able to flow southward instead of northward, as it formerly had. A third reason for this belief is that the rock floor of the valleys, as revealed by borings, indicates a northward flow for some of the Ohio headwaters.

FIG. 202.

Probable preglacial drainage of Upper Ohio region. Chamberlin and Leverett.

There are many other interesting effects of the glacier on the drainage of the state. For instance, notice on Fig. 199 how peculiarly St. Joseph's and St. Mary's rivers unite. They flow together, one from the southeast, and one from the northwest, as if they were going toward the Wabash; but, instead of doing this, they unite and flow back toward Lake Erie through the Maumee. Together the three streams form something like the barbed head of an arrow. The reason for this, as you can see on the map (Fig. 199), is that the two rivers flow on the western side of a moraine, which prevents them from sooner turning toward the east. It will be noticed that several other streams have their courses determined by the moraines.

When the ice was withdrawing from this section, a tongue, or *lobe*, extended up the Maumee valley, causing the moraine to turn southwest in that valley; but in time the ice front began to withdraw from the Maumee. This river naturally flows northeastward, and consequently the ice formed a dam across the river (Fig. 203) so that the Maumee could not flow into Lake Erie as it now does (p. 292). This caused a lake to form, which had an overflow past Fort Wayne, Indiana, into the Wabash. The shores of this lake can now be plainly seen in the Maumee valley at an elevation of about 250 feet above the lake and along the line marked on Fig. 199. It passed through Findlay, Delphos, and Bryan. Where the overflow occurred, near Fort Wayne, there is a broad channel cut in the earth, which is now not occupied by a stream.

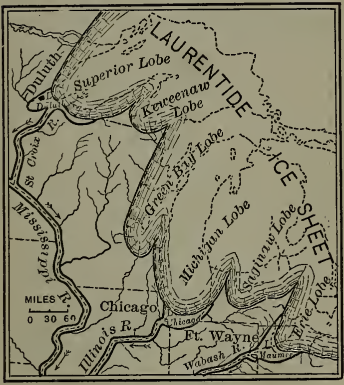

FIG. 203.

Map showing outline of glacier front and position of glacial lakes while the ice was receeding. Present lakes shown by dotted lines. Taylor in Dryer's Indiana Studies.

As the ice withdrew still further from this region, it opened a still lower outlet for these waters past the present city of Chicago, and then the Maumee lake fell to a lower level (Fig. 204), and while the water stood here another beach was built. It passes through Tiffin, Belmore, and Delta (Fig. 199). This beach extends eastward along the shores of Lake Erie, passing through the city of Cleveland; and there are still lower beaches between these and the lake, marking drops in the level of the water as lower outlets were discovered, until, finally, the outflow was eastward when the ice front had melted back far enough to the north to allow the waters to flow in that direction.

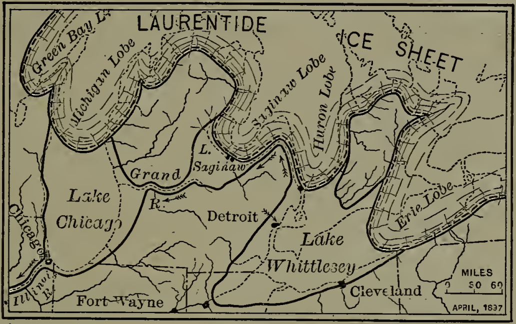

FIG. 204.

Same as Fig. 203, later stage when the outflow was past Chicago. Taylor in Dryer's Indiana Studies.

Not only are there beaches of sand and gravel along these lines, but also extensive deposits of clay in the Maumee valley and along the Erie shore. These were clays deposited in the glacial lakes along the ice front, somewhat as clay is now being carried into Lake Erie by the various streams and deposited over its floor. In this clay-covered section of Ohio there were extensive prairies (p. 335) when the state was discovered; but in some of the other parts of the state forests existed, though most of them have now been removed because of the value of the land for farming.

Industries of the State. — A region owes its industries and material development to its physiography; and even the people themselves are influenced by it. Few states furnish a better illustration of this influence than Ohio. The climate is pleasant and temperate and the rainfall heavy enough, and generally uniform enough, to ensure good crops. This rain falls upon plains, which, even where most dissected, are only cut into hills and valleys of moderate slope. This surface is for the most part covered with a rich soil, and over the larger part of the state by a soil brought by the glacier. In places where a soil has resulted from the decay of sandy rocks (p. 256) it is liable to be sandy and sterile; but when the soil has been transported, as in most of Ohio, even a sandy rock may be covered by a blanket of rich soil. Because of the level surface, the fertile soil, and the rainfall, Ohio is eminently adapted to successful agriculture. So it is that the state is so productive of the various farm crops, dairy products, and wool.

Besides the general conditions of climate, there are many local modifications, as, for instance, along the shores of Lake Erie, where the climate is made more moderate by the presence of the water, so that fruit raising is one of the industries there. In the southwestern part of the state, fruit, tobacco, and other delicate crops thrive well because of the more southern latitude; and oftentimes there is a difference in effect of climate between hill top and valley bottom.

Beneath the soil are other natural resources. The coal beds furnish abundant fuel; petroleum and natural gas[1] furnish heat and light; and the iron beds have been of

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[1] These substances are hydrocarbons, one liquid, the other gaseous, and both derived from the distillation of organic remains in the rocks, notably, in Ohio, in the Trenton limestone. They are formed somewhat as marsh gas is formed in swamps; but, being unable to escape from the rocks, they have slowly accumulated there until men have bored wells to the places where they are stored. For an excellent account of the Ohio oil and gas, see Orton, in the Ohio State Geological Survey Report, Vol. VII., or Part 2, Eighth Annual Report, U. S. Geological Survey.

importance in starting iron manufactories, though some of them are now maintained by iron brought from beyond the state. The excellent building stones found among the horizontal sedimentary strata have been a source of wealth, and other mineral resources have been of importance.

With the natural resources of the state, of necessity manufacturing has developed to meet the needs of the producer and consumer. All of these industries have been greatly aided by the drainage lines and the general levelness of the region. The great Ohio, swelled in volume by the addition of extensive headwaters, is navigable, and upon it, as upon its larger tributaries, the crops and manufactured articles have been shipped with ease. Many towns and cities on these rivers, headed by the largest city in the state, Cincinnati, prove the importance of these drainage lines; for at these places factories have been started, and material shipped in such quantities that cities have of necessity grown.

Then, also, Lake Erie bounds northern Ohio, and the products of the state may be shipped over it, while the products of other sections may be brought in upon the same waters. This opens up not only all of the immense area around the Great Lakes, but even the ocean itself. Along the lake shore manufacturing towns and shipping ports have grown, and these are naturally located where vessels may enter to load and unload their cargoes: that is, where there are harbors. Toledo, on a harbor at the extreme end of the lake, and Sandusky, on another harbor, are illustrations of this. Cleveland, a city almost as large as Cincinnati, is also situated on a natural harbor which was large enough for all purposes when the city was founded, but has long since become too small, so that now an artificial harbor has been made necessary. With the growth of the city an extensive breakwater has been built in order to accommodate the growing shipping industry. Each of the large cities, as well as most of the small ones, owes its location to some natural feature which gave it some superior advantage and permitted it to grow. A person living in such a place can easily find out what this was in each particular case.

Man has of course been at work improving the opportunities that nature offers. He has not merely tilled the soil, extracted the mineral treasures, and manufactured articles from these products, but he has improved the means of carrying these materials about. First of all, before railroads were of importance, canals were dug, and this was made possible in Ohio by the levelness of the surface. Over these canals products could be carried from places which had no natural waterway, and in this way also towns were caused to develop. The building of canals in this state has had an important effect upon the growth of many towns, and even large cities, such as Toledo, Cleveland, and Cincinnati; for the canals connect them with large areas of the state by a very serviceable waterway.

Now that railroads have been built they have served chiefly to make the cities previously established grow more rapidly. These cities got their start because of natural advantages, and the railroads were obliged to go to them, so that even the railroads themselves have been influenced by the natural features; and this, too, in still another direction, for if you will look at a map of Ohio you will see that a great many of the railroads follow the valleys, though in the places where the surface is most level it has been possible for them to extend across country.

All who study this book may, if they have the desire, learn some interesting and valuable lessons in attempting to find out how far their homes, and even their very lives, have been influenced by the physical geography of the region in which they dwell. Many gifts have been placed before man, and he has not been slow in finding them and putting them to the uses for which they are suited. If you have learned this lesson, and seen its application in some cases, you have been rewarded for this study.

The teacher may wish to read more upon the subject of the physical geography of Ohio, and for this reason these few references are appended. First of all are the reports of the Ohio State Geological Survey, every one of which contains much of value, and in some of which the county geology is discussed. These books are in many private and public libraries, and copies may often be found in the second-hand bookstores. Dryer's Studies in Indiana Geology (Inland Pub. Co., Terre Haute, Ind., 1897, $0.50) contains much on the physical geography of Ohio, especially on the Great Lake history. The change in the Ohio drainage, mentioned above, is discussed by Chamberlin and Leverett in the American Journal of Science, 1894, Vol. XLVII., pp. 247–283; and the moraine of Ohio by Leverett in the same journal, 1892, Vol. XLIII., pp. 281–301. There are many other papers on the geology of the state, and reference to some of these may be found in the sources mentioned in this paragraph.

Part I

INTRODUCTION

FIRST BOOK OF PHYSICAL GEOGRAPHY

CHAPTER I

CONDITION OF THE EARTH

Form of the Earth: *The Earth a Sphere.* — Standing upon the seashore, and looking out upon the broad expanse of water, we see ships sailing along, some near at hand and some far away. Those that are near show the sails, spars, and even the hull down to the water's edge, but only the sails and masts of the more distant ones are seen, and perchance one in the offing is detected only by its topmast (Fig. 1).

Fig. 1.

The ocean surface to show curvature of the earth.

This is because the surface of the earth, and the water upon it, is curved (Fig. 2). The vessel gradually disappears behind the curvature of the earth, just as a man disappears from sight as he passes over the crest of a hill. There are other proofs that the earth is a spherical body. For instance, if we should start on one of the ships, we might pass entirely around the globe and return to the point whence we started. Or, by travelling over land and water, we can go due east or due west, and in time find ourselves back at the starting point (see a globe).

FIG. 2.

To illustrate curvature of earth. A person standing at *B* could not see an object at *C* unless it rose to the level of the line *AB*.

Longitude. — Should a dozen people start from as many places, such as New York, San Francisco, London, etc., and be able to go due north, their paths would all converge toward a point at which they might eventually meet; and this point, which is so enwrapped in ice and snow that it has not yet been visited by man, is called the *North Pole*. Passing due south from these same places, the travellers would in time meet at a point in the south, which is called the *South Pole*, and this region also is inaccessible to man.[1]

In mapping the globe, geographers are in the habit of projecting lines in the direction of these imaginary journeys, and these all converge toward the poles. These *meridians*, or lines of longitude, are 360 in number, and each of these is spoken of as a *degree of longitude*.[2]

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[1] The North and South Poles are the imaginary points on the surface of the earth through which the axis of the earth emerges. This axis is that about which the earth rotates, just as a globe or an apple may be made to rotate about an axis. These are not the same as the *magnetic poles* toward which the compass needle points. The north magnetic pole lies to the southward of the true North Pole, and is situated in Boothia Land, north of Hudson's Bay.

[2] Since there are 360 lines of longitude it follows that at the equator the length of a degree of longitude is very nearly 69.16 miles. As

The distance between these varies, for they broaden out and spread apart as the distance from the poles increases (Fig. 3). Where furthest apart the distance between two meridians is about 69 miles. Each *degree* (°) is divided into 60 *minutes* (′), and each minute into 60 *seconds* (″), and the longitude of any place is given in degrees, minutes, and seconds. Greenwich Observatory, England, has been chosen by English-speaking people as the place from which to start in numbering these degrees.[1] From Greenwich as the zero, the meridians are numbered toward the east until 180° is reached, and this is known as *east longitude*, while *west longitude* is located in the same way

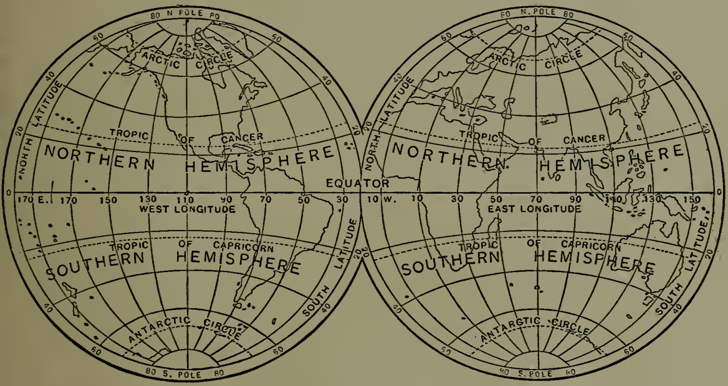

Fig. 3.

To illustrate latitude and longitude.

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we proceed toward the poles the length of a degree of longitude becomes less and less until it is 0 at the poles.

[1] In France the Observatory of Paris is taken as the starting place, and this lies 2° 20′ 9″ east of Greenwich; but English-speaking people do not use this.

toward the west. Thus the United States is in west longitude.

Latitude. — In order to locate places on a sphere, we must know not only the longitude, or the east or west distance from a place, but also the distance in a north or south direction from some definite part of the earth. Therefore a series of imaginary circles are passed around the earth in an east and west direction. In numbering these, the zero circle is placed midway between the two poles, and to this the name *Equator* is applied. The space between each pole and the Equator is divided into 90°, the length of a degree of latitude varying somewhat, but being about 69 miles. These degrees are also divided into minutes and seconds.

Since degrees of latitude are numbered from the Equator as zero, toward each pole, *high latitudes* are nearer the poles and *low latitudes* near the Equator. All north of the Equator is called the *northern hemisphere*, and all south of it the *southern hemisphere*. Since latitude is measured both north and south of the Equator, there is *north latitude* and *south latitude*, the United States being in the former. Since we know the size of the globe, if we determine the latitude and longitude of any given place, we can easily tell its exact distance from any other known part of the earth.[1]

The Earth an Oblate Spheroid. — The diameters of a *true* sphere must be the same in all parts; but that of the earth is 7899.1 miles, measured along the axis from pole to pole, and 7925.6 miles at the Equator. This shows a

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[1] It would be well to spend some time upon this subject, giving the students some practice lessons, so that they may fully grasp the meaning of latitude and longitude.

slight flattening in the polar regions, and a protuberance, or bulging, in the equatorial part, and the sphere is thus distorted into an *oblate spheroid.* In an ordinary study of the earth's surface this flattening by about 13¼ miles at each pole would not be noticed; but in the movement of the earth through space, this deflection from a sphere has produced very marked effects. Because of this difference, the length of the degree of latitude varies from equatorial to polar regions, being less than 68 miles in India, and a little more than 69 miles in Sweden.

General Condition of the Earth. — Speaking broadly, there are three parts to the earth: (1) the solid earth itself; (2) the partial water envelope; and (3) the gaseous envelope, or atmosphere.

Air. — The air is in constant movement, performing many tasks of importance. We breathe it; it gives life to plants and animals; it diffuses the heat and light which reach the earth from the sun; it brings us our winds, clouds, and storms; it furnishes the oxygen by which our lamps may burn and our fires glow; it ruffles the ocean surface with waves, and drives our ships along; and in many hundred other ways it serves us. Yet the air is merely a thin, transparent mass of gas, whose constant presence about us is hardly realized (Part II).

Ocean. — The ocean shuts out from view nearly three-fourths of the solid earth, and in places buries it beneath a depth of four or five miles of water. Its surface is so nearly level (that is to say, it is parallel to the general surface of the globe), that we may sail upon it for thousands of miles without a glimpse of any other irregularity than the waves which disturb its surface.

Like the air, the ocean enwraps the globe, and conforms to its general outline, being held in place by the force of gravity, by which the earth binds to itself all movable objects on its surface. This level water surface, the *sea-level*, is the plane from which we determine the elevations on the land. It is not strictly level, but is slightly distorted by various causes.

The Solid Earth. — Some portions of the land are still inaccessible, and great areas near each pole have so far baffled all the efforts of venturesome explorers; but while we have now visited most lands, our knowledge almost ceases when we pass below the very *surface*. Accumulated *on* the surface there is generally a soil, and beneath this, usually at depths of only a few feet, hard rock of various kinds is encountered. Here and there wells and mines pierce to the depth of a mile or more, and to this depth, at least, the solid rock extends; but we can only speculate concerning the conditions below this level.

In all deep borings and shafts, it is found that the temperature of the earth increases with the depth; and while there is a considerable variation from place to place, the average condition shows an increase of about 1° for every 50 or 60 feet of descent. If this continues toward the centre, as it probably does, the temperature of the earth must be very high at the depth of a few score of miles. Indeed, it seems that at great depths the temperature must be higher than the melting point of rocks at the surface. In fact, here and there melted rock comes to the air, through cracks reaching down into the earth, and in this case volcanoes are formed.

It was once believed that these facts proved the earth to be a great globe of liquid, molten rock, around which was a solid rind or *crust*. But astronomers have shown that this cannot be; for in its behavior toward the planets, the earth acts like a *rigid body*, and if there is molten material, the outer crust must be very thick. Scientists now believe that the interior is *highly heated*, but that it is kept in a solid condition by the great weight of the overlying rock.[1] We still use the term *earth's crust* as a convenient word to express the solid and relatively cold outer part of the earth.

Surface of the Earth: *Continents and Ocean Basins.* — When the earth is represented by a map or globe, it is customary to make the surface perfectly smooth; yet we all know that the earth's surface is very irregular. This is because the irregularities with which we are familiar are small compared to the size of the earth. While the diameter of the sphere is about 7900 miles, the greatest irregularity of the land above sea-level is only about five miles.

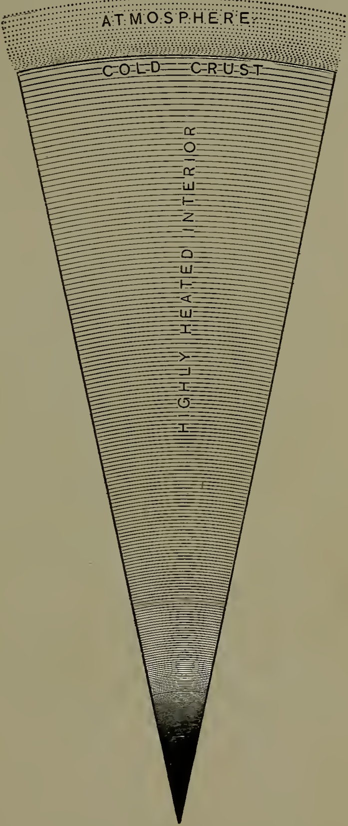

FIG. 4.
Section to show relative amount of air and solid earth, and the supposed condition within the earth.

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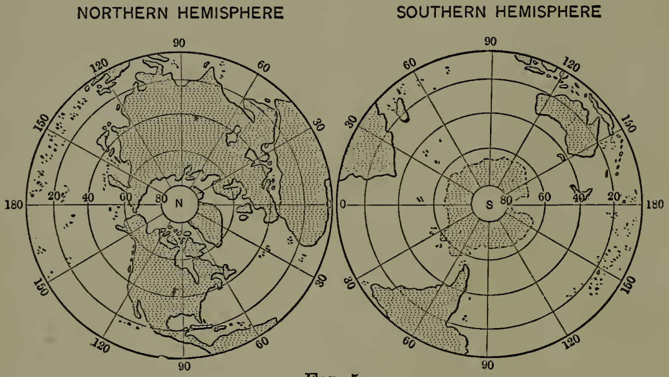
[1] It may be stated that an increase of pressure *raises* the melting point; and at a depth of several miles in the earth, the pressure of the load of

The surface is diversified by a series of grand elevations and depressions, the full extent of which is obscured by the ocean. The continents are the elevations, the ocean beds the depressions. There are two sets of continents, the New World, including North and South America, and the Old World, including Eurasia, Africa, and Australia.


NORTHERN HEMISPHERE

SOUTHERN HEMISPHERE

FIG. 5.

The two hemispheres, showing the grouping of continents and oceans.

On a rather arbitrary basis it is customary to divide these land masses into individual continents. The smallest, Australia, is quite completely separated from the others, though there is a partial connection with Asia by way of the East Indies. Europe and Asia cannot be *naturally* separated. Africa is removed from Eurasia only by the relatively narrow Mediterranean and Red seas, being connected at the Isthmus of Suez; and the two Americas are directly connected by the Isthmus of Panama, and partly also by the West Indies and the Antilles.

rock above must be very great — so great, in fact, that melting may be impossible.

Between these groups of continents there are two great oceans, the Atlantic and Pacific, while between the African and Australian prolongation of the Old World land-group, is another large ocean, the Indian. Around each pole there is some land and much water. That around the South Pole is called the Antarctic Ocean, and that surrounding the North Pole the Arctic. Although open to the Atlantic, the Arctic is much more enclosed than the Antarctic, which has no natural boundary line between either the Pacific, Indian, or Atlantic. The Arctic may be considered to be a northern prolongation of the Atlantic, and the Antarctic to be parts of the Pacific, Atlantic, and Indian.

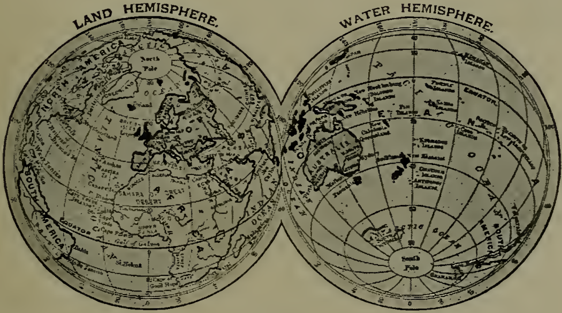


Fig. 6.

Land and water hemispheres.

Viewing the globe as a whole, we find that the water predominates in the southern hemisphere, and the land in the northern. It is also noticeable that the water projects, in somewhat triangular tongues, from the great nucleus around the South Pole, toward the North Pole, and that the continent groups project somewhat triangular tongues from the land area of the northern hemisphere toward the South Pole. This development of the land in one hemisphere, and the water in the other, makes it possible to divide the earth into two hemispheres, in one of which there is little land, while in the other the land is distinctly in excess of the water (Fig. 6). These are called the land and water hemispheres.

Not only does the sea cover a greater area than the land,[1] but the *average* elevation of the land is much less than the average depth of the ocean.[2]

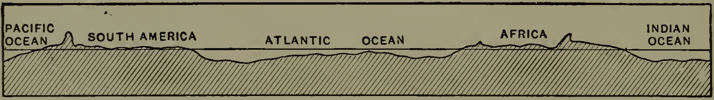


Fig. 7.

Section across South America, Atlantic Ocean, and Africa, showing greater depth of ocean.

Mountain Irregularities. — The second group of irregularities are those occurring along relatively narrow lines. Upon the continents, ranges and ridges of mountains rise above the general level of the land, usually from the crest of a high plateau. The most remarkable of these mountain groups is that facing the Pacific in the two Americas, and extending from Alaska to Cape Horn. Occasional peaks in these mountains attain an elevation of three or four miles above sea-level; and often, as in the case of the

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[1] The area of the earth is not far from 190,700,000 square miles, of which about 144,700,000 is water surface and 52,000,000 land, the area of the water being about three-fourths of the total.

[2] The average depth of the ocean is computed to be about 12,000 feet, while the average elevation of the land above the sea, is only about 2500 feet, though if the ocean could be removed, the continents would stand as great elevations rising, on an average, fully 14,000 feet above the ocean beds. In some places of exceptional ocean depth and land height, the difference between ocean bottom and mountain peak would amount to about 60,000 feet, or over eleven miles, and in a single view there would be some cases of elevation amounting to fully eight miles.

Rocky Mountains, the plateau above which they rise is fully a mile above the sea.

At times mountains extend into the ocean, as in the case of the Kamtchatka peninsula. By means of these mountains, great peninsulas and chains of islands, such as the Japanese group, partially cut off and enclose arms of the sea. Very often, elevations rise entirely *in* the sea, perhaps in mid-ocean, and then, as in the Hawaiian Archipelago, there are produced chains of *oceanic islands*. These are often the higher peaks of a partly submerged mountain range; and not uncommonly they are volcanic cones, just as some of the higher peaks of the mountains on the land are volcanoes (Chapter XX).

Minor Irregularities. — There are many minor irregularities of the land, which are mainly the result of the carving of the surface, by the weather, rivers, and ocean. By these forces the land is constantly being cut into hills and valleys, so that in the course of long periods of time, our land surface has become very much worn, dissected, and sculptured. Some of the causes for these irregularities are described in the chapters on the land (Part IV).

Movements of the Earth: *Rotation.* — Every day, over most of the earth, the sun rises in the eastern sky, and after travelling across the heavens, sets in the west. Between sunrise and sunset the earth is bathed in light and heat; at night darkness prevails, and coolness takes the place of warmth. Before it was known that the earth was a sphere, it was thought that the sun actually rose and set, making a daily journey across the heavens; but for a long time we have known that this *apparent* movement of the sun is really due to the motion of the earth. Our globe is spinning about an axis which passes through the poles, as one might make an apple rotate by using the stem as an axis.

This spinning or *rotation* of the earth is constant and quite uniform, and the complete rotation is made in a little less than 24 hours (23 hours and 56 minutes), or the time between two sunrises. So, as the earth rotates, turning toward the east, the sun appears to rise in the east and to move across the heavens as the day advances. If we could travel across the earth at the Equator, going at the rate of about 69 miles in 4 minutes, the position of the sun in the heavens would remain the same: starting at the sunrise, the sun would remain on the eastern horizon, and at the end of the 24 hours we would be at the starting place, with sunrise still present; but those who remained behind would have experienced the complete changes of day and night.

This is the same as saying that the earth rotates at this rate, and that the sun's rays advance over the land in this rapid way. But the diameter of a circle of latitude decreases from the Equator toward the poles, and therefore the sun's rays creep across the globe at a less and less rapid rate as the distance from the Equator increases. It takes the earth about 24 hours to make the complete rotation, whether at the Equator or near the poles; and hence the time between two sunrises is everywhere the same, although the *distance* over which the rays pass from hour to hour decreases toward the poles.

The division of the earth by meridians is based on this fact, the distance between two of these lines being that which the sun passes in about 4 minutes. This distance is greatest at the Equator, and hence the meridians spread further apart as the equatorial belt is approached. The sun travels from meridian to meridian in 4 minutes; and as there are 24 hours in which to make the journey, this necessitates 360 meridians on the earth (24 × 60 = 1440; 1440 ÷ 4 = 360). For the same reason, if we travel toward the west or the east, we find the time to be constantly changing, the rate of change being 4 minutes for each degree of longitude.[1] While the sun has been an hour above the horizon with us, 15° west of us it is just rising.

If a body on the earth at the equator travels over a distance of 25,000 miles in a day, going at the rate of about 17 miles a minute, the question may be asked, Why are not air, water, and all movable bodies, left behind and hurled into space? The answer is that *gravity* draws all things towards the earth and binds them to it. They are a part of the earth, moving with it, just as a person becomes a part of a train which is whirling along at the rate of a mile a minute. If the earth could suddenly stop, all movable bodies would be hurled away, just as, when a train suddenly stops, the people are thrown forward.

Revolution: THE SUN IN THE HEAVENS. — Though rising and setting every day, the sun each morning rises in a different place from that of the preceding day. This is scarcely noticeable in two succeeding mornings, but from month to month is distinctly seen. The sun slowly changes its path through the heavens, now being low, again high at midday; and as this path changes, our seasons vary. In about 365 days (365.24 days) the cycle of seasonal

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[1] In this country, in order to avoid the confusion resulting with every town having its own true or *solar time*, artificial boundaries have been drawn parallel to the meridians, so that at distances of 15° the time changes one hour, while all places between two such meridians have the same *standard time*. There are several such belts, and now, when we travel across the country, we are obliged to set our watches when we come to the boundaries, setting them back on the journey west and ahead when going eastward. In this country there are five divisions of Standard time as follows: Intercolonial (52½°–67½°), Eastern (67½°–82½°), Central (82½°–97½°), Mountain (97½°–112½°), and Pacific (112½°–127½°).

changes — *the year*, we call it — has been passed through; and then we again go over the same cycle.

If we could spend a year at the equator and others at various points between this and the poles, we should find an entire difference in the seasons of the several places. In *each place* the sun would have a new series of movements, but in a *single locality*, the cycle would be the same year after year.

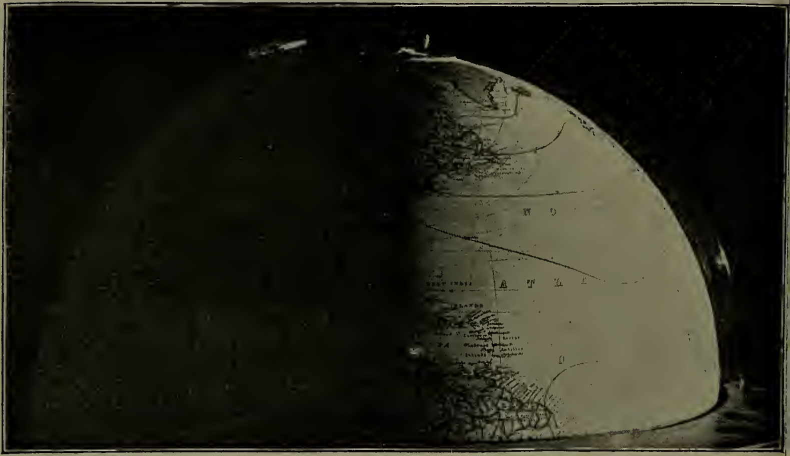

Fig. 8.

To illustrate day and night at equinox, when the sun's rays reach both poles.

At the equator the sun would rise nearly in the east, pass almost directly overhead at noon, and set in the west. During the season which corresponds with our winter, the midday sun would be somewhat south of the zenith, and during the season corresponding to our summer, it would be an equal distance north of the vault. Passing 23½° northward, we should find the sun to be always *south* of the zenith, excepting in midsummer, when it would exactly reach the zenith at midday; in midwinter it would be furthest south. Passing north of this, the sun would *always* be found in the southern half of the sky. At midday, in winter, it would be very low, while at the same time, the days would be short and the nights long.

These conditions continue to increase until within 23½° of the pole, where the midsummer sun rises fairly high in the heavens, but in midwinter just reaches the southern horizon. Beyond this the sun does not *generally* have a daily rising and setting, but remains above the horizon for weeks, and further north for months at a time. Then it passes below the horizon to stay during the long, cold winter night.[1] What is said of the northern hemisphere is equally true for the southern, if we change south to north, and north to south. Our winter is the southern summer, and *vice versa*.

CAUSE OF SEASONS. — These peculiarities are the result of a second movement of the earth, its *revolution* around the sun. Although the sun is on the average about 92,800,000 miles distant, the tie of *gravitation*, which extends throughout the solar universe, keeps the sun and earth together, while the latter revolves around the former, whirling through space at the rate of 1000 miles a minute, and making the complete journey in a year, and year after year going over approximately the same path. If it were not for the revolution, and the earth were merely a rotating

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[1] During the summer the sun circles near the horizon, dipping toward it at night, when it is near the north (Fig. 71), and rising higher at midday, when it has circled into the southern quadrant. Between the winter night and summer day there are short seasons when the sun does actually rise and set. Exactly at the pole the sun is above the horizon half the year, and below it the other half.

sphere fixed in space, we could have no seasons, but each day would be like the preceding. The same would be true if the earth revolved about the sun with its axis vertical to the plane of revolution. Then the sun's rays would reach the equator over the zenith at noon of every day in the year, and north of the equator, at any given place, every day would find the sun in the same part of the heavens, and the sunrise and sunset would always be at the same place. As the poles were approached, the sun would be lower and lower in the heavens, until at the exact pole, it would be seen making a complete circuit of the horizon. This is exactly what happens twice each year, at the time of the *vernal* and *autumnal equinoxes* (the spring and autumn, March 21 and September 22

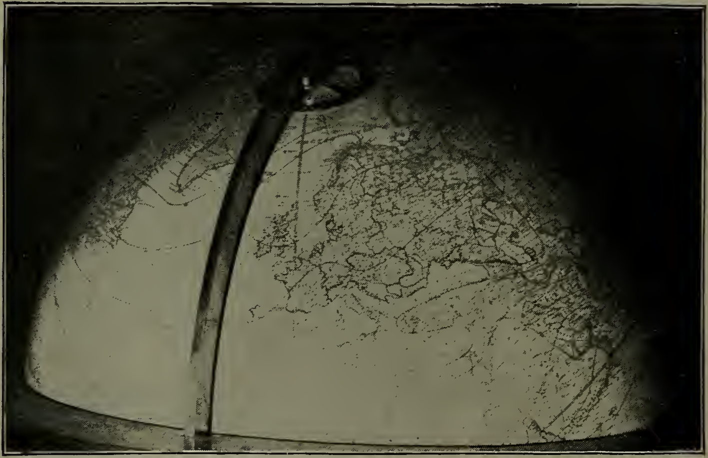

FIG. 9.

To illustrate conditions in northern summer when the whole Arctic is bathed in sunlight.

respectively), when the day and night are equal in length, each being 12 hours (Fig. 8).

In reality, the earth revolves with its axis inclined at an angle of about 23½° (exactly 23° 27′ 21″) to the plane of revolution, and it is because of this that we have the seasons. Imagine the earth fixed in space and rotating about an axis inclined 23½° to the plane of revolution of the earth about the sun. Suppose that the North Pole is inclined *away from* this plane, and the South Pole toward it (Fig. 10). Then the sun will be vertical at Lat. 23½° south of the Equator, or over the *Tropic of Capricorn*. The whole of the south polar region will be bathed in light, giving perpetual day in that part of the earth. All the southern hemisphere would be light. In the northern hemisphere the sun will everywhere be in the southern heavens, and at a distance of 23½° from the North Pole, the solar rays will cease to light the earth, while beyond this line, which forms the *Arctic circle*, perpetual night will prevail.

Fig. 10.

Condition during northern winter when the sun's rays just reach the Arctic circle.

If on the other hand, the axis is turned with the North

Pole *toward* the sun (Fig. 9), the reverse will be true, and the sun's rays will always be vertical at noon over the northern tropic, *Cancer*, which is 23½° north of the Equator. Beyond the *Antarctic circle*, or a distance of 23½° from the South Pole, a condition of perpetual night is present. If this position were maintained, the one hemisphere would have perpetual winter, the other perpetual summer; and the temperature would decrease from that tropic over which the sun was vertical, toward each pole.

Since the axis *is* inclined, and is year by year pointing toward nearly the same place in the heavens[1] (the north pole pointing approximately toward the North Star), the revolution of the earth about the sun turns the North Pole now toward and now away from the sun (Fig. 11), and so the two hemispheres enjoy alternation of seasons, and are thus treated alike.[2] This is the same as saying, that when the South Pole is turned from the sun, and when winter prevails in the southern hemisphere, we in the northern hemisphere have long summer days with the sun high in the heavens at noonday. This then gradually changes to autumn, when the days become equal in length, and our sun is less high in the heavens. At this time, the rays of the sun cover the entire earth, which is the condi-

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[1] In the course of long periods of time this does change, but this is a question of astronomy which does not bear especially upon the present subject.

[2] It is very commonly the case that the pupil merely memorizes these facts without really grasping the fundamental principles; but the teacher should see to it that each student really understands these points. This can be easily done if the teacher will make intelligent use of a globe, or of any spherical body, showing the way in which the axis maintains its position while the earth moves, and the hemispheres face toward and away from the sun in the different seasons.

tion that would exist if the earth's axis were at right angles to the plane of revolution.

Gradually the sun takes a lower position in the heavens, the day shortens, and midwinter is reached, while at the same time summer prevails south of the Equator. Then begins the return of warmth with the spring and lengthening days. Soon the yearly cycle is over, because the revolution is complete, and the sun has come back nearly to the place where it started the year before. As soon as one revolution is finished a new one is begun, and so year after year the earth pursues its path about the sun, and year by year we find the same alternation of seasons. So distinct is this cycle, that astronomers are able to predict just what the position of the sun, and the length of the day, will be a hundred years from now.

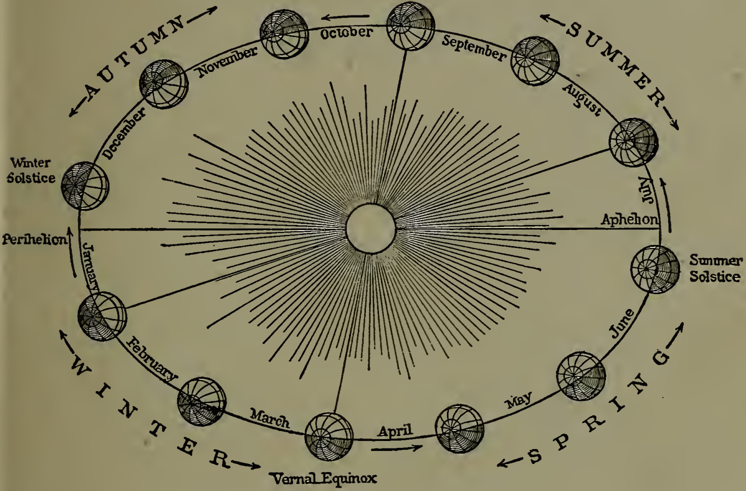

FIG. 11.

To show change in seasons as the earth revolves about the sun (ellipse exaggerated and relative size and distance not shown).

CHAPTER II

THE UNIVERSE

The Solar System: *The Sun.* — The earth is but one of a great family, all having certain resemblances, and all bound together by the common bond of gravitation. They pass through *space*[1] in company, yet each performs certain duties and movements of its own. The central body is the

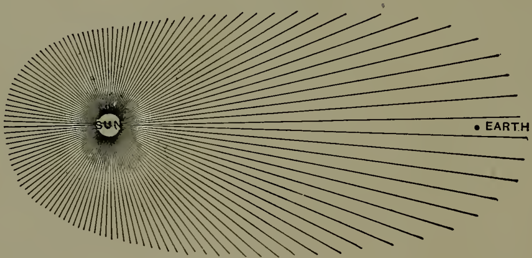

FIG. 12.

To show that of all the light and heat sent from the sun in all directions, the earth receives but a very little.

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[1] Space is the great unknown expanse which surrounds the earth, and so far as we know, extends without limit in all directions. We are unable to conceive of anything without an end, and yet we are unable to conceive of an end to space: space baffles our most acute perception. It is believed to be empty of all substances with which we are acquainted; yet since light and heat pass through it, it is thought to be pervaded by a mysterious *ether*, which allows waves of light and heat to pass from the sun to the earth. Its temperature is believed to be very low, perhaps 200 or 300 degrees below zero.

sun, a hot glowing mass, apparently composed of the same elements as the earth itself, but so highly heated that both heat and light are emitted in all directions into space (Fig. 12). A small part of this is intercepted by the earth as it moves around the sun, and this form of energy performs work of immense importance. Like the earth itself, the sun is a great spherical body, its diameter being about 860,000 miles, or more than 100 times that of the earth. If the centre of the sun were within the earth, its body would not only cover all the space between us and the moon, but it would extend two-thirds as far beyond.

The Planets.[1] — While the earth revolves around the central sun, and receives its light and heat from this source, it is not alone in this, for there are other great spheres which also revolve about the sun in orbits which bear a general resemblance to that pursued by the earth. These are called *planets*, and there are eight of these, which, named in the order of their distance from the sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. They are all somewhat flattened spheres (oblate spheroids), revolving in nearly circular elliptical paths about the sun, and those that are well enough known have been found to have a rotation about an axis. In the heavens they shine as stars; but their light is reflected from the sun. Some, at least, have an atmosphere, but at present our knowledge of most of the planets is very slight.

Jupiter, the largest of these (86,000 miles in diameter),

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[1] Besides the planets there are smaller spheres, called *asteroids*, in the space between Mars and Jupiter. The largest is about 520 miles in diameter, and the smallest less than 40 miles. There are also comets and shooting stars moving in the space occupied by the solar system.

has a mass greater than all the others combined; but it has only one-tenth the diameter of the sun. On the other extreme, Mercury, the planet nearest the sun, has a diameter of about 2992 miles, being only a little less than one-half as large as the earth. The other planets range in size between these two extremes. While the distance of the earth from the sun averages about 92,800,000 miles,

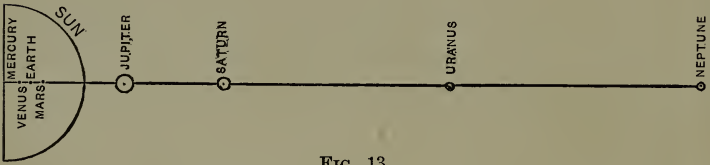

FIG. 13.

Diagram to show relative distance of the planets from the sun, and also their relative sizes.

Mercury is only 35,750,000 miles distant, Jupiter about 480,000,000, and Neptune, the most distant of the planets, is 2,775,000,000 miles away. In travelling through these immense distances, in their journey about the sun, the earth occupies 365 days, Mercury 88 days, Jupiter 12 of our years, and Neptune about 165 years.

Satellites. — While each of the planets is revolving about the sun, all but two of them, Mercury and Venus, have smaller bodies revolving around them. These *Satellites* vary in number, Saturn having eight.

The earth's satellite, the moon, is a cold sphere with a diameter of about 2160 miles, and an average distance from the earth of about 240,000 miles. In company with the earth it moves about the sun, and as it goes, makes the journey around the earth every 29½ days. When it shines, it does so by reflected sunlight.

Being so near the earth, the moon has been carefully studied by the aid of powerful telescopes, and we know more about its surface than we do about any other body in space. Only one side is turned towards us, and we never see the opposite face. On that side which we see there is neither water nor atmosphere: its surface is very rough, and many of the irregularities are great crater-like pits, resembling immense volcanic craters (Fig. 14). It is thought by many that these are craters of ancient volcanoes which are now extinct. Thousands of them, great and small, pit the surface of the moon.

FIG. 14.

Craters and ridges on the moon.

The Universe. — While the earth seems so large to us, and while most of us see but a tiny part of it, and know of the rest only from the description of others, it is, relatively, but a tiny speck of dust in the great universe upon which we gaze every starry night. When we look upon a twinkling star, we see a sun so distant that the very light which meets our eye may have left the star hundreds of years ago; and perchance the star that we see, no longer exists.

In the Milky Way also, which to the unaided eye looks like the gleam of the sun's rays reflected from a thin cloud in the upper air, the telescope finds myriads of stars, one beyond the other; and beyond these are still others which even the telescope cannot distinguish. In this belt of abundant star-dust, the limit of suns cannot be told; and yet all of these bodies are so fixed in space that year by year their position appears to be unchanged.

What is this space, the nature of which no man can even guess, and the limits of which no man has yet been able to find? Can those who believe that they know the origin of the universe, and who think that they can reduce it to a system of natural laws, throw any light upon this? If so, they have yet to announce an explanation which satisfies the average mind. There is something in this wonderful system that may well cause the human mind to recognize its own smallness and insignificance.

In the heavens there are large clusters of stars, which to the eye are unknown, but which the telescope reveals; and these may be other *stellar systems*, like that which we view when we look into the star-lit vault of the heavens. Is our stellar system, of which the great solar system is but a small part, itself a small portion of a great universe of *many* stellar systems? Here again no answer can be given. Are the tiny stars each a mother sun, with a family of planets? and if so, do these planets resemble ours, and are they inhabited by life? Again we cannot even guess: but why may not this be so; for is it probable that in all this great and apparently endless universe, our tiny earth is the only favored spot?

The power of the human mind is indeed restricted, for we learn by experience. The infant reaches out to grasp objects that are far beyond its reach; the child of two or three will try to make an object pass through a space smaller than itself, and will learn better only by repeated experiments; the boy of ten or fifteen, who has known only his own town or country, can have only a slight conception of the size of the earth; and the man, accustomed to measure by his experiences on the earth, can have no proper conception of the distance of the sun, and cannot even dream of the meaning of a billion miles.

The best that one can do, in lieu of our inability to really conceive this, is to become impressed with the immensity of these distances of space by some comparison with things of ordinary experience. An express train in most cases goes no faster than 60 miles an hour, and as it passes us, it comes and goes with a rush that is almost startling. Let us suppose that we could start on a journey from the sun to Neptune, passing the earth, and the moon, and travelling continuously at the rate of 60 miles an hour. At this rate of speed, it would take 17 days to travel around the earth at the Equator. Starting at the sun, a little more than 176 years would be occupied in reaching the earth. A little more than 166 days would take us to the moon, and the journey from the sun to the planet Neptune would require 5280 years. To reach the nearest star would take several hundred times as many years. That is to say, if one had started from the sun at the beginning of the Christian era, he would still be journeying, and would be only part way between Saturn and Uranus; yet during this period of time a great part of the recorded history of the human race has taken place.

The Nebular Hypothesis: *Symmetry of the Solar System.* — Reviewing the conditions shown by astronomers to exist in the solar system, it is found that the regular members are all spherical bodies, and those that are near enough to have been studied carefully, show a flattening in the polar regions. All that are well enough known, show a rotation about an axis passing through these flattened parts of the sphere; and all of them revolve about the sun in the same direction. The axes of rotation are all inclined to the plane of revolution. The satellites show similar uniformity; and in addition they are revolving around their parent planets. These movements are all so regular that astronomers can predict in advance exactly what they will be. The paths pursued by these bodies are all nearly circular ellipses, at one of the foci of which is situated the central body, the sun, around which the revolution is made. There is therefore a wonderful symmetry of form and movement of the spheres; all obey the laws of gravitation, by which they are all bound together in this regular, well-established system of movement.

There is harmony also in other respects. Astronomy tells us something of the composition of the sun, and in this are found some of the very elements which compose the earth. There appears to be a progressive decrease in heat as the size of the sphere diminishes. The sun, the largest, is intensely hot; Jupiter, next in size, is apparently warm, but is not luminous at the surface; the earth is cold at the surface, and hot within; the moon appears to be cold throughout its entire mass. Again, from Mercury, the planet nearest the sun, to Neptune, the most remote, there is an almost uniform decrease in density of the materials composing the planets.

The Explanation. — It has seemed to men that these conditions called for a uniformity of origin; and before all of these facts were known, philosophers and astronomers had proposed the brilliant explanation for the solar system which we know as the *Nebular Hypothesis.* This is still held by astronomers, and many new facts have been brought to its support. While it cannot be said to be more than a theory, it has the advantage of explaining nearly all the facts, while there is little to oppose it. It is now more firmly grounded than ever before.

Briefly, the Nebular Hypothesis is this: In the beginning, the solar system was a mass of glowing gas, slowly revolving in the direction which the planets now pursue in their movement around the sun. The mass was cooling by the radiation of the heat into space, just as the sun and earth are now still losing heat. There was a certain loss of bulk from contraction, and in the course of time this caused the parent mass to throw off rings, something like those which rise from an engine as it is starting from a railway station. These continued to slowly revolve in the original direction, and gravity gradually drew the mass of each ring together into a spherical body, about some portion which was originally more dense

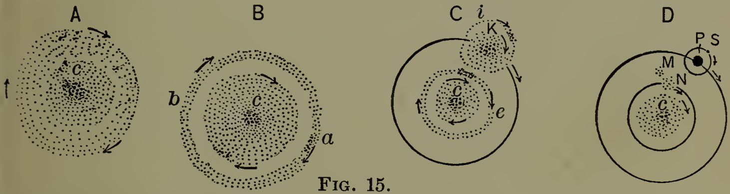

FIG. 15.

Diagram to illustrate Nebular Hypothesis. A mass of heated gas (*A*) more dense at centre (*c*) is rotating in the direction of the arrows; in *B* a ring *ab* is thrown off, more dense at *a* than elsewhere; in *C* this ring has gathered (*K*) around a centre (*a* in *B*) and has itself thrown off a ring (*i*), while another ring (*e*) has come off from the central mass; in *D* a planet (*P*) and Satellite (*S*) have formed, and these are revolving in the direction of the arrows. The ring (*e* in *C*) have also gathered into spheres (*M* and *N*).

than the rest. The sphere of gas continued to revolve about the parent nebula, and to rotate as it went. Some of these spheres have themselves thrown off rings, which upon passing through the same history began to form spheres, which revolved around their parents.

As the heat became less intense, in the course of time these began to solidify, the smallest, and those that were first thrown off, being the first to reach the solid stage. Therefore the sun, which is the largest and most central body, is the hottest, while so small a body as the moon, and so distant a planet as Neptune, are the coldest.

Facts accounted for. — This hypothesis accounts for the uniformity of rotation and of revolution: it explains the spherical form, because gravity, acting upon a gaseous body will necessarily produce a sphere.[1] It explains the flattening at the poles, because, by the centrifugal force, a rotating sphere of gas, or of liquid, will bulge at the Equator, where the rotation is most rapid. It accounts also for the heat of the sun and the earth's interior. It also explains the decrease in density from the inner to the outer members of the system; for the first rings thrown off would be composed of the less dense outer portions of the nebula (just as the air and water of the earth are outside of the denser crust); and finally, it tells why the sun and the earth contain the same elements. At the same time it must be understood that this satisfactory explanation depends upon some very distinct assumptions, and it presupposes that there *was* a nebulous mass of hot gas, revolving and under the influence of gravitation.

If this explanation is correct, the earth is descended from a much hotter body, and has now reached a stage in cooling when only the interior is hot; and it will continue to lose heat until the condition of the moon is reached. In time, in the course of indefinite ages, the sun also will lose its heat, and our globe will be cut off from the supply of heat and light energy which are of such vital importance to all life.

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[1] This may be illustrated by a globule of oil in water, and the flattening may be shown by revolving such a sphere.

Other Nebulæ. — Far away in space, the telescope has revealed masses of glowing gas like that which the Nebular Hypothesis conceives; and some of them show the condensing rings and spheres, like those supposed to have existed when the solar nebula was forming. From this it seems possible, that in the far-away confines of space, other worlds are even now in process of formation. Whether true or not, it is a beautiful hypothesis. It is an attempt of the human mind to explain the most profound mystery of nature, — to account for the wonderful law and symmetry that everywhere prevails; but the mind, although always impelled to *attempt* explanation, is liable to error, and is very limited in its power of conception.

Fig. 16.

The Andromeda nebula showing rings and denser parts in a nebulous mass.

PART II. — THE ATMOSPHERE

CHAPTER III

GENERAL FEATURES OF THE AIR

Importance of the Air. — An invisible ocean of elastic gas surrounds the earth with its life-giving substance. It fans the surface with breezes and disturbs it with violent winds. It carries invisible vapor from water to land, where it falls as rain. It spreads light and warmth over the globe, and in many ways its presence works to the advantage of the varied life that overspreads the earth. Although invisible, the air has substance, and when it is in motion we feel the breeze or wind. We breathe it, and it gives to us materials that are necessary for our existence.

Place an animal in a small enclosed space, and it soon exhausts the air, and although a gas still remains, it is different from the original. The breathing has caused a chemical change, and unless new air is furnished the animal dies. A candle placed in a similar position will soon cease to burn, and it is then found that the gases of the air have been changed by the burning of the candle.

If an animal should be placed under a closed cylinder on an air pump, and the air be exhausted, death would soon result, for there would be no air to breathe and perform the work which the body constantly demands of it. For a similar reason a person suffocates and drowns when kept for a few minutes under water, which excludes the air from the lungs.

Composition: *Oxygen and Nitrogen.* — Careful study has shown that the air is made chiefly of two gaseous elements, *nitrogen* and *oxygen*, about 21% of the latter to 79% of the former.[1]

In the air, nitrogen (and also argon) is a very inert element, which acts as an adulterant to the active oxygen, in a manner similar to the adulteration or weakening of a solution of salt when water is added to it. It is oxygen that is doing the work in the bodies of animals, and causing many changes on the earth. Nevertheless nitrogen is a very important part of the atmosphere; for if it were absent, the bulk of the air would be very much less, and the work of the oxygen more rapid. An animal cannot live in pure oxygen, for this works more rapidly on the tissues than does the adulterated oxygen of the air.[2]

Carbonic Acid Gas. — In a burning candle or lamp, the oxygen of the air is producing a chemical change in the burning substance. If we should exhaust the oxygen, the light would go out. If more oxygen were added, the light would burn much more brilliantly. This *combustion* or *oxidation* is somewhat like that which takes place when a man breathes the life-giving oxygen into his lungs, for then also the oxygen gas combines with other substances.

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[1] In 1894 a new gaseous substance, called *argon*, was discovered in the atmosphere, of which it forms a considerable proportion. It may appear strange that an element which we have always been breathing should so long have escaped detection; but this new element resembles nitrogen so closely that the two have been confused. At present it is impossible to tell much about the new gas.

[2] It is something like the difference between a fire with the draft closed and one with an open draft, through which more oxygen is furnished, thus causing more rapid burning. The teacher can easily show this by an experiment, making and collecting oxygen in a receiver in which a candle is burning.

In a lamp, and in the lungs, oxygen combines with carbon, producing the gas which is known as *carbonic acid gas* (carbon dioxide). This is why a lighted candle in a small jar soon ceases to burn; for after awhile all of the oxygen is consumed by combining with the carbon of the candle, and its place is taken by the newly made carbonic acid gas. For the same reason an animal cannot live long in a closed space a little larger than itself.

Growing plants perform the reverse work of converting carbonic acid gas back to oxygen. They need carbon, and they take it, furnishing in return pure oxygen. Hence in a measure they act as purifiers of the atmosphere, destroying some of the carbonic acid gas made by animals, and replacing it by oxygen.

But carbonic acid gas forms an appreciable part of the air (about .03% of the whole), and it is everywhere present. There are several sources from which it is known to come. When breathing, every animal is furnishing some, and everything that burns supplies this gas to the air. Every animal and plant that is dead and decaying is giving out this gas, and a supply is also obtained from the earth itself. Much carbon is locked up in the earth, as for instance, where plants have not decayed but have been changed to mineral coal. We burn this in our stoves, and one of the products is carbonic acid gas. It is also constantly escaping from many springs, and probably also from the soil. Also when a volcano breaks forth in eruption, large quantities of this gas escape. Because of the large amount of fuel burned there, more carbonic acid gas exists in the air near cities than in the open country.

This gas serves well to illustrate how beautifully everything is adjusted to the existence and development of life on the earth. Here, for instance, is a gas, forming only .03% of the entire atmosphere, which if decidedly increased, or slightly diminished, would be fatal to all animal life on the land. If very much increased, it would be directly fatal; if diminished, the plant life that depends upon it for existence would perish; and as the animals of the land cannot take their food directly from the earth, but obtain it entirely by means of plants, the destruction of these would necessitate the death of all animals excepting those that could draw entirely upon the ocean for their subsistence. But for untold ages this harmony of nature's balance has been maintained, and the earth has been clothed with vegetation and occupied by myriads of animals, great and small.

Water Vapor. — While there are minute quantities of many other gases in the air, there is but one other really important gaseous constituent. When wet clothes are placed upon the line to dry, little by little the water disappears, until finally none is left. Also after a rain, the pools of water in the road slowly disappear, the mud dries up, and the water is gone. In both cases it has *evaporated*, and has changed its form from the visible liquid to the invisible gas which we call *water vapor* (Chapter IX).

This process of *evaporation* is somewhat like that which is producing steam. The kettle on the stove boils, steam issues from the neck, and in time the kettle becomes dry, the water having changed to vapor, which is still present in the air of the room, though no longer to be seen. That it is present may be shown on a frosty day; for then when the vapor-laden air of the room encounters the cold window, some of the vapor is condensed back to water, forming drops on the glass.[1] If the day is very cold, it solidifies into fantastic frost crystals, the solid, icy form which water takes when the temperature has descended below the freezing point. Even the breath may furnish enough vapor to cause this, and on cold nights our chamber windows are covered with frost.

The housewife knows that some days are better drying days than others. When the warm sun shines upon the clothes, they generally dry quickly, for evaporation takes place more rapidly in warm than in cold air. But heat is only one of the aids to evaporation, and this is illustrated by the fact that some of the hot, muggy days of summer are not such good drying days as the cold, windy spells of winter. This is because the air cannot contain more than a certain quantity of vapor, and on the muggy summer days the air is nearly *saturated*, while it is relatively dry during the cold, windy days of winter. Because it moves the air, the wind also favors evaporation, and thus does not allow it to remain near the damp object long enough to become saturated.

The amount of water vapor that the air can contain depends upon the temperature,[2] warm air being able to

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[1] The teacher may illustrate this by bringing a pitcher of ice water into a warm room.

[2] The comparison may be made (though it is only partly analogous) to a salt solution. If several spoonfuls of salt are placed in a dish of cold water, all of it may not dissolve. Heating this water, more salt is taken into solution, and then if the salt water is allowed to cool, some of the dissolved salt will be precipitated in the form of crystals. So it is with the air; cold air can contain little vapor, warm air will hold more; and if this is then cooled, some of the vapor may be forced to assume the liquid or solid forms of rain, fog, dew, or frost.

When saturated, at ordinary pressure, a room 10 feet high and 20 feet square contains 346 pounds of air, if the temperature is 0°. In this, if carry more than cold. Nevertheless, air will carry some vapor even when its temperature is below the freezing point. This is illustrated on a cold winter day, when the clothes freeze upon the line but still continue to dry. The rate of evaporation depends partly upon the dryness of the air; for just as a saturated solution of salt cannot be made stronger without increasing the temperature, so air, having as much vapor as it can hold, will take no more, while dry air greedily absorbs it.[1] Hence dry air evaporates water more rapidly than nearly saturated or *humid* air. If of high temperature, more can be evaporated than at lower temperatures, and if moving, it takes vapor more readily than if quiet.

Although present in very small quantities, forming only a small proportion of the entire atmosphere, water vapor is one of the most important constituents of the air. Even in the driest parts of the land it is always present, although then in very small quantities. The conversion of water vapor back to water or snow is constantly in progress. Every cloud, every fog particle, every glistening drop of dew, and every drop of rain or snow crystal, is a witness of this remarkable transformation; and as it

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saturated, there is an amount of vapor which, transformed to water, would weigh one-third of a pound. If the temperature is increased to 60°, and the air still saturated, its weight is 301 pounds, and the vapor when condensed would weigh 3¼ pounds. If the temperature is raised to 80°, the air weighs 291 pounds, and the vapor if condensed, 6¼ pounds. A pound of water equals about one pint.

[1] For purposes of graphic description it is convenient to make this comparison; yet physicists know that evaporation would occur if there were no air, for it depends not upon air, but upon the water; but the air is *important* in evaporation, because it bears the vapor away and also warms the water by its presence.

silently and almost mysteriously proceeds in the change, a work of vital importance is performed.

It sprinkles the land with showers, causing countless myriads of plants to burst forth into leaf, flower, and fruit. It transforms the salt water of the sea to fresh drops of rain; and this, in our rivers, lakes, and springs, furnishes the water supply upon which we are so dependent. Without this ingredient of the great atmospheric ocean, the earth would be a desert sphere whirling aimlessly through space.

Dust Particles. — Even more minute in quantity than either of the gaseous elements of the air is the solid constituent. The solid particles that float about in the air are commonly known as *dust;* and when a beam of light enters a room, the larger dust particles are seen dancing to and fro. In the term *dust* are included many different particles which are so light that they may float in the air. Some are visible to the eye; others, and the majority, are microscopic in size.

When wood is burned, carbon combines with oxygen to form carbonic acid gas; but there are some solid particles which do not become transformed to gas. Portions of this are left behind as ash, while some rise into the air and float away, as we may see by watching the smoke rising from a chimney.[1] In large cities so much smoke is sent into the air, that a dull cloud hovers over them, and the sun shines less intensely than in the open country. Dust is also blown into the air from the ground, and there are many microscopic microbes, and quantities of tiny solid substances of various kinds.

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[1] That solid particles are rising from even the blaze of a candle may be proved by holding a piece of glass over the flame and watching it become covered with soot.

So much dust comes from these various sources, that if allowed to accumulate, the air would in time become so impure that the sun's rays would be obscured, perhaps even more than they are in the large cities, on days when the air is quiet; but the dust is constantly being removed, some by slowly settling to the earth, some by the action of rain, which as it descends through the air, catches and carries it to the ground. So the rain purifies and freshens the atmosphere; and if a raindrop is examined under a powerful microscope, it is found to contain many minute solid bits.

The amount of dust varies greatly; at times the air is clear and free from these impurities, and then the sun shines brightly and the sky has a beautiful blue tint. Again, particularly during drouths, when forest fires are common, and rains have not come to remove the solids, the air is hazy and the sky and sun dull, sometimes almost obscured. At such a time the raindrops of a slight shower contain enough dust to discolor white paper. Over some cities where soft coal is burned, the dust of the air settles in sufficient quantities to discolor white objects.

Although near cities there is more dust in the air than elsewhere, there are times in desert regions when sand particles, even of considerable size, are whirled into the air by the wind, and kept there by its motion, producing sand storms which shut out from view even the objects close at hand. These days are exceptional, and the sand soon settles when the air again becomes quiet. A violent volcanic eruption also causes dust to spread high into the air, and this at times travels for thousands of miles before settling to the earth, while near the volcano the darkness of night may be produced at midday. Over the ocean there is less dust than over the land, and high in the atmosphere, and on mountain peaks, the air is purer than on the lowlands.

Dust particles are of much importance in the action of the air. The microbes which are present, spread disease. The solid particles appear to serve as nuclei around which vapor condenses to form fog particles and rain; and their presence in the atmosphere is responsible for many of the effects of sky and cloud color with which we are familiar.

Height of the Atmosphere. — It is not to be supposed that the upper limits of the air are sharply defined, like the surface of the liquid ocean. So far as we know, the atmosphere becomes less and less dense as the distance from the ground increases, and probably gradually fades away, until there is an almost indefinite boundary separating it from the great void of space. No one has ever been near this limit, and so we can only conjecture as to its nature; but that there is some such boundary between empty space and terrestrial atmosphere, is proved by the behavior of meteors and shooting stars.

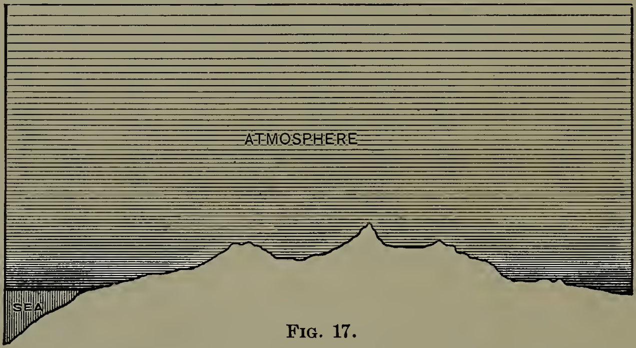

FIG. 17.

To illustrate the decrease in density of the air from sea level to the higher regions.

These wanderers in space, though sometimes large, are usually tiny particles, which, like the earth, are moving in an orbit around the sun, travelling also with terrific velocities. When in space they are cold, and to us invisible; but when they cross the path of the earth, and encounter the gases of the atmosphere, the friction causes heat, just as heat is generated when a knife is held upon a dry grindstone that is revolving. The meteors then begin to glow, and in most cases to finally burn up and disappear. They flash out suddenly as brilliant beams of light, and leave behind a track of fire, which itself quickly disappears. This furnishes proof that the meteors come from a place where nothing impedes their passage, to one where they encounter resistance, which, though only that caused by an invisible gas, nevertheless serves to destroy all but the largest, which sometimes fall to the earth.

In balloons, and on mountain tops, men have ascended to a height of five or six miles above the level of the sea. Air is still found, but it is so light and rarefied that breathing is difficult, and such ascents are sometimes dangerous even to life. The air has definite weight, which can be measured (Chapter VII); and from measurements at various heights, we know that more than one-half of its whole bulk rests within four miles of the earth's surface, and fully two-thirds within the lower six miles (Fig. 17). But while so large a percentage of its total bulk is near the earth, the atmosphere is not limited to so shallow a depth. As the elevation becomes greater, the molecules of gas become further and further apart, and the air less dense. The measurements of the height at which shooting stars begin to glow, seem to prove that there is some air at an elevation of fully 500 miles from the surface (Fig. 4).

Changes in the Air. — Already it has been hinted that the atmosphere is elastic and mobile, and that there are many changes in progress. The heat from the sun warms the earth and air, heating some parts more than others, warming by day, and allowing cooling at night, causing intense warmth in some seasons and allowing the opposite season to be cool or cold. So the temperature varies from one point to another, and from day to day, as well as from season to season. Since the air is elastic and easily disturbed, these differences in warmth cause movements; and so the air is in constant motion, now violent, now moderate (Chapter VII).

Water evaporates from the land and the seas, and the changes in temperature and movement of the air cause dry winds to-day, and possibly damp winds to-morrow. The vapor condenses, forming dew, or possibly clouds; and even storms may develop, moving across the land and causing rain to fall. So the air is ever variable, and no two successive days are exactly alike. The weather of a place near the seashore is different from that in the interior of the continents; of the equatorial regions, from that of the higher latitudes; of the mountain top, from the plain. Infinite variety is thus introduced, and while it will be impossible to state all of these differences, in the next few chapters we will point out some of the principles upon which they depend, and illustrate them by a few examples.

CHAPTER IV

LIGHT, ELECTRICITY, AND MAGNETISM

Light

Nature of Light. — When a bar of iron is placed in a fire, it becomes hot, and soon begins to glow; its black color is lost, and it becomes red or even white hot. It then gives out light and heat, and we are able either to read by its light, or to warm our hands by holding them over it. Like the iron, the sun is a very hot body which shines with a fiery light.

If we place a white-hot bar of iron at the end of a room, it can be seen from the opposite side, and we may even be able to see it at a distance of half a mile. Something comes from the iron, which upon reaching our eyes, produces there the sensation of light. The hypothesis which physicists have for explaining this, is the *undulatory theory of light*, according to which it is believed, that a series of undulations, or waves, are started in an invisible, and to us entirely mysterious substance, called *ether*, which pervades all space. These waves are thought to be somewhat like those in water, but they travel at the almost incredibly rapid rate of about 180,000 miles a second. So if a lamp is lighted at a distance of a mile, we perceive it almost at the same instant.

The hot solar orb is at all times emitting this *radiant energy* (light and heat) into space in all directions. So rapid is the movement of the rays, that the light and heat travel across space to the earth, over a path of more than 92,800,000 miles, in a little over 8 minutes. Only a very small part of the light and heat from the sun reaches us (Fig. 12) and most of it goes out into space, where, so far as we know, it is lost.[1] Just as warmth and light from the hot bar of iron diminish as the distance from it is increased, so the heat and light of the sun lose intensity, until at the planet Neptune their amount must be slight.

According to this theory, light is not a simple wave, but a complex series moving with slightly different wave lengths, and upon reaching the eye they together produce the phenomenon which we call *white light.*[2] Sometimes, and by various causes, this white light has some of its waves removed, and then we obtain color. So while light is ordinarily white, the sky is blue, the sunsets red or yellow, the leaves of trees green, and the flowers varicolored. The difference in color depends upon various conditions, some of which may be simply stated, while others cannot be discussed in this book.

Reflection. — During a part of the month the moon shines brightly in the heavens with a silvery white light, and again it disappears; when the moon is young or old, we see the bright crescent, but the dull remainder of the

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[1] It is somewhat as if we compared a lamp in a room to the sun, and a speck of dust on the wall to the earth.

[2] White light is made of a number of waves each having a color of its own. We recognize only seven of these, called *primary colors,* — violet, indigo, blue, green, yellow, orange, and red, — the colors of the spectrum, which we see in a rainbow. This may be illustrated by a prism, which breaks up the white light into its component colors.

sphere does not shine brightly. Like the earth, the moon intercepts some of the sun's rays, and at times these are reflected to the earth, just as we may cause a sunbeam to be reflected from a mirror to some place which the sun's rays do not reach directly. On the moon the earth appears as a brightly illuminated orb in the sky.

Gases do not readily reflect, but instead, allow the light to pass easily through them, being *transparent;* but a water surface does reflect readily, and as the sun's rays reach the surface of a water body, we find them reflected from this in the form of a dazzling beam of light.[1] So, too, when the sun's rays reach a dense cloud bank, the water or snow particles which compose the cloud may reflect the sunlight; and while the great mass of the cloud appears black or leaden gray, the edge upon which the sunbeams strike, becomes transformed to dazzling white. If the sunlight is colored, because of some change in the light rays, such as those explained below, *the reflected light may be colored.*

Pure air of uniform density does not of itself reflect the light; but when a beam of sunlight passes through a gap in a cloud, its path to the earth may be seen, and the sun is then said to be "*drawing water.*" This appearance must be the result of reflection of light, for otherwise the distant rays would not be visible. If the air did not reflect light, the illumination of the earth in the daytime would be very different. The places in shadow would be very dark, if light were not reflected to them from the air and from the land. By means of a mirror, we may reflect enough sunlight upon a shadow to entirely destroy it;

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[1] By an experiment with a dish of water, or a mirror, placed in the sunlight, the teacher can make the subject of reflection plain.

and in a less complete way the natural reflection from many surrounding objects is engaged in the partial destruction of shadows.

Shadows are less intense on hazy than on very clear days; for then there are many solid particles in the air; and it is these *dust particles*, rather than the air itself, which cause the reflection which is seen when the sun is "drawing water." In addition to the reflection from the dust, there is sometimes reflection from the air itself. This is because the atmosphere *varies in density.* We may see this on any hot, close summer day, when walking along a road or on a railway track. The warm air is set in motion, and the little currents thus started differ in density, and as they reflect light from their surface we see them dancing about. Each different layer acts somewhat like a mirror.

It is upon this principle that the *mirage* is caused. The traveller on the desert often fancies that he sees a sheet of water when he looks down upon the air that is warm near the surface, so that it has different density from that above, causing it to reflect light. On a lake or seashore the mirage *lifts* the distant shores above the water level, and ships may be seen apparently sailing in the air. When there is a warm layer of air *above* the surface, reflections may be caused from it, and objects may then appear inverted, so that a ship may sometimes be seen apparently sailing in the heavens with its masts pointed toward the earth.

In the Arctic regions, during the summer, the mirage is very common; and when sailing in the midst of floating ice, the effect of the mirage in raising the ice floe above the water level, often transforms the broken ice surface into a marvellously complex and beautiful series of white imitations of cities, castles, and turrets. A single piece of ice is sometimes duplicated, until four or five pieces appear one above the other. Sometimes these join, forming a column; or, when partially joined, a sculptured turret; and as one looks upon such a scene, there is constant variation, and no two times is the same view seen in the same direction.

Absorption. — Light rays pass easily through some substances, which are then said to be *transparent*. Nearly all gases are transparent, or nearly so (then called *translucent*), and many liquids also allow light to pass easily through them; but solid substances are more rarely transparent. An instance of a transparent solid is glass, the transparency of which serves us so well in our windows.

When light encounters bodies, even those that are most transparent *absorb* some of the light, while the remainder is either reflected or allowed to pass on *into* the substance. Those solids and liquids which do not allow light to pass easily through, and which are then called *opaque*, absorb most of that which encounters them. When very little of the light is absorbed, the object is white in color; when nearly all is absorbed, it is black. But as white light is a complex of many waves, each producing separate colors, it happens that many objects allow *some* of the rays to pass, while *others* are reflected, and then the sensation of color is produced. If green is reflected in excess of the others, the color is green; if more red is reflected than others, a red is produced, etc.

This absorption of sunlight is important in the economy of life, particularly of many forms of plant life. While a potato will sprout and grow in a cellar, it does not produce fresh green leaves, but instead, a sickly, yellowish-green stalk and leaves. Even men who dwell away from the sunlight lose their freshness.

Selective Scattering. — The light of the sun is probably bluish when it enters the upper layers of the atmosphere, becoming white in its passage through the air. In this passage, light rays suffer much change, a change which is not at all times the same. Sometimes the sky is a deep azure blue, again it is a pale, almost colorless blue, and there have been times when its color was a brassy yellow.

Light waves, which are of various lengths, when passing through air that is impure, find their progress partially checked. The *coarser waves* of yellow and red light are less easily disturbed than those having a small wave length, like the violet and blue. This may be compared to the ripples on a lake, which may be checked in their motion by a small sand spit, while the larger storm waves break over the obstacle.

By this *interference*, some of the rays are turned to one side and *scattered*. Since the waves that have small wave length are more easily turned aside, the violets and blues of the white light are scattered even if the air is very clear. Hence the intensity of the blueness of the sky is greater on particularly clear than on hazy days, when the scattered blue rays are partially obscured by the scattering of the other and coarser rays. When there is much dust in the air, even the yellow may be scattered; and these, being then more intense than the blue, give to the sky a yellowish tinge. The color of the sky therefore depends upon *which of the rays are scattered;* and since certain waves are *selected*, according to the obstacle encountered, the process is called *selective scattering*.

Refraction. — While there are several other peculiarities of light, some of which are important, only one more can be easily explained in this book. When a stick is placed in a quiet body of water, with a part extending above the surface, it appears broken at the water surface.[1] This is due to refraction, the light ray itself being bent as it passes into the denser medium. If we could look from the water to the air, the stick would still appear broken, but would incline in the opposite direction.

This bending of the rays affects those colors which have the shorter wave lengths, in a different way from those with the longer wave lengths. So if we allow a sunbeam to pass through a glass prism, refraction bends the rays and affects the various colors differently. Hence, when a light ray emerges from a prism, instead of all the rays combining to cause white, the colors of the spectrum are thrown upon the floor, and we are then able to recognize the seven primary colors mentioned above. Many of our atmospheric colors, especially those of sunset, depend in part upon this principle of refraction of light rays, in passing through substances of different density.

The Colors of Sunrise and Sunset. — When the sun is setting, its brilliancy is usually so decreased that we may look directly at it; and if the air is dusty, it may be a great red orb, because the more delicate light waves have been scattered in passing through the great thickness of dust-filled air (Fig. 21). As the sun disappears, a glow of yellow, or red, overspreads the sky in the west, because, in addition to the blue light waves, the coarser reds and yellows have been scattered in passing through the mote-filled air. Those rays which come from near the horizon are most destroyed, and hence the coarsest of all prevail there, giving red colors, while those above the horizon, passing through less air, are yellow.

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[1] This is an experiment which any pupil can try for himself.

These solar rays are bent, or refracted, in passing through the dusty air, and when we see the sun just beginning to descend behind the hills, it is really *below* the horizon. This refraction lengthens the zone of coloring, so that the sunset colors often extend far on either side of the setting sun. In a clear sky the colors of sunset are arranged in a semicircular series, with the sun near the centre. At first the colors are yellow, fading out through tints of green to the sky-blue above. The yellow changes to red near the horizon. A second fainter series of colors, the *afterglow*, often illuminates the sky, after the first glow of sunset has faded. In reverse order the sunrise colors exhibit the same changes.

At sunset there is a delicate pink tint in the eastern sky, grading upward and downward into the blue, forming an arch, known as the *twilight arch*. This is the result of reflection of some of the scattered rays produced at sunset; and the dark or blue color, below the reflected pink, is the shadow of the earth cast against the sky.

These are some of the normal effects of the setting sun in clear weather. An increase of dust in the air, at first *increases* the intensity of the coloring; but beyond a certain point, the dust *deadens* the colors, so that in a very hazy sky the sunset colors are absent, because even the waves of red and yellow light are so scattered that they do not reach the eye. Very often, both at sunset and sunrise, the horizon is partly occupied by clouds, and the cloud particles reflect and refract the light rays, producing a marvellously beautiful and varied series of shades and tints of reds, yellows, brilliant gold, and deep purple. Our most *perfect* sunsets are in a clear sky; but the most *beautiful* come when the heavens are partly clouded.

The Rainbow. — Standing at the foot of Niagara Falls, one may often see a beautiful rainbow outlined in the spray that dashes into the air at the base of the mighty cataract. Though forming an arc of a smaller circle than that seen in the eastern sky after a summer thunder storm, it is the same in cause. In each case there are drops of water — spray in Niagara, and raindrops in the rainbow — through which the rays of the sun are passing; and as the rays enter and emerge from the water drops, they are refracted, just as in the case of the light passing through a prism of glass. This *refraction* separates the rays into the rainbow colors, and these are sent back to the eye by *reflection* from the drops of rain.

The form of the rainbow is that of a segment of a circle, with the ends resting on the horizon; and the extent of the arc depends upon the position of the sun, being small when the sun is high in the heavens, and nearly a semicircle when it is near the horizon. The colors of the rainbow are those of the spectrum, with the red outside, and at times a second bow is produced above the true rainbow. In this the red is on the inside. Each person sees a different rainbow; but all see the same general features, because the raindrops always act in the same way in refracting light.

Halos and Coronas. — There are other peculiar and exceptional effects of light, only two of which will be briefly mentioned. The *halo*, or ring around the sun or moon, occurs when the upper air is overspread with nearly transparent clouds, composed of particles of ice. Usually the halo is a ring of white light; but when best developed it has the colors of the spectrum, with the red inside. Arctic explorers describe brilliant halos, for in these cold regions, the air often bears numerous ice crystals, and it is refraction of light passing through these, and reflected from their surface, that produces the halos.

When denser clouds partly obscure the sun, the interference of these with the rays of light, sometimes produces *coronas*, which are circles of colored light concentrically arranged, and usually of small diameter, with the red on the outside. At other times a bar of light sometimes extends from the sun, and at times a cross is formed by two such bars. In rare cases these bars occur at the same time with coronas, and the circles are then divided into four segments.

Sunlight Measurement. — Physicists have measured the velocity of light by various means; and nearly all the phenomena of light have received a satisfactory explanation on the basis of the undulatory theory. With these measurements we are not concerned; but meteorologists sometimes study the *intensity* and *duration* of sunlight. The former may be obtained by means of the black bulb thermometer (p. 69), the latter by the *sunshine recorder*. This is a metal box so placed that from sunrise to sunset the sunlight shines into it through a hole. On the inside of the box a piece of photographic (or blue print) paper is placed, and the sunbeam, entering the hole, travels over this, thus marking its presence by a line that is continuous if the sun shines all day, and broken if interrupted by clouds. At night the photographic paper is taken out and developed, and thus a line is marked where the sun shone, while no line is present if the sun's rays were interrupted. A similar result may be obtained from the black bulb thermometer.

By such means we learn that in 1892 the sun at Yuma, Arizona, shone for fully 80% of all the time that it stood above the horizon; at San Diego, California, 62%; at Salt Lake City, Utah, 57%; at Washington, D.C., 52%; at St. Louis, Missouri, 44%; at Eastport, Maine, 44%; at Buffalo, N.Y., 40%.

Electricity and Magnetism

Lightning. — During thunder storms, and other violent disturbances of the air, an electric spark is often caused to pass from cloud to cloud, or from a cloud to the ground. *Lightning* is then produced, and the sound caused by the passage,[1] as it echoes and reverberates among the clouds, causes the roar and crash of *thunder*. When thunder storms are at a distance, and often when they are below the horizon, a flash of lightning illuminates the distant sky, and we see *heat lightning*. It is possible that atmospheric electricity has some influence upon the formation of rain, though of this there is some doubt; and although producing some vivid effects in the form of lightning, it is not now recognized as an important feature of the air.[2]

Magnetism. — Every one is familiar with the common magnet, which is a magnetized piece of iron capable of attracting other particles of iron. The earth is a great magnet with two poles of attraction, one south of Australia, in the Antarctic region, the other on Boothia Island, north of Hudson's Bay, in the Arctic. These poles attract the needle of the compass, which is a piece of magnetized iron, so that the north end of the needle points toward the *north magnetic pole*. The attractive force is *beneath* the earth's surface, so that near the pole the magnetic needle dips vertically toward the ground. This condition of terrestrial magnetism is exceedingly important, for it furnishes us an easy means of obtaining directions by compass. This subject calls for constant study, because the attractive force steadily varies, so that the pole is not always in the same place.

Magnetic action is also present *in the sun;* and on the earth we are able to detect this by means of delicate instruments. Sometimes this solar magnetism produces what

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[1] By an electric spark from Leyden jars an imitation of lightning and thunder may be produced. An electric car furnishes frequent illustrations.

[2] Just how this electricity is generated, and why it appears, is not exactly understood.

are known as *magnetic storms*, when electric apparatus is disturbed and the atmosphere seems to be under the influence of magnetic action. There is some relation between solar magnetism and sun spots.

At times the northern sky may become illuminated at night, by the strange light known as the *Northern Lights*, or *Aurora Borealis.* This is apparently some magnetic disturbance in the air, by which a faint light is produced. Usually colorless, the aurora sometimes assumes various tints, and a variety of form that at times is remarkable, now waving like a drapery, now shooting backward and forward with great rapidity, while always it is so dim that the stars shine through it. The Northern Lights are much more frequently and better developed near the magnetic pole than elsewhere, although they may often be seen in the United States. In some way this appears to be related to the magnetism of the earth itself.

Although careful studies have been carried on for a long time, the question of magnetism is still far from settled; and when it is understood, the explanation may throw much light upon various questions. There is reason for believing that the north magnetic pole of the earth, and the magnetism of the sun, are among the causes which produce, or at least direct, the great rain storms which travel across the country, causing most of the rain that falls in the northern states. Here is one of the great unsolved problems with which Nature confronts us, and yet one whose influence is constantly present and important. Our sailors, surveyors, and map makers are making use of a force whose nature no one understands.

CHAPTER V

SUN'S HEAT[1]

Nature of Heat. — Like light, our supply of heat comes directly from the sun, whence it is emitted in company with light.

Some hot bodies, like a stove, do not usually produce the sensation of light on the eye, but if their heat is increased, light is finally produced. Bodies which reflect sunlight, such as a piece of white paper, do not become warm as quickly as those like black paper, which do not reflect light. However, there is an intimate connection between these phenomena of radiant energy (light and heat), which have the same origin, and are possibly merely different expressions of the same thing exactly.

Heat, like light, travels to us across space as a series of waves, moving with exceedingly rapid vibrations. It is the great life giver, for it warms our sphere, and upon its presence all forms of life depend for existence. Like light, heat changes its behavior on reaching the earth, and therefore, for an understanding of the distribution of solar heat over the globe, we must first learn something of its peculiarities.

Reflection of Heat. — Most bodies that allow light to pass easily through them, offer as little resistance to heat.

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[1] It is exceedingly important that the students *thoroughly* grasp the principles treated in this chapter.

Hence radiant energy (both light and heat) enters and passes readily through the transparent atmosphere; and if the temperature out of doors is zero, a thermometer in a room placed near a window, in the direct rays of the sun, will record a much higher temperature than that of the air outside. Such bodies as air and glass, which are transparent to heat, are said to be *diathermanous.*

As in the case of light, *all* bodies can reflect some heat, and we even obtain a small quantity of reflected heat from the moon. Smooth bodies, and those having a light color, reflect both heat and light better than others, and we may prove this at any time by standing in a shadow upon which the light and heat from a window are being reflected. Quarrymen working in pits partly enclosed by rock walls, notice the same thing on a hot summer day, when the walls of the quarry reflect heat, and add to that which falls directly upon them from the sun. It is partly for this reason also, that the streets of a city are hotter in summer than the open country; for then not only does heat fall directly upon the street, but some is reflected from the enclosing walls of buildings. So also we may become sunburned in summer, even though our face is kept in shadow by means of a broad hat. The reflected heat from the ground performs this work; and since a water surface reflects better than the ground, one becomes sunburned much more quickly when on the water than on the land.

During their passage through the air, some of the heat rays are reflected and scattered by the dust particles that are present; but most of them pass on and reach the ground. Most of the light immediately escapes, and when the sun's rays are absent, darkness prevails; but heat in part remains, and its effect is still felt, to some extent, even when the sun rises in the morning.[1] However, a large percentage of the heat rays that reach the earth, pass directly away, being turned back by reflection; and so, as far as the earth is concerned, these are lost in space.

Absorption of Heat. — A portion of the heat is absorbed. Black bodies absorb so much of the sunlight that they return to the eyes no distinct color. Such bodies also absorb much of the heat that comes to them, and hence in summer the asphalt pavement of cities, or the black rocks of the country, become hot. If we place a piece of black cloth upon a snow bank, in such a position as to be exposed to the direct rays of the sun, its warmth, resulting from absorption, will cause the snow beneath it to melt, and the cloth will sink into the snow even during cold weather; but if a white cloth is used, much more of the radiant energy is reflected, and the cloth does not become nearly so warm. Hence the warming effect of the sun's rays varies greatly, not only with the location, but also with the material that is being warmed.

Radiation of Heat. — When we receive heat from a stove, rays come to us that are being *radiated* from the iron. The heat that comes from the sun is similar radiant energy which this great body is emitting; for a heated body is able to give out its heat to cooler surrounding areas, until the temperature of the two is equalized. Hence the sun will continue to radiate heat into space in all directions, until its temperature is reduced to that

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[1] This may be illustrated in this way: if the sun shines into a room, it becomes light and also is warmed; close the blinds and the light ceases, but objects that were reached by the sunlight will still remain warm.

of space: just as a stove in which the fire has gone out will continue to radiate heat into the room until its temperature is reduced to that of the surrounding air.

The same is true of the heat which comes to the earth from the sun, and which stays upon the surface for awhile. Some of this is absorbed, and the ground is warmed; but during all the time that this heat is coming to the earth, it is being sent away into space, some by reflection, some by *direct radiation;* and it passes through the atmosphere in a way similar to that in which it entered. Even during the hottest summer days, radiation is in progress; but the ground continues to warm through the day, because *more* heat is being absorbed than can be radiated. However, as soon as the sun descends behind the western horizon, the supply is cut off, while radiation continues, and hence the ground becomes cooler, and continues to cool until the sun again rises.

During the summer the days are longer than the nights, and more heat comes than can be radiated. Therefore the ground warms day after day; but in the winter, radiation is in excess of the supply, so that the ground becomes cooler and cooler, until the days have again perceptibly lengthened. In this way the earth disposes of its surplus heat, and hence the heat of one year is not greatly different from that of the preceding. If it were not for this action of radiation, each year would witness an increase of heat; and the air and earth would soon become intensely hot if all of the rays were not sent away.

Radiation is extremely important in explaining many of the features of the air, and in later pages we will need to refer to it again and again. Some bodies radiate much better than others: grass and leaves are better radiators than the bare ground, and the earth radiates more readily than water. Hence the sun's rays affect various parts of the earth in a different way, and here is another reason for variation in temperature of the earth's surface.

Conduction of Heat. — If the end of a rod of copper, or even of iron, is placed in the fire, the end in contact with the fire becomes very hot, and soon the other end, which is entirely away from the source of heat, itself becomes warm, and after awhile so hot that it cannot be held. The heat of one end passes through the iron by *conduction*, being transmitted from molecule to molecule. In the same way, the rays of the sun, which come in contact with only the *very surface* of the land, have their heat gradually conducted down into the soil. But the ground is not so good a conductor as iron, and at a depth of three or four feet, the sun's rays produce little effect even in summer, while at a depth of ten or twenty feet, the influence of the sun is almost absent. Thus the sun warms only the *very surface* of the land. Water and air are even poorer conductors; but the air which rests directly on the ground, is gradually warmed by contact with the warm earth, and by conduction this heat is slowly transmitted into the air to a slight distance above the ground.

Convection. — When a kettle of water is placed upon a stove, the iron bottom is warmed, and the heat is conducted from the iron into the water. Heat causes expansion, as any one may see by watching a blacksmith put an iron tire on a wheel. The iron is warmed and placed outside the wheel, which it fits very loosely; but as it cools by radiation and conduction, it contracts and binds the wood of the wheel firmly together.[1]

The expansion of a liquid or a gas makes it *less dense or lighter.* Therefore when the water in the bottom of the kettle is warmed, it becomes lighter than the layers above. This is an unnatural condition, for the lightest things float, as oil or wood will float on water. As the warming proceeds, the light layers of lower water are forced to rise by the sinking of the heavy cold layers, which are drawn down by gravity. This causes a *boiling or convection.* In the same way the lower layers of the atmosphere are warmed by conduction from the ground, which has absorbed heat. These become lighter, and an *atmospheric boiling or convection* is inaugurated.

Ordinarily this convection is quiet and unnoticeable; but on a dusty road, or a railway track, during a hot summer day, the boiling of the air may be actually seen, as the little rising currents of warm air reflect light to the eye. The air seems to be in violent motion, and sometimes this is enough to obscure objects at no great distance. By this process of convection the atmosphere is set in motion in a much larger way, and this action furnishes an explanation of many of the winds of the earth (Chapter VII).

Heat on the Land. — A few words in summary will show how the land is warmed and cooled. During the daytime the earth *absorbs* heat, much in summer and relatively little in winter; and at all times it is *radiating*, though

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[1] So also the warming of the rails of a track in summer causes them to expand, so that the joints fit together, while in the cold winter they contract and spread apart. Therefore in laying rails it is necessary to leave a small space for this movement.

at night, when no heat comes, the *effect of radiation* is most pronounced. Some of the heat is *conducted* below the surface, so that the upper layer of the ground is less excessively warmed than it would be if all remained where it fell. Moreover, the *air* that rests upon the surface becomes warm by conduction, and this also takes away some of the heat. If the air were immovable, very little would be thus carried away through so poor a conductor; but as soon as a layer of air near the ground is warmed, it rises, cooler air forcing it up and taking its place; and hence much heat is thus removed and distributed from place to place.

The warming of the land is more effective in some situations than in others. In the case of black and light-colored rocks, we have instances of two extremes. The warmth of the land also *depends upon its outline.* The hilltop, being more exposed to the wind, and being able to radiate heat through *less* air than that which covers the valley bottom, is cooler than the valley. The increased warmth of the valley also partly depends upon the fact that the sides *reflect* heat into the valley, and check radiation from it, while the hilltop is open to the sky, and can radiate heat in all directions. A valley facing toward the south, and hence exposed to the direct rays of the sun, becomes warmer than one facing toward the east or west, and hence in shadow during part of the day.

Warming of the Ocean. — For various reasons, water increases in temperature much less rapidly than land. In the first place, heat rays are more readily reflected from the smooth and often glassy water surface. The heat that is absorbed, and causes a rise in temperature, also expands the water. Since it is a mobile liquid, it is then set in motion, and currents are caused as a result of the change in density thus produced. So, while on the land some places become warmer than others, on the level ocean there is a uniformity of conditions, the material being all alike, and so movable that if one part becomes warmer than another, the difference is quickly equalized by means of a current.

There is still another reason why water temperature is less easily raised than that of the land. It takes much *more heat* to raise the temperature of a certain bulk of water one degree, than it does the same amount of earth or rock. Also, water can be *evaporated*, and in doing this, much heat energy is used; but this heat is *not made apparent* by an increase of temperature, and so is called *latent heat* or *heat of evaporation.* The vapor thus produced rises into the air and passes away in the winds, so that when it finally changes back to liquid water, the latent heat, which *then becomes apparent*, may appear at some very distant point and warm the air, instead of the ocean where it fell. Hence much of the solar heat that enters the water is borne away in vapor.

For these reasons water warms very slowly, and even in midsummer the sea breeze that blows upon the land from the ocean, is a cool, refreshing breath of air. At night, and in winter, the water cools to a less degree than the land, because radiation from its surface is less rapid. Therefore in day and summer the ocean is relatively cool, and in winter, and during the night, it is warmer than the land. Hence *the climate of the ocean is equable*, and one of slight change; and the influence of this uniformity is felt upon the land which borders the sea. Because of the same peculiarity, even lakes of small size influence the local climate perceptibly.

Temperature of Highlands. — After a storm in the mountains, or even in a hilly country, one may often see that snow has fallen on the hill or mountain tops, while rain fell in the valleys. If one should carry a thermometer on a journey to a mountain top, he would find the temperature steadily descending; and the same condition is noticed by balloonists who ascend high into the air. By such observations, it is proved that the temperature of the air decreases with elevation above the sea. The rate varies somewhat, but on the average there is a decrease of about 1° for every 300 feet of elevation. Even in the hottest parts of the earth, mountains may rise high enough to reach the region of eternal snow.

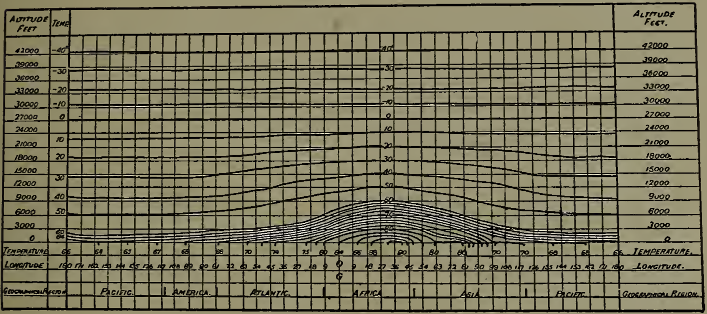

FIG. 18.

Ideal section of atmosphere in temperate and equatorial regions, showing temperature at the surface and at various elevations.

This cold is partly *inherent* in the thin upper layers, and it is partly due to *distance from the warm earth*, which causes the temperature of the air near the ground to rise. The low temperatures of mountain tops are *intensified by radiation*, for the direct rays of the sun reach the mountains, just as they do the lowlands, though after having passed through a thinner layer of atmosphere. This heat is rapidly radiated, because radiation proceeds with much greater ease through the thin layer of rarefied upper atmosphere, than it does through the denser, dust-filled air near the sea level. Hence the nights and winters on mountain tops are intensely cold, partly because of the cold air which surrounds them, and partly because of the easy radiation.

Effect of Heat on the Air. — On a very clear day, the noonday sun sends its rays through the air with little interruption, and the larger share of those that enter, reach the ground. Being clear, radiation and reflection from the surface are also easy, and much heat goes directly back, while at night, if the same condition of the atmosphere exists, radiation continues to proceed rapidly. Thus on a midsummer day, with the sun shining brightly, the air may be refreshing both by day and night. The heat is not imprisoned nor entrapped.

If the sky is overcast with clouds, the heat rays pass with difficulty, and because so little heat reaches the ground the day is liable to be cool. After such a day, although little sunlight has passed to the earth, the night time is usually not cold, because the cloud covering, which prevented rays from entering, also acts as a blanket, and prevents the escape by radiation, of the heat which had previously come to the earth. At such times the temperature of day and night may remain about the same, because little heat comes and little leaves.

If the day is hazy, or if the air contains much vapor, and is "muggy," this, to a certain extent, checks the passage of rays from the sun; for the foreign particles absorb some of the heat as it passes; but much heat still reaches the earth, and the impure air acts also as a barrier to its outward passage by radiation. So on such days, the ground and air are warm, and the day oppressive. Since radiation is partly checked, even the night time may offer no relief from the oppressive heat; and man and beast suffer, until finally relief comes when the air is again clear, and some of the excessive heat can be radiated into space.

An atmosphere composed of pure nitrogen and oxygen, would offer little resistance to the passage of heat rays, because these gases are very diathermanous; and in this case the air would be very slightly warmed by the passage of sunlight through it. But water vapor and dust particles exist in the air, and these intercept some of the heat and thus become warmed. This heat is to some extent imparted to the neighboring air by conduction. These foreign substances intercept both the direct rays from the sun and those radiated from the earth, so that there is a double cause for warming.

However, the air receives its warmth mainly in an *indirect* way. On a hot summer day, a thermometer placed a foot from the ground registers a considerably higher temperature than one 10 feet above it; for the lower layer is warmed by *contact* with the heated earth. So by *conduction* the air temperature is raised, and then by *convection* the warm lower layers rise, and the heat from the ground is distributed, just as the air of a room is warmed by a stove, or by a steam radiator.

There are many differences in warmth of the air from place to place, from hill to valley, from land to ocean, from one kind of ground to another, and from one latitude to another. By means of these differences in temperature, the elastic air is set into motion, and directly or indirectly winds, clouds, and storms are caused. The air is therefore a carrier of heat, and it is always at work equallizing the differences in temperature, and hence in density.

If in their passage through the atmosphere the heat rays are checked by dust particles when the sun is nearly vertical, and the thickness of the air is least, we can easily understand that at night, or early in the morning, when the rays pass through so much more air (Fig. 21), their effect is greatly decreased. This is one of the reasons[1] why the afternoon sun of summer loses its power as it sets toward the west, and why the morning sun does not quickly warm the earth and air. It is also one of the reasons why, even at noonday, the winter sun does not generally warm the land; for then the sun is low in the southern heavens, and the amount of air through which the rays must pass is similar to that of the afternoon sun.

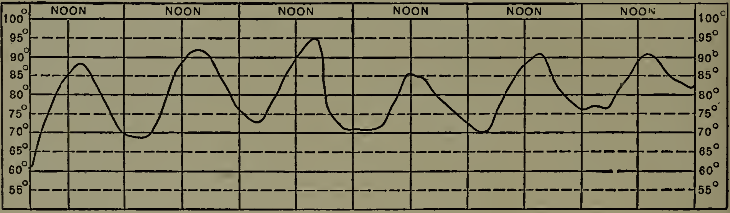

Fig. 19.

Diagram showing change in temperature for six successive summer days, the temperature rising in the morning and early afternoon, and then descending until the sun again rises.

Effect of Rotation. — By the earth's rotation, in most parts of the earth, the sun each day mounts higher and higher in the heavens, first warming the earth feebly, as its rays traverse the great thickness of lower dense and dusty air, then increasing in intensity until afternoon, and again losing intensity as the horizon is neared.

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[1] Another is the different *angle* at which the rays reach the surface.

There is another important action of rotation which affects the moving currents of air and water. In the northern hemisphere it causes them to turn to the right, in the southern toward the left; or in other words, if they are moving toward the Equator, they are turned toward the west; if from the Equator, toward the east. The deflective influence is greatest near the poles and least near the Equator. It varies also with the velocity of the moving current, being greatest with those that move most rapidly. We shall have occasion to call attention in several places to the effect of this *right-hand and left-hand deflection* of air and water currents.[1]

Effect of Revolution. — Every part of the earth has its temperature influenced by revolution, for this causes seasons (p. 17). At *all* times the belt near the Equator receives more heat than that near the poles, for in the latter the rays never reach the earth from overhead, while in the former the sun is never far from vertical at midday. The angle at which the sunlight reaches the earth during the polar summer, corresponds in a measure to that of the light which comes to us late in the afternoon; but in winter *no* sunlight reaches the polar regions.

Because of the difference in the amount of heat received, the earth is divided into five great zones: (1) the *Tropical*, *Equatorial*, or *Torrid;* (2) the *North Temperate*, between the Arctic circle and the Tropic of Cancer; (3) the *South Temperate*, between the Antarctic circle and the Tropic of Capricorn; (4) the *Arctic* or *North Polar zone*, within the Arctic circle; and (5) the *Antarctic* or *South Polar zone.*

So the solar rays vary in effect from one latitude to another, decreasing toward the poles; but this variation is partly checked by the revolution, which in all other

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[1] No attempt is made to explain this phenomenon in this book, for the explanation is difficult to give without the use of mathematics.

zones than the Tropical, produces seasons of alternate warmth and cold. Ordinarily the sun rises and sets; but within the Arctic and Antarctic circles the revolution of the earth, with its axis inclined, destroys the difference between day and night during a part of the year. Even outside of these zones, the relative length of day and night is caused to constantly vary, even as far as the Equator; and in our latitude we have long nights in one season and short nights in the opposite. In the United States the noonday sun of summer shines from a point near the zenith. Six months later it is far down in the southern heavens, and day by day these conditions change.

From this statement it will be seen that the question of temperature distribution over the earth is a complex one, and that there must be many variations from day to night, from season to season, from one latitude to another, from mountain to plain, and from land to sea. But if we understand the *principles* which have been dwelt upon in this chapter, we may study and understand the variations in the temperature of the earth's surface.

Temperature Measurement. — Various instruments are in use for determining the temperature of the air; but the ordinary *mercurial thermometer* is the most common and useful. A glass tube, sealed at both ends, and terminating in a bulb at the base, contains mercury with a partial vacuum above. The principle of its action is that liquids expand with warmth and contract with cold. Hence an increase in air temperature causes the mercury to rise in the tube, and the lowering of the temperature makes it necessary for the mercury to sink. The liquid thread which rises and falls, is forced up and down by the expansion and contraction of mercury in a cistern or bulb.

Either the glass tube, or the standard upon which it is mounted, is graduated into a scale, the one in ordinary use in English-speaking countries being the *Fahrenheit*, in which the freezing point is 32°, and the boiling point 212°. Certain temperatures are carefully determined, and marked on the tube, and then the remainder of the scale is graduated. On the European continent, the *Centigrade scale* is commonly used, this having 0° for freezing point, and 100° for boiling. It is a more simple scale, and is coming into use in this country.[1] Since the degrees recorded by warm conditions are high, we speak of *high temperatures* as synonymous with warmth, and *low temperatures* with cold. Other liquids can be used, and alcohol is commonly employed where very low temperatures are encountered, for then mercury freezes and ceases to act, while alcohol does not.

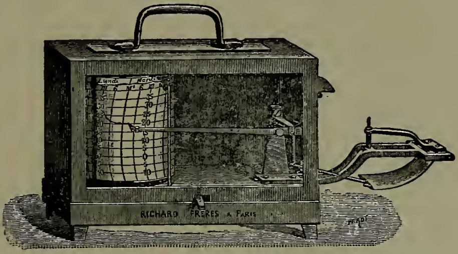

Fig. 20.

A thermograph.

A thermometer is now made of metal, with a clock face over which a hand moves. The operation of this depends upon the expansion and contraction of metal strips, and this change is conveyed to the hand, which moves over a graduated dial. Such metal thermometers may be connected with a pen point, which presses against a moving paper run by clockwork. These *thermographs* automatically write a continuous record of the temperature changes, the time of which may be told because the paper is moved regularly by clockwork.

There are thermometers constructed to register the highest temperature of the day (maximum thermometers), and others to register the lowest (minimum thermometers). The *black bulb thermometer* may be used to tell the intensity of the sun's rays, and also for the purpose of recording the amount of sunlight. The instrument consists of two thermometers, an ordinary one, and one with a bulb blackened by paint or lampblack. Both are exposed to the sunlight side by side, and since the blackened bulb absorbs more heat than that of the ordinary thermometer, its record of temperature is higher.

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[1] To convert the Centigrade to the Fahrenheit scale, multiply by 1.8° and add 32°.

CHAPTER VI

TEMPERATURE OF THE EARTH'S SURFACE

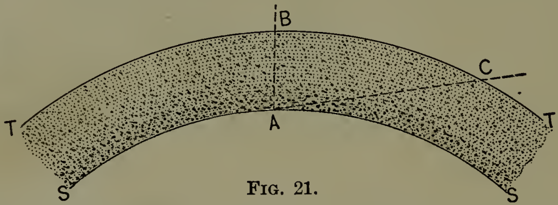

FIG. 21.

Diagram to show difference in amount of air (*TS*) passed through by rays reaching the earth's surface (*SS*), nearly vertically (*BA*) and obliquely (*CA*).

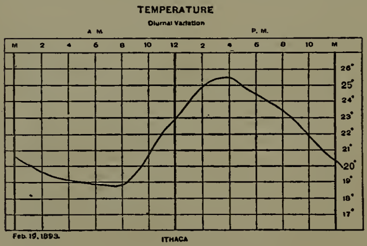

FIG. 22.

Day and Night Change: *Daily Range.*—When the sun rises above the horizon in the morning, the temperature of both land and air is increased, though from the effect of radiation during the preceding night, it takes some time for the sun's heat to warm them. The temperature continues to rise until mid-afternoon, and then, as the sun's rays reach the earth at a greater angle, and after passing through an increased thickness of air (Fig. 21), the effect is lessened, and radiation exceeds the supply of heat. Then the temperature descends, slowly at first, then more and more rapidly as the sun sinks behind the western horizon (Fig. 22). Radiation proceeds to lower the temperature until the sun again rises, and therefore the coldest period is that just before the sunrise. By this means we have a *normal* rise and fall of the temperature each day that the sun shines. But there are many causes which modify this normal change or *range*, so that it differs from place to place (Figs. 23 and 24), and even in the same place, from time to time (Figs. 19, 26, and 27).

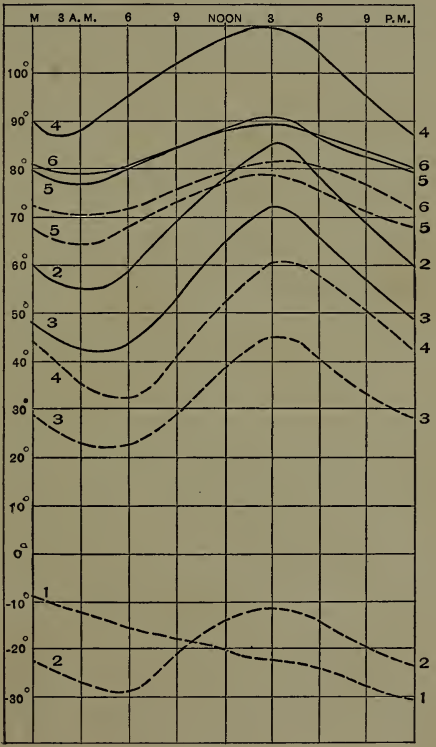

Fig. 23.

Summer (heavy line) and winter (dotted line) daily range of temperature for several places. (1) Arctic day; (2) St. Vincent, Minnesota; (3) Djarling, India; (4) Jacobabad, India; (5) Key West, Florida; (6) Galle, India. 5 and 6, near the warm sea.

Change with the Seasons.—This curve or range is not the same in all latitudes, but varies with the position of the sun in the heavens. Within the tropics, at all seasons, the midday temperature is very high, and after sunset it does not fall low enough to produce cold nights. Within the temperate zones a warm day may be followed by a frosty night. As the season changes, the daily range in temperature varies. During the summer, the normal change is from hot midday to cool night; but in winter the change is from very cold night to cool or cold midday. In the polar zones, the summer day is cool, and since the sun does not set, the night temperature is but little lower. In the winter, the temperature of day and night may be exactly the same; but between these two extremes, when the sun does rise and set, a cool midday is followed by a cold night.

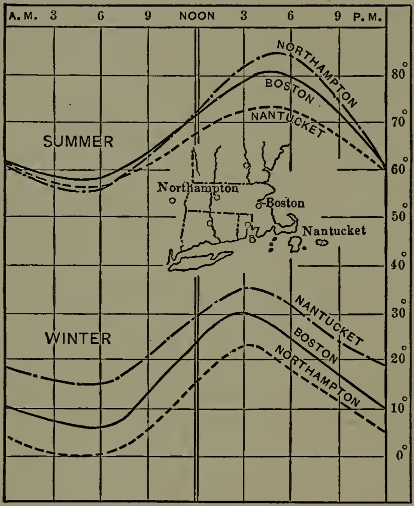

Fig. 24.

Diagram to show influence of ocean on daily temperature range in summer and winter.

Effect of Land and Water. — There is also a change with altitude, for even at midday in summer, the temperature of highlands and mountains is not high, and the nights are cool, because these rise into the cool, thin, upper layers of air, where radiation is always very rapid. In the winter similar change is noticed, though the temperatures are lower.

Between the ocean and the inland, there is also a decided difference in the daily temperature changes (Figs.

23 and 24). The ocean warms slowly, and it does not cool rapidly, while the land warms and cools with much greater rapidity. So the daily temperature range is greater in the interior of continents, than on the ocean, or on land that is influenced by the neighboring sea. Desert lands, being covered by a blanket of cool dry air, are greatly warmed in the day and cooled at night, because the heat of the sun passes easily through this air, and is radiated with equal ease; but humid lands are not subject to so much change, because they are blanketed by a vapor-laden air. Therefore, the daily temperature range of the Sahara is considerably greater than that of the tropical belt of heavy rains in northern Africa, south of the desert. In the latter the temperature of both day and night is high, while in the Sahara very hot days are followed by relatively cool nights (Fig. 25).

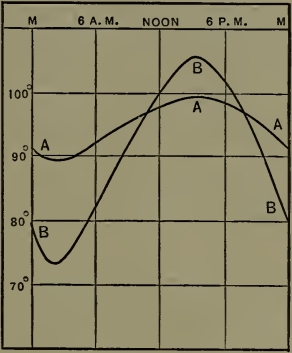

FIG. 25.

Diagram to illustrate greater daily range in temperature in a dry desert climate (*B*) than in an equally hot, but humid, tropical land (*A*).

Irregular Changes. — There are many reasons why the daily rise and fall of temperature may be checked. If the sky becomes cloudy at midday, the sun's heat is partly prevented from reaching the land, and the temperature may not continue to rise, or if it does, it rises very slowly. A cool breeze may check the rise of temperature, so that the hottest part of the day is reached before noon. Clouds at night, or a warm breeze, may prevent the temperature from descending as it should. A humid or muggy air causes a smaller range of temperature than a clear, dry air; and when humid conditions prevail, the day and night temperature may change very slightly. Again, a storm or a cold wave may so interfere with the daily range, that the temperature may rise at night and fall in the day. Therefore, in reality, only a portion of all the days exhibit the *normal* rise and fall of temperature, because this range is checked or altered in many cases, and as the result of various causes (Figs. 26 and 27).[1]

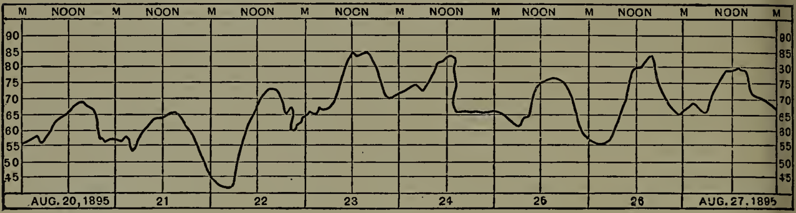

FIG. 26.

Diagram to show irregularities of the daily temperature range. Compare with Fig. 19.

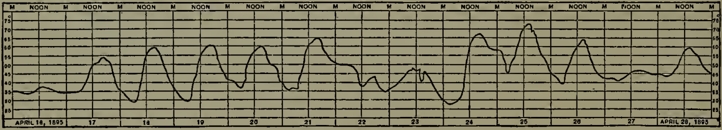

FIG. 27.

Diagram to show regular daily range of temperature and irregularities due to various causes. Notice April 22d and 27th.

Seasonal Temperature Change: *Seasonal Range.*— As in the case of day and night, the temperature of the year rises

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[1] The teacher can use these diagrams to test the ability of the students to detect illustrations of the points discussed in the text.

and falls. The cold ground of winter begins to warm as the sun rises higher in the spring, and the rays reach the earth more nearly vertically, after passing through *less* air. As this continues, the ground and air, cooled during the preceding winter, become warmer; and then, even after midsummer (or June 20), the temperature continues to rise, although the sun's rays reach the earth less vertically. Therefore, the warmest time of year does not coincide with midsummer, but occurs later. After that, the temperature decreases as the rays reach the earth less vertically, and the days become shorter. We have our coldest days in January, because radiation is in excess of the supply of heat, and the ground and air continue to cool even after the shortest day (December 21).

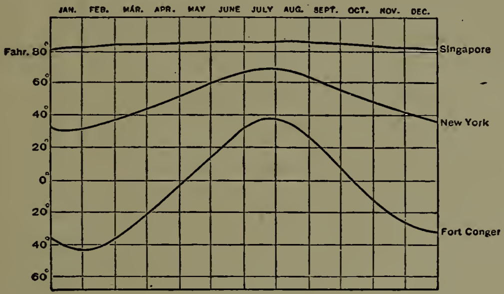

FIG. 28.

Seasonal temperature range at several places. Singapore, in tropical ocean,

Taking the average of all the temperatures of all the days of the year, we find a gradual increase from winter to summer, followed by a decrease until the coldest part of winter. Such a curve, if made accurately, would be somewhat irregular, because there are cool spells in summer and warm periods in winter; but in spite of these temporary variations there is a progressive change. This average *seasonal change* or curve (Fig. 28) may vary a little from one year to another, but in any given place it is nearly the same from year to year, although, of course, there is much variety in the temperature conditions from day to day. But in various parts of the earth, there is a very decided difference in the *nature* of this seasonal change, dependent upon latitude, altitude, and remoteness from the sea.[1]

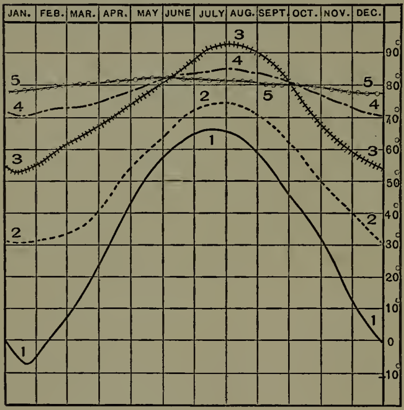

FIG. 29.

Seasonal temperature range in several places. (1) St. Vincent, Minnesota; (2) New York state; (3) Yuma, Arizona; (4) Key West, Florida; (5) Galle, India.

Influence of Latitude. — At the Equator the noonday sun is always high in the heavens, and the days and nights are nearly equal in length. There is enough change in these respects to cause seasons; but since the summer and winter temperatures are both high, the range from season to season is not great. Within the temperate zones the sun is high in the heavens in summer, and the *days* are long, while in winter the sun is near the horizon and the *nights* are long. Hence the winter is cold and the summer warm or even hot.

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[1] It will furnish good practice to have the students look up the location, elevation, etc., of these places; and by this they will better appreciate the meaning of the differences.

Near the poles, within the frigid zones, the sun rises high enough in the heavens to raise the temperature considerably in summer, for then the sun remains above the horizon for weeks, or even months; but during the winter it stays below the horizon, and then radiation cools the land and causes very low temperatures.

Influence of Altitude. — Altitude is almost as important in determining the seasonal temperature of a place, as latitude. Even near the Equator there may be a frigid climate, with perpetual snow on the highest mountain tops; and in the temperate zones many of the mountains reach the height where snow can remain all the year round. In such places the summer temperatures are never high, while the winter is cold. Therefore in the *same latitude* the seasonal range may vary greatly with elevation above the sea. In ascending mountains the average temperature descends, and this change is sufficient to influence the growth of plant life, so that forests change in nature and then disappear (Fig. 85), just as they do on the way from temperate to polar latitudes.

Influence of Land and Water. — Practically the same effect is produced by land and water upon seasonal range, as upon the daily change in temperature (Figs. 28, 29, and 30). Even in the temperate latitudes, where there is so much difference between summer and winter, the water of the ocean does not become highly heated in summer, nor very much colder in winter. This is partly because the water does not warm or cool quickly, and partly because it is in constant motion. Currents of cold water from the Arctic, and of warm water from the Tropics, are constantly flowing in the north Atlantic, and influencing the temperature of the air. Therefore the seasonal range over the ocean is never so great as it is on the land. One may feel this moderating influence of the water even on the shores of a lake, and the influence of the ocean itself is felt to a considerable distance from the shore.

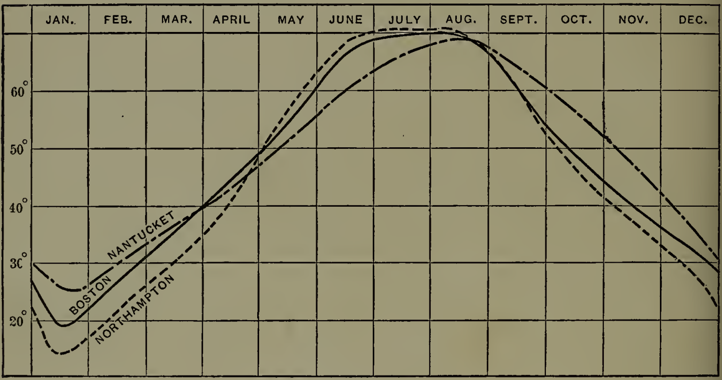

FIG. 30.

Influence of water on seasonal range of temperature. Summer temperature at Nantucket low, and winter temperature high — the reverse at Northampton. Compare with Fig. 24.

Climatic Zones.—Because of these peculiarities the earth may be divided into five great zones of different temperature conditions: (1) the warm *Tropical belt*, in which the temperature is always high, and the range moderate; (2) the *Temperate zones* (one north and one south of the Equator), where the temperature is high in summer and low in winter, and the range great, while the average temperature is moderate; and (3) the *Frigid zones* (one about each pole), where the temperatures are always low and the range considerable.

Each of these zones must be further subdivided. In each there are *insular* or *oceanic* climates, differing from

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of the Globe for
JULY

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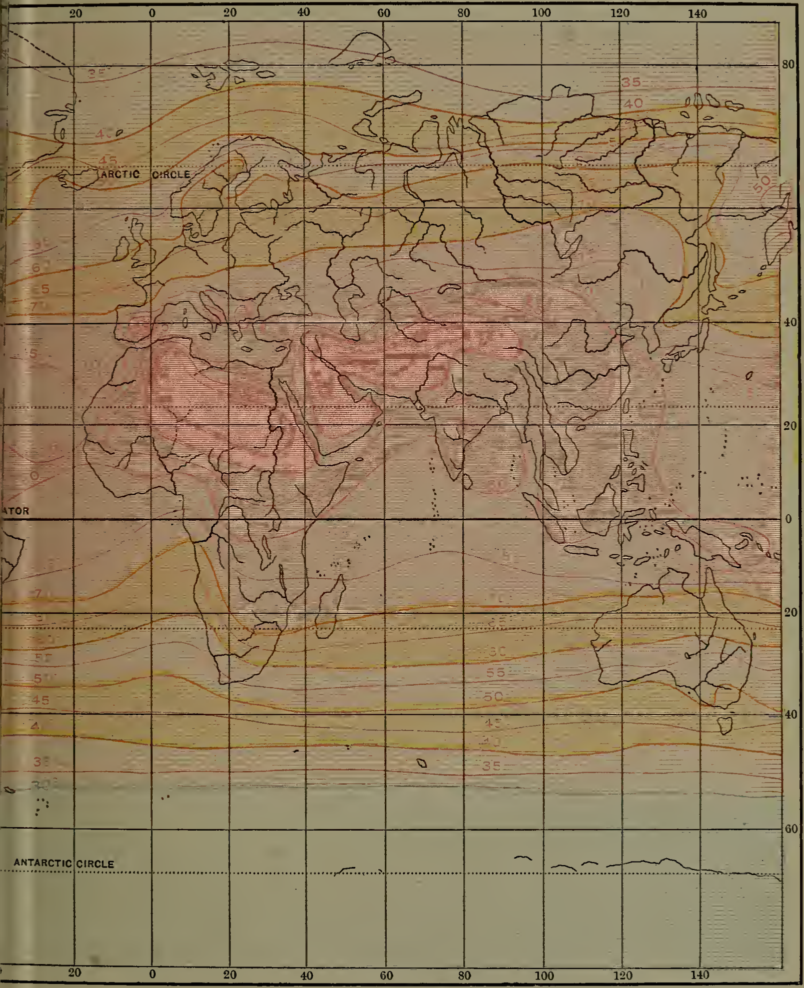

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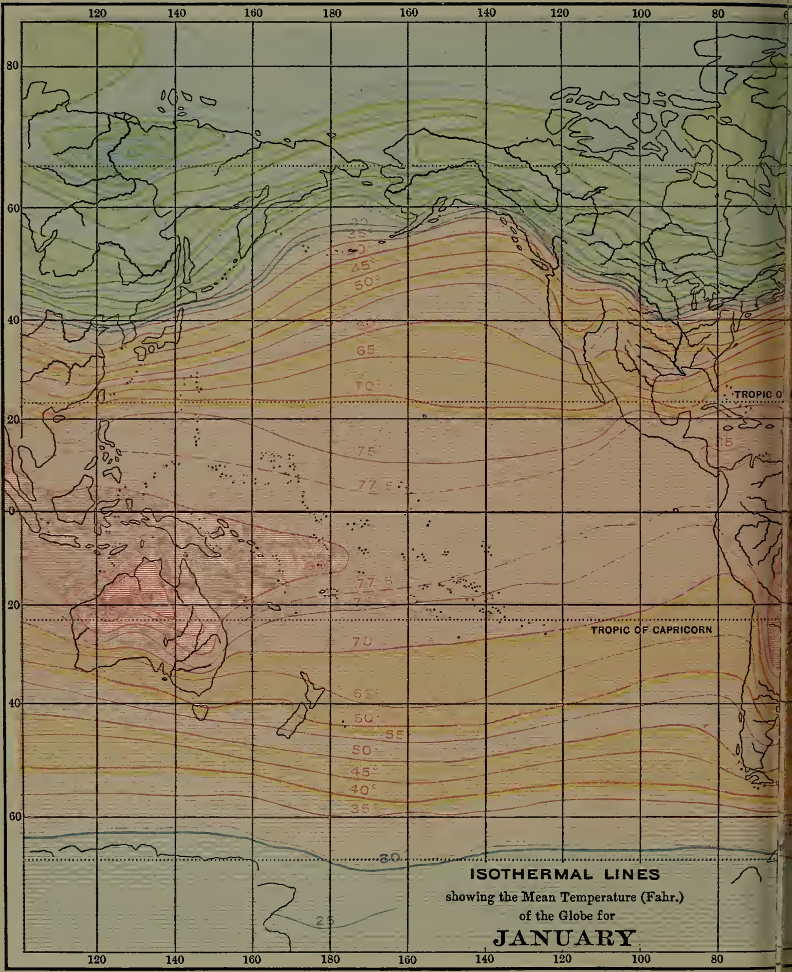
the inland or *continental;* and there are *highland* and *mountain* climates, differing from those of the lowlands. Hence there is no *single* feature of the earth, which by itself will determine the temperature conditions. Latitude produces the most decided influence, and as we go from Equator to pole we pass through regions in which the average temperature is decreasing. Still places on the same latitude do not necessarily have the same climate.

This can be very well illustrated by following a parallel of latitude, such as the fortieth parallel, which passes near Philadelphia. Crossing the Atlantic, where the temperature is moderate, it enters Portugal, where the climate is very warm, then across the plateau of Spain, a warm, dry, semi-arid country, and emerges upon the warm Mediterranean, crossing the southern part of Italy, below Naples, the place to which people go for the purpose of a moderate winter climate. It then crosses Greece and Asia Minor, after which it enters the dry, cold plateau region of central Asia, crossing China, near Pekin, and northern Japan. The parallel passes across the warm Pacific, enters the United States north of San Francisco, where the climate is very equable, and ascends the mountains and plateaus of the west, now passing over a cold mountain top, and again descending to a warm, dry plateau enclosed between the ranges. It then passes between Kansas and Nebraska and then into Missouri, central Illinois, Indiana, Ohio, and southern Pennsylvania. There is every gradation from the warm, almost tropical climate of the Mediterranean, to the frigid climates of the high plateaus and mountains.

Isothermal Lines.—An isothermal line is one which extends through places having the same average temperature. That is to say, all the temperatures observed during a month (for instance) are *averaged* to furnish the *mean temperature* for that month, and the places having the same average are connected by a line which we call an *isotherm.* In the same way the average temperatures of the year give a basis for the construction of isotherms for the year. A map in which the lines of equal temperature are drawn is called an *isothermal chart.* Since the temperature varies from one place to another on the same latitude, the lines of equal temperature, or isotherms, do not pass around the earth parallel to the degrees of latitude, but in a very irregular manner.

Examining the charts which illustrate this chapter, we may see how the average temperatures of the world are distributed. The warmest belts are near the Equator, and the coldest near the poles; but the hottest part of the earth is not exactly at the Equator, but north of it. This zone of greatest heat may be called the *Heat Equator*, and the reason why this is north of the geographic Equator, is that there is more land in the northern hemisphere than in the southern. This becomes warmer than the water, and hence the temperatures in the northern hemisphere are higher, on the average, than those in the southern. Of course, we know very little about the climate in the coldest parts of the earth, and nothing whatever about the conditions *at* the poles; and so it is impossible to say just where the very coldest places are, though the coldest known place, or the *cold pole* of the earth, is in northern Siberia, near the Arctic circle.

There is an *average* decrease in temperature from the warm equatorial region toward the poles, and therefore the isotherms extend around the earth, following the direction of the parallels of latitude in a general way; but



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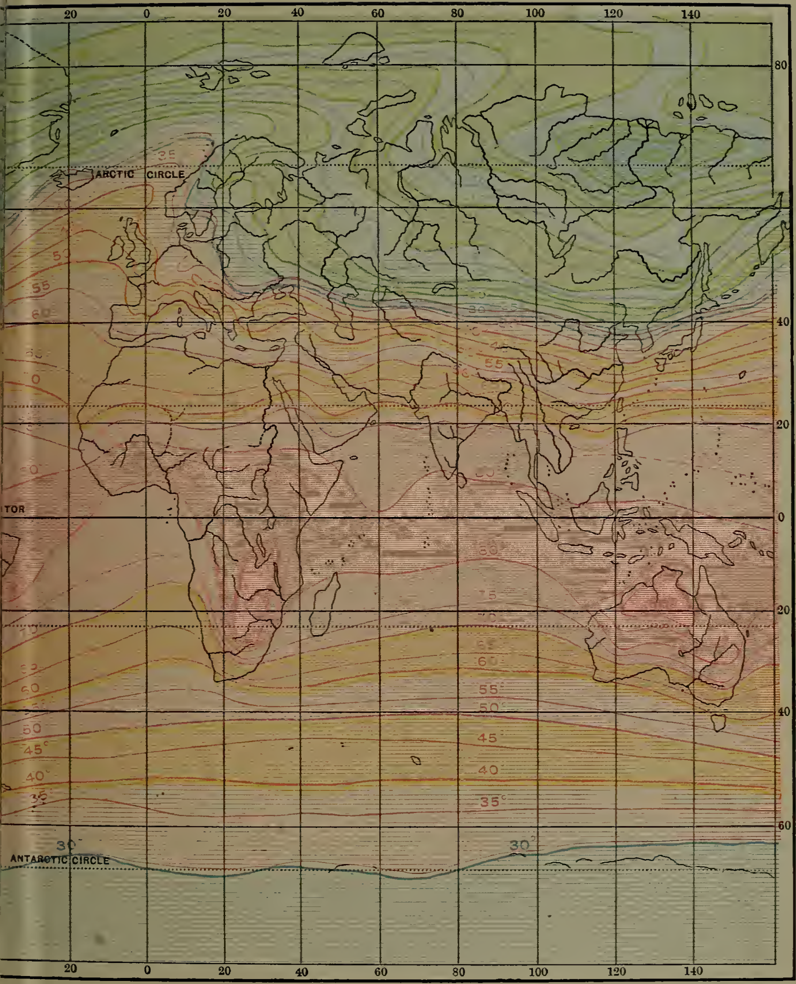

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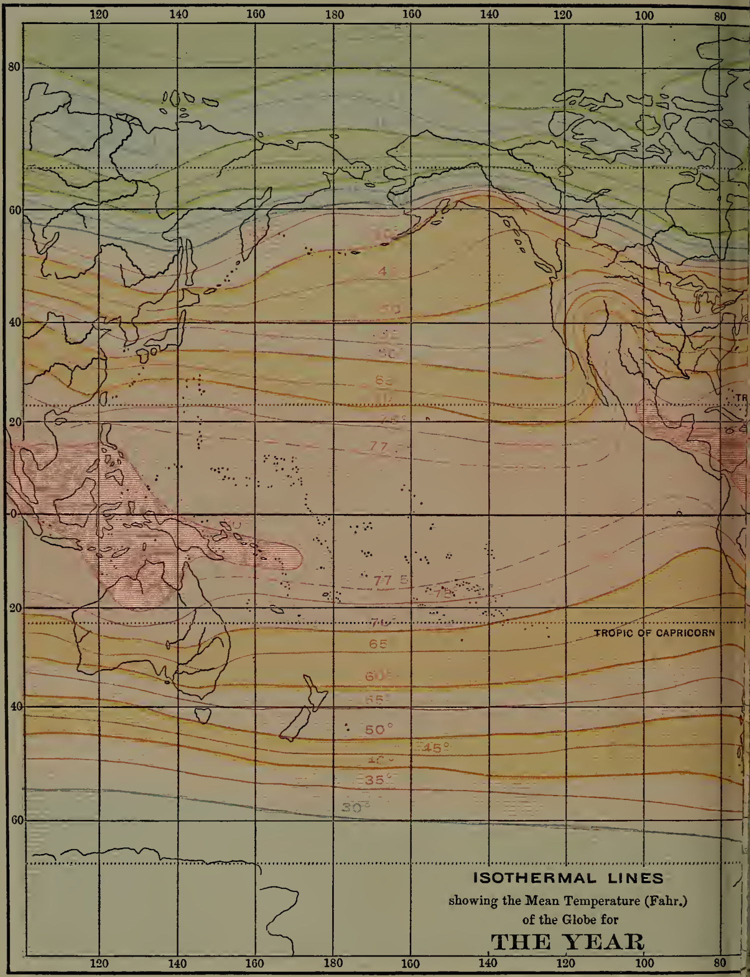

ISOTHERMAL LINES

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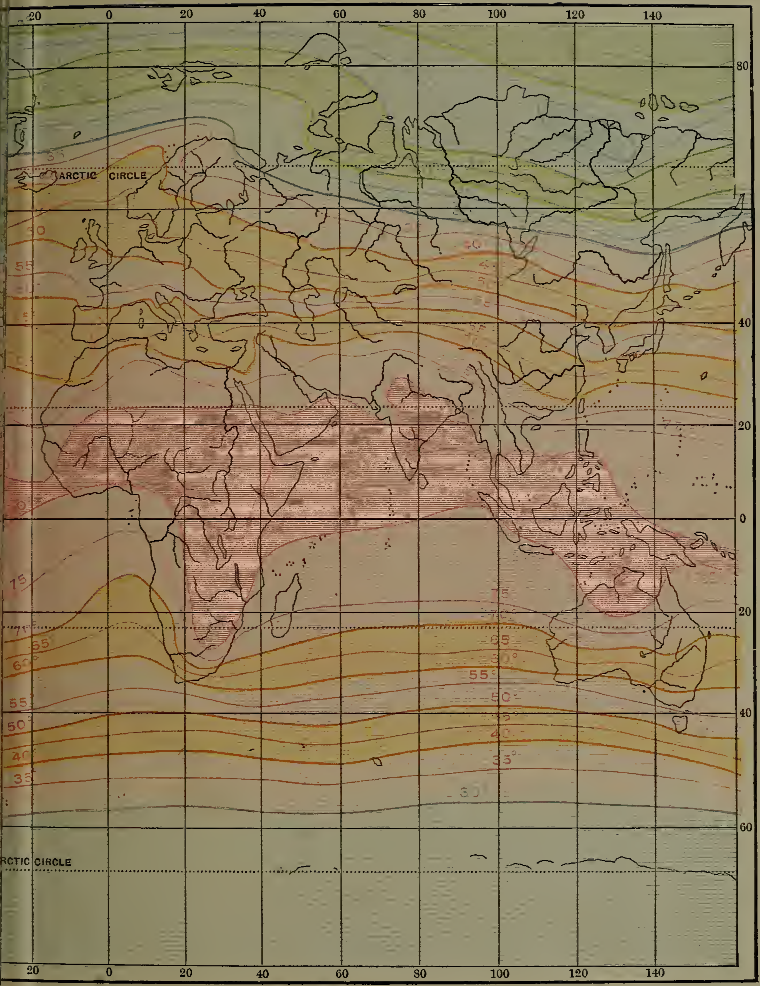

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they do so very irregularly, and this is particularly true in the northern hemisphere, where there is so much land, varying from plain to mountain, and separated by water bodies. In the southern hemisphere, where there is less land, the isotherms extend over the water surface in a direction nearly parallel to the lines of latitude. It will be instructive to follow one of these isotherms for each hemisphere; and for this purpose we may select the isotherm of 50° (the one which passes through all points whose average temperature for the year is 50°), which is the one passing through Boston, Mass.

Crossing Massachusetts Bay to the tip end of Cape Cod (between 42°–43°), this isotherm extends northeastward fully 10°, crossing the middle of Ireland and England. It then descends to the Black Sea, crossing the northern end of the Caspian, and passing through central Asia near the parallel of 45°. It then descends below the 40th parallel, crossing Corea and northern Japan at about 40°, and entering the Pacific. Then passing northeastward, the isotherm enters this country near the mouth of the Columbia and passes into Canada, then again descends into the United States, passing along the southern portion of the Great Lakes.

In the southern hemisphere this same isotherm passes around the earth nearly on the 40th parallel, generally being south of it, though sometimes passing to the northern side. Therefore in the northern hemisphere this isotherm ranges through about 15° of latitude, and in the southern hemisphere through not more than 8°. Some of the isotherms show even a greater difference than this.

Comparing the January and July isothermal charts, we may see how much difference there is between the temperature of the coldest and the warmest months. In the north Atlantic the isotherm of 40° for January reaches above the 60th parallel, while in China it descends to the 30th, ranging through more than 30° of latitude in the two regions. During July this isotherm is entirely within the Arctic circle, and in some places nearly reaches the 80th parallel. In the southern hemisphere, during the southern summer (January), the 40° isotherm runs nearly parallel to and a little north of 60° south latitude, while in the southern winter it is just north of the 50th parallel. So the climate of the north temperate zone is shown to be more extreme than that of the oceanic southern hemisphere.

The study of these charts reveals many other features. Where they flow, *warm* ocean currents raise the temperature of the sea and bend the isotherms *toward the poles;* a *cold* current, coming from the north, cools the air and bends the isotherms *toward the Equator.* Each of these features is very well shown in the north Atlantic on the January chart. A comparison of the charts shows how cold the interior of the continents becomes in winter, and how warm they are in summer; and we find here an excellent illustration of the difference between the oceanic and inland climates.

The world is so large that such maps as these can do no more than show the most general features. On those of the United States we may find other features, the result of minor causes, such as the influence of highlands in disturbing the direction of the isotherms. Thus on the Pacific slope the isotherms run nearly parallel to the coast, because the air, blowing in from the Pacific, rises against the mountain ranges and cools. These ranges

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PLATE 4.

Isothermal Chart of United States, July.

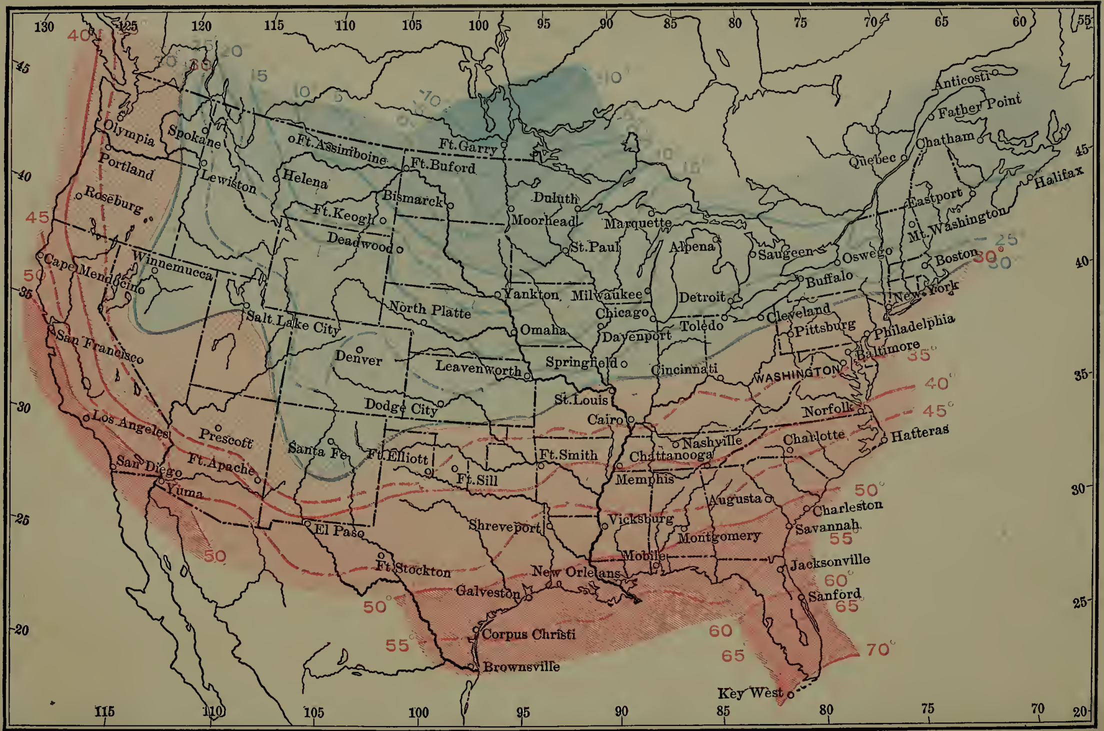

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PLATE 5.

Isothermal Chart of United States, January. Blue, below freezing point; red, above freezing point.

are nearly parallel to the coast, and so the isotherms run in this direction, each one representing a greater distance from the sea, and a greater elevation. If we could have even a more detailed chart of a small area of country, such as a state, we would find many other variations. In New York, the Hudson and Mohawk valleys are warmer than the enclosing highlands, and the shores of the Great Lakes are more equable than the country which lies at a distance from these large water bodies. In New England, the Connecticut valley is warmer than the high-

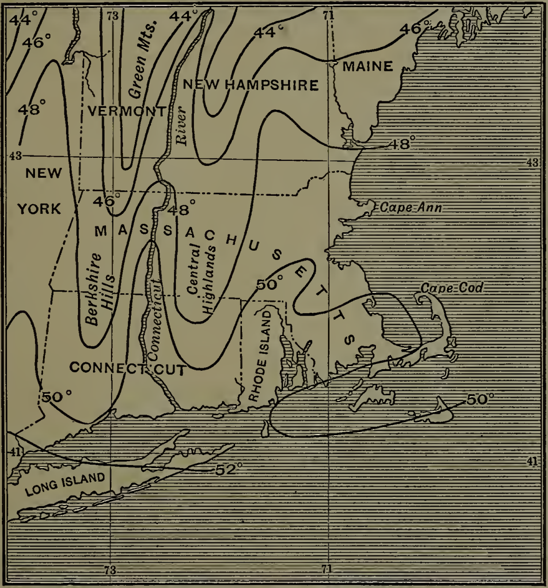

FIG. 31.

Isothermal chart of southern New England, showing influence of high and low land.

land region on either side (Fig. 31[1]), and the same is shown in many other regions.

Because of the many variations in heat effect described in the preceding pages, there are numerous kinds of climate, — the warm and equable ocean, the heated desert, the interior plain, with extremes of heat and cold, the cold mountain tops, etc. There are also many other indirect effects. The sea is set in motion, winds are formed, vapor is taken from the water, rains are caused, storms arise, and the air is constantly doing work of various kinds.

Temperature Extremes. — Owing to the *irregular* changes of weather, which are common in the temperate latitudes, we may have a great temperature change in a few hours. In Montana a daily range of 50° is not uncommon, while at Key West, the difference between the record of temperature in day and night is generally from 5° to 10°.[2] In Montana the range between the highest temperature of summer and the lowest of winter is about 145° (– 40° in winter and 105° in summer). At Key West the range is only about 40° (50° in winter and 90° in summer). In Montana a fall of 100° has been recorded in a few days, while at Key West there is never a great range. The one place has an insular climate, in the midst of a warm ocean current, the other is an elevated interior plain, far from the sea, and covered by relatively dry air, through which the sun's heat falls readily to the earth in summer, while in winter radiation proceeds with equal ease. Other parts of the country show ranges between these two extremes.[3]

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[1] The teacher would do well to devote considerable time to the study of these charts, and to a discussion of the many features shown, for which space cannot be given in this book.

[2] In the clear, dry region of Thibet a range of 90° in a single day is reported, 68° at midday and – 22° at night.

[3] The highest air temperature ever recorded is 127° in Algiers, and the lowest – 90° in central Siberia, which is the coldest known part of the earth. Higher temperatures than that of Algiers have been recorded from near the ground, for at times the earth of deserts, particularly if its color is dark, becomes so hot that it is painful to walk on the sand.

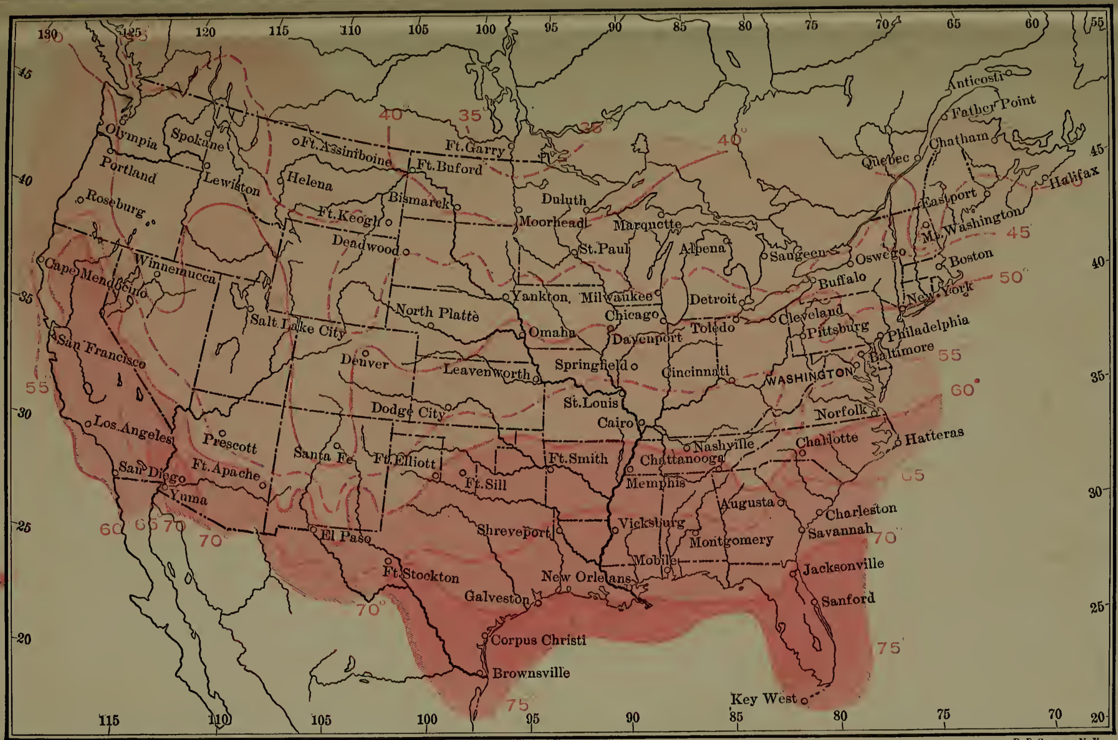

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PLATE 6.

Isothermal Chart of United States for the year.

CHAPTER VII

WINDS

Air Pressure. — About us is a mass of air which presses down upon every part of the earth. At the sea level the pressure of the air amounts to about 15 pounds on every square inch of surface. A man therefore bears a weight of many thousands of pounds upon the outside of his body, but he moves about without realizing this, because the pressure is equal in all directions.[1]

The pressure of the air is not the same in all places, nor at all times (Fig. 32). For various reasons it changes from day to day, and is greater on cool, dry days than in stormy weather. The weight of the air also varies with altitude. While it amounts to about 15 pounds to the square inch near sea level, the pressure decreases as one ascends a mountain; for of course there is less air over a mountain top than above a neighboring plain. It is found also that there is a difference in the air pressure even at sea level in different latitudes. The reason for this is explained below.

Measurement of Air Pressure. — If we should fill with water a glass tube 35 feet long, having one end sealed, and then invert it with the

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[1] One can prove the existence of this pressure, if he places his hand upon the top of a cylinder on an air pump, from which the air is then exhausted. The pressure is then removed from the under side, but the weight of the atmospheric column above is felt, and the invisible load presses on the back of the hand with such force as to be painful.

open end in a dish of water, there would be a column of the liquid rising in the tube to the height of about 30 feet. This column of water represents the actual weight of an air column having the same area of cross section. Such a tube may be called a *barometer*, and if we watched the top of the water day by day, we should find that it rose and fell, indicating a change in air pressure. Since these changes are in reality detected by a similar instrument, it is common to speak of a *change in barometer* as synonymous with *change in pressure* (Fig. 32). When the air is heavy, the barometer rises, and we have a *high barometer;* when it is light, we have a *low barometer*.

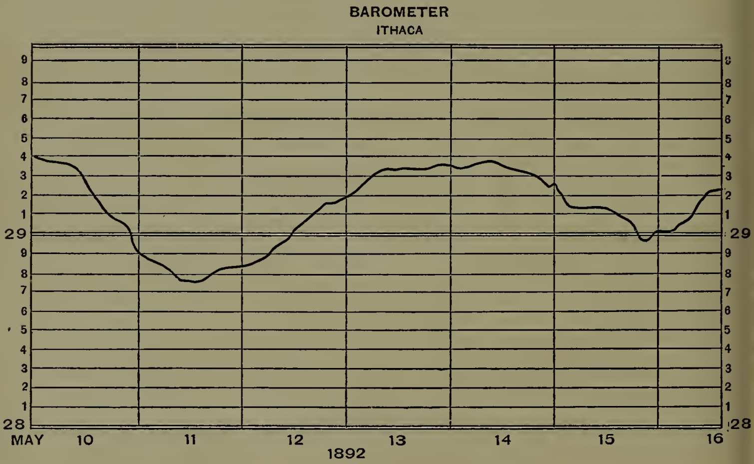

Fig. 32.

Diagram showing change of pressure for seven days. Figures on the side are inches and tenths of inches: —28.9, 29.1, etc.

It is upon this same principle that the ordinary pump is constructed. A tube leads to the well, we exhaust the air from the tube by means of the handle, and then the air, pressing on the surface of the well, forces water into the tube. By such an arrangement we cannot possibly draw water 40 feet above the surface of the well. A special kind of pump is necessary to raise water above the height of 25 or 30 feet.

Such a barometer as that described above is too cumbersome for use, and for it is substituted the *mercurial barometer*. The liquid mercury is very much heavier than water, and hence the weight of the air cannot force it so high in a tube which has a partial vacuum at the top. While water can be forced up to a height of about 30 feet, mercury is made to rise only about 30 inches. Any one can make a mercurial barometer by filling with mercury a glass tube 33 or 34 inches long, with one end sealed, and then inverting it with the open end under the surface of a small dish of mercury.

The ordinary barometer is made in exactly this way, although there are many changes in detail, in order to increase its perfection. One of these is the mode of reading the *height of the barometer*, or the elevation of the mercury column in the tube. The barometer is graduated in inches, and it is possible to read to tenths or even hundredths of an inch, so that very slight differences in air pressure are noticed. In speaking of the height of a barometer, we say that it reads 29.8, 30.1, etc., inches. A barometer at sea level has a higher reading than one at an elevation above the sea, and from day to day every barometer situated at one place is subject to change.

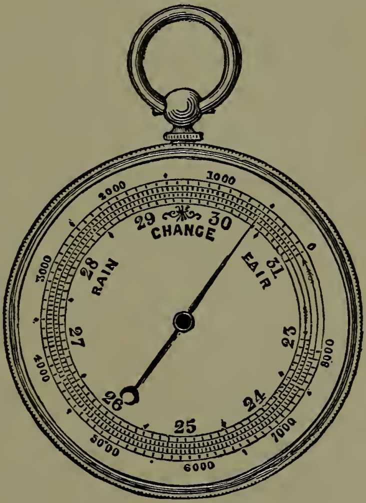

Fig. 33.

Aneroid barometer graduated in feet (outside) and inches (inside).

Even the mercurial barometer is somewhat cumbersome, and is especially unfit for transportation. When kept standing in one place it does very well, but it soon gets out of order when carried about. For some purposes it is important to transport barometers, especially when it is desired to measure the elevation of any part of the land. Since there is *less* air above a high land than above the sea, a barometer carried up a mountain side is subjected to *less and less pressure*, and the mercury correspondingly sinks a certain amount; and hence for a fall of a fraction of an inch, we are able to calculate the amount of elevation over which we have passed. So the *height* of a mountain can be determined by means of the barometer. A change in pressure of an inch means an elevation of about 900 feet, though this varies somewhat with the amount of elevation.

For this class of work a special form of barometer has been devised, called the *aneroid* (Fig. 33). Here instead of a liquid, the pressure of the air exerts its force on a metal diaphragm within a metal case. The change produced on the diaphragm is communicated to a hand which moves over the face, somewhat as the hands of a watch pass over the dial. The face beneath the hands is graduated to feet, so that as the index moves, a person may read the change, just as he reads the time on a watch. In climbing an elevation, the hand moves in one direction, and in descending, in the other. The entire instrument is so small that it may be carried in the pocket.

Aneroids are also used in *recording* a change in pressure. The instrument is placed in the proper position, and since the pressure varies from day to day, the hand moves backward and forward according to these changes. On it is fixed a pen which presses against a sheet of paper moved by clockwork (as in the thermograph). The pen therefore *marks* the changes in pressure, while the *rate* of movement of the paper keeps record of the time, so that a continuous record is kept both of the time and amount of change in air pressure. Such a self-recording barometer is called a *barograph*.

Change in Air Pressure.—When air is warmed, the molecules are spread apart, and it becomes lighter. The same is true of a liquid. This can be proved by a simple experiment: place a drop of colored ice water in a glass of water having a temperature of 40°, 50°, or 60°, and the colored water will sink, because it is heavier than the remainder. Also on a cold winter's night, when the air outside is perfectly still, if a window in a warm room is opened, the heavy cold air from out of doors pours into the room. The same principle is illustrated by a stove or a lamp. The air near this is warmed, and hence made lighter than that which occupies the more remote parts of the room. The heavy air presses down and forces the warm air to rise, causing a circulation in the room. By standing on a chair in a well-warmed room, we may see that the cooler air stays at the bottom, while the warm air rises to the top. Oftentimes the upper layers are suffocatingly hot, while those near the floor are only comfortably warm.[1]

The atmosphere may be likened to the air of a room. Some places are being warmed more than others, and those that are most warmed are lighter than the colder portions. For instance, the air over the Mississippi valley may be warm, and that over New England cold, and we then have a high barometer, or heavy pressure, in the latter place, and a low barometer, or low pressure, in the former place. The barometer may register a difference of an inch in the two places. This difference in pressure gives rise to what is called the *barometric gradient*, and the air will move from the New England region toward the low-pressure area of the Mississippi valley, causing winds from the east. It does this because the atmospheric gases are so mobile that even *slight differences* in pressure cannot long exist.

It is somewhat like pouring a glass of water into a basin. The water that is poured in does not stay in one place, raising the surface of that part of the basin, but flows about, and causes the neighboring layers to move, with the result that the entire surface is raised a little, and the *pressure remains the same* in all parts of the basin. Just so in the air: no sooner is a difference in pressure introduced than movement begins to equalize

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[1] This subject of air circulation may well be prefaced by an experimental study, or a consideration of ventilation.

it, and attempt to make the pressure everywhere the same. It is upon this principle that most of the winds of the globe depend.

Planetary Winds: *Theoretical Circulation.* — The earth is divided into zones: there is cold about the poles and heat at the Equator. Therefore we may expect a great planetary circulation similar to that in a room containing a stove. Warmed most around the equatorial belt, the air here is expanded and made light, while on either side, north and south of this, there are belts with a cooler climate. In the latter, since the air is heavy, there must be a flow toward the warm region, in order to equalize the pressure produced by the difference in temperature. This will force the air near the Equator to rise, just as air ascends in a fireplace, or through the draft of a stove, or of a lamp. But if it rises, while air from the north and south flows in to become warmed and also rise, there must be some escape. Otherwise so much air will reach

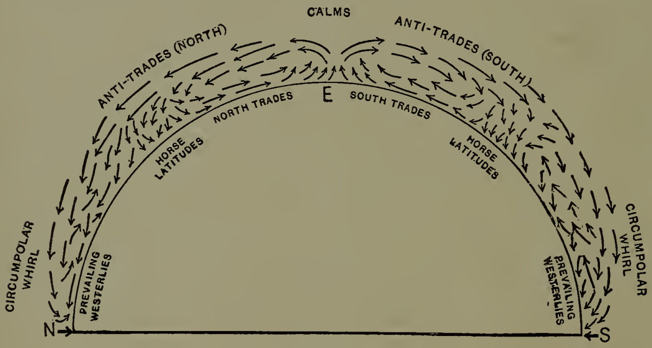

FIG. 34.

Cross section of atmosphere showing, very diagrammatically, the general air circulation. *E*, equator; *S* and *N*, south and north poles.

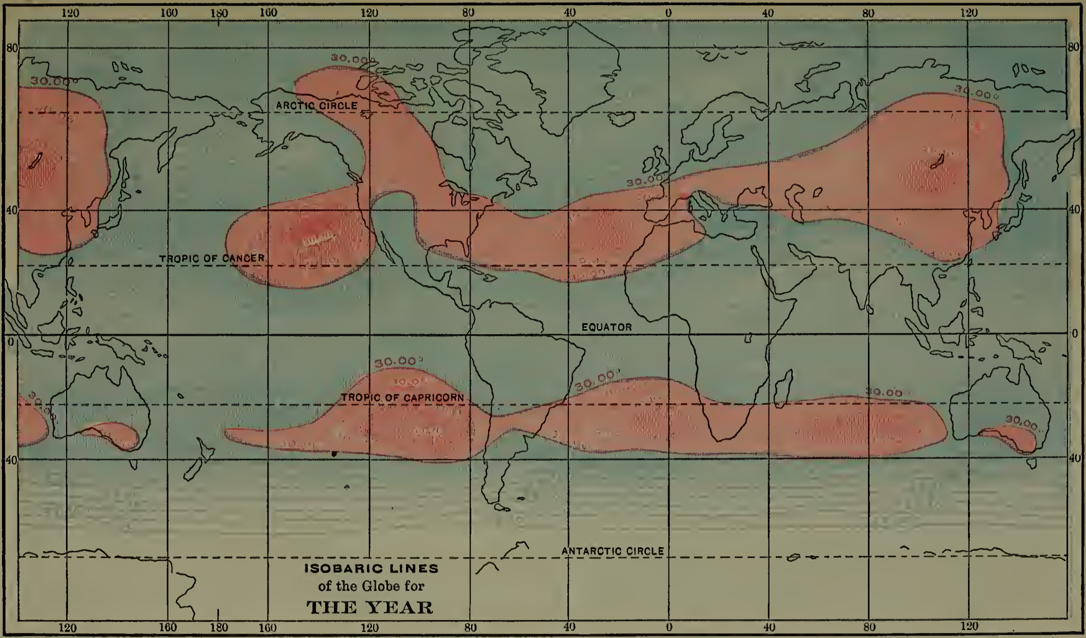

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PLATE 7.

Isobaric lines showing variation in pressure. Pressures higher than 30 inches in red, lower than this in various shades of blue, the lowest pressure being the lightest.

the Equator that the increase in bulk will make the pressure as great as that in the colder temperate zones.

The cause for this imaginary circulation of the air is at work every day in the year, and hence a movement of a very permanent nature must be begun. Again, we may make a comparison to a room containing a stove. Here the air is warmed near the stove, cold air flows in, forcing up the warm layers, which thus reach the ceiling and flow away to the sides of the room, while the air that moved in toward the stove is warmed and also made to rise. At the ceiling the air is cooled by contact with the cooler body; it settles, and again flows toward the stove, so that a constant circulation is maintained. Here, then, we have four zones of movement: (1) the current along the floor *toward* the stove; (2) the vertical current over and near it; (3) an upper current moving *away from* the stove, above that on the floor, and in the opposite direction; and, finally, (4) the settling of the upper air on the opposite side of the room. Upon a much larger scale this is what we may expect to find on the earth.

Trade-Wind Circulation. — Near the Equator there is a *belt of calms*, which is the place where the air is rising. This ascending air cools, some of its vapor is condensed, and rain storms are of daily occurrence. It is therefore not only a belt of calm air, with light and variable winds, but also a very rainy belt, and it is sometimes called the *doldrums.* Moving toward the doldrums, on either side, are the trade winds, which flow over the ocean in a remarkably permanent manner, both winter and summer. These represent the cooler, dense layers near the earth, which are moving in toward the great terrestrial stove, the equatorial belt of calms. Above these, and flowing in an opposite direction, are the *anti-trades*, whose existence is proved by the movement of clouds high in the air, and also by actual observations on mountain tops, where peaks rise above the trade winds, and enter the upper currents. Near the tropics, at the place where the trades begin to be permanent, there are regions of settling air, known as the *horse latitudes;* and thus the theoretical circulation is completed, and in fact we find what was predicted in theory.

There is a very important difference, however: according to theory, the trades should blow southward in the northern hemisphere and northward in the southern, moving directly toward the Equator, and the anti-trades should blow in the opposite direction. In reality this is not so; the trade winds of the northern hemisphere blow toward the *southwest*, while the southern trades move toward the *northwest*, the northern anti-trades toward the *northeast*, and the southern toward the *southeast*. The reason for this is the influence of the earth's rotation (p. 67). Any current on the earth, whether of air or water, is turned to one side as it moves, to the right in the northern hemisphere and to the left in the southern. Hence the trades do not approach the Equator along the meridians.

The belt of calms is not stationary, as is the Equator, but migrates with the seasons (compare Plates 8 and 9). During our summer, when the sun is vertical over the northern tropic, the belt moves to the northward; and in winter it migrates to the south, because the greatest effect of the sun's heat is first north and later south. Hence as the equatorial belt of greatest heat migrates, the trades change their position, in the summer being further north than in the winter. This change influences the climate of various places very perceptibly.

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PLATE 8.

Map of the world showing the general circulation of surface air for July with names applied to the various belts.

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PLATE 8.

Map of the world showing the general circulation of surface air for July with names applied to the various belts.

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PLATE 9.

Map of the world showing the general circulation of surface air for January with names applied to the various belts.

Prevailing Westerlies. — Since the polar regions are places of greater cold, we might expect that in these zones the air pressure would be high; but such is not found to be the case, and we must look for some explanation. There certainly must be a settling of dense air in the high temperate and polar latitudes, because the cold of these regions makes the air heavy. We *know* that there is a rising of the air near the Equator, but the settling of this in the region of the horse latitudes does not take place so far north as this zone of greatest cold, but rather in the warm portions of the temperate zones, where the trade winds begin to blow. Here, however, only a part of the air settles, and some of the upper currents, which extend as anti-trades from the place of equatorial upflow, pass along toward the poles, constantly turning more and more to the east, under the influence of the earth's rotation.

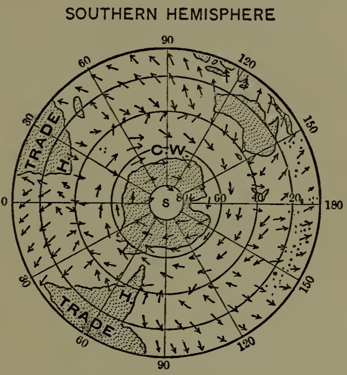

Fig. 35.

Ideal circulation of air near the surface, in the southern hemisphere. Trade: trade-wind belt; *H, H,* horse latitudes of uncertain winds; *C. W.*, circumpolar whirl, or prevailing westerlies.

West winds therefore prevail in the upper air of the high latitudes, and this is also the prevailing direction of the winds near the ground, though there are so many disturbing causes here that they are not so permanent as they are high up above the earth. Since both in the higher temperate and polar zones of the northern and southern hemispheres, the air movement, both aloft and near the ground, prevails from the west, these winds are called the *prevailing westerlies.* They complete the great planetary circulation of the atmosphere, and from them we obtain an explanation of the low pressure near the poles, where at first thought a high pressure would be expected.

The air is moving toward the poles, where, because of the cold, there is greater density; but as it comes from the broad temperate into the polar zones, it is passing *toward a point*, the pole, and is constantly coming toward a narrower and narrower space. It would be impossible for all the air that starts to reach the polar zone, and hence some sinks and returns toward the Equator; but much keeps on. A deflection results from the influence of rotation, which turns the currents to one side, and a whirl is begun, which is somewhat like that produced in water which is escaping from a basin. In this case the water is flowing from a broad area toward a narrow orifice, and if we look at such a whirl, we find that the water surface is *lower* in the centre than on the sides, and that around the depression the water is whirling in spiral currents.

Conditions similar to this evidently prevail in the region surrounding each pole, and the whirl of air, in the belt of prevailing westerlies, forms what is known as the *circumpolar whirl.* Because of this spiral whirling movement, there is actually *less air* near the poles, and hence, notwithstanding the fact that it is colder and denser than in other parts of the world, its pressure is less than would be expected if it were not for the whirl.

The great system of winds described above is better developed in the southern than in the northern hemisphere, because there is less land in the former. The great expanse of water south of the Equator allows the air circulation to proceed with less interference than in the northern hemisphere, where bodies of land and water alternate (Plates 8 and 9). The heat of the sun affects the land much more than the water, and this difference causes other winds from water to land, or the reverse, which mask, and at times even destroy the great planetary winds near the earth's surface. However, in both hemispheres the currents in the *higher altitudes* are remarkably permanent, as may be seen in the United States by watching the passage of clouds high in the air, which are generally moving from the west.

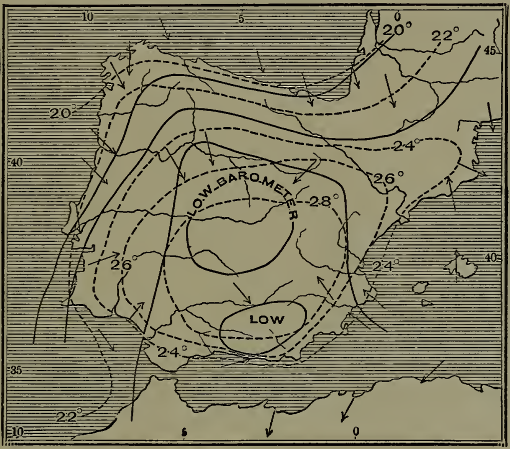

FIG. 36.

Map of Spanish peninsula, showing lines of pressure and temperature with winds for July, when the summer monsoon prevails.

Periodical Winds: *Monsoons.* — The effect of the sun's heat upon the land is greater than on the water, and radiation from the land surface produces a greater effect than upon the water. Hence if there is a large land area, in summer it becomes warmer than the neighboring water, and in winter cooler. This may be seen by examining the map of the Spanish peninsula (Fig. 36). There, in summer, the air is less dense over the land than over the water; and, as in the case of the stove, a circulation must result. Therefore the denser air, which in summer lies over the Mediterranean and Atlantic, settles and forces the lighter air over Spain to rise; but during the winter, when the land is colder than the surrounding water, the dense cold air over Spain settles and flows out toward the sea, causing winds in the opposite direction. These are *monsoons*, and they are periodical winds because they blow at certain definite periods of time.

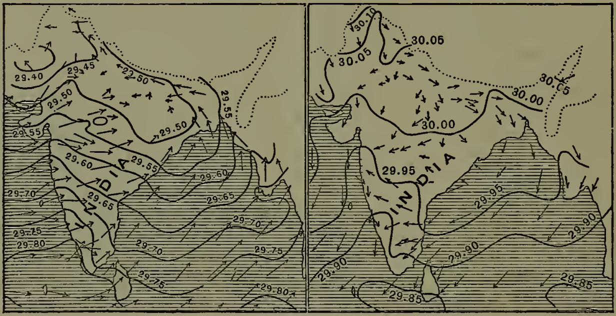

FIG. 37.

The summer (left hand) and winter (right hand) monsoons of India.

The typical monsoon is found in Asia, but it occurs also in Spain, Australia, Texas, and elsewhere. In Asia, particularly over India (Fig. 37), the monsoon winds are remarkably permanent, and are important both in modifying the climate and in navigation. In the warm part of the year, the summer monsoon brings warm, damp air from the ocean, and heavy rains result; but the winter monsoon, blowing from an opposite direction, bears cold, dry air from the land. Year after year these changes of wind direction come as regularly as the seasons; but there are of course other winds, due to different causes, which at times bring air from other directions.

Land and Sea Breezes. — People go to the seashore to escape the heat of the summer, and they do this because the ocean does not become so warm as the land. This is very well illustrated in hot summer days, when the heat of the land is oppressive, and when, by going to the coast, one finds relief from the heat. Soon, if the day is quiet, a gentle breeze may be seen ruffling the surface of the sea (the same may be seen on large lakes, like the Great Lakes), and after awhile a cool draught comes from the water. This is the *sea breeze*, to which the dwellers by the seashore look for a relief from the oppressive heat of the summer day. It may reach a score or more of miles from the coast, but its chief effect is felt near the sea.

At such a time the sea breeze may become a strong wind, and often in regions of permanent winds, such as the trades, a sea breeze may arise which succeeds in entirely changing the direction of air movement. Here, as in the monsoon, the cause is the heating of the land, so that the denser cold air of the sea flows in over the heated land. Before it begins to blow, the temperature by noon may have mounted into the nineties; and then, with the coming of the breeze, the temperature may fall 10° or more in less than an hour, so that the time of greatest heat does not fall in the afternoon as usual.

At night, when the land cools by radiation, the dense air settles and flows out toward the warm sea, causing a *land breeze*, which, however, is not so pronounced, nor so frequent in its occurrence, as the sea breeze. The sea and land breezes are also felt along the shores of the greater lakes, though these are perhaps more properly called lake and land breezes. Even near some of the smaller lakes, similar air movements are noticed, though here only as slight draughts of air. This illustrates how easy it is for the atmosphere to move when the pressure varies slightly by differences in temperature.

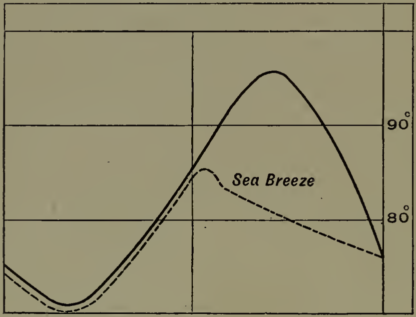

Fig. 38.

To show effect of sea breeze upon the daily temperature range. The normal range shown by heavy line, the influence of the sea breeze by the dotted line.

Mountain and Valley Breezes.—Among mountains, and even in hilly districts, the cooling of the air by radiation at night, causes a contraction of the lower layers, which becoming heavier, flow down hill toward the lower ground. Like water, the flowing air chooses the valleys down which to pass, and sometimes, in a valley having numerous branches, the breeze from the mountains and hills becomes very strong, and even increases to a gale before morning.

In the daytime the warming of the mountain sides sometimes starts a reverse movement, which gives rise to a noticeable but less pronounced breeze *up* the mountain sides. Those dwelling in hilly regions may often feel the first-named wind during warm summer nights, but the breeze moving up the hillside is much less noticeable.

Irregular Winds. — There are other winds of less importance, and also a great group of winds having irregular directions, and associated in cause with extensive storms. These are the winds which are most pronounced in the United States, but their consideration must be postponed until we understand something about storms (Ch. VIII).

Velocity of the Wind. — The velocity of the wind is commonly stated in miles per hour, meaning the rate at which the air travels. A wind with a velocity of 10 miles is one in which the air would move 10 miles in an hour. A slight breeze has a velocity of from 2 to 10 miles, a strong wind from 20 to 30 miles, a gale from 40 to 50, or even very rarely 60 miles, while in a tornado (or what the newspapers call a "cyclone"), the velocity may be 100 or 200 miles an hour. The rate at which the wind travels, varies with the difference in pressure, which the moving

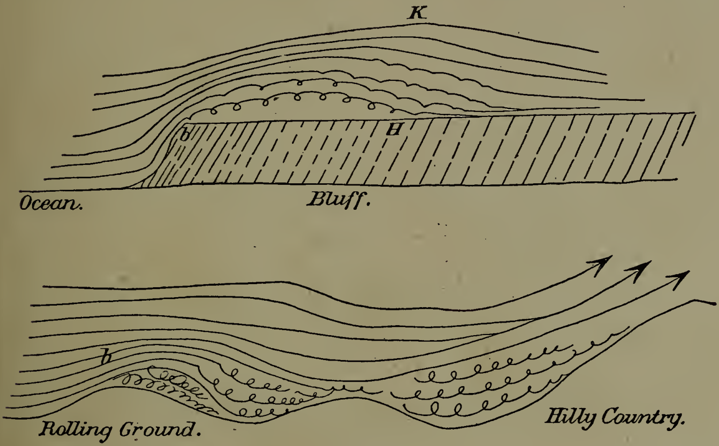

FIG. 39.

Diagram to show two of the several possible causes for the wave-like movement of the air. Here the air is disturbed in passing over hilly ground.

air is endeavoring to equalize; but this rate is retarded near the ground by the friction of air with the irregular earth. Hence on the tops of high towers, and especially of mountains, the wind blows with much greater force than it does on the ground; and it is also stronger over the smooth surface of the ocean than on the rough land.

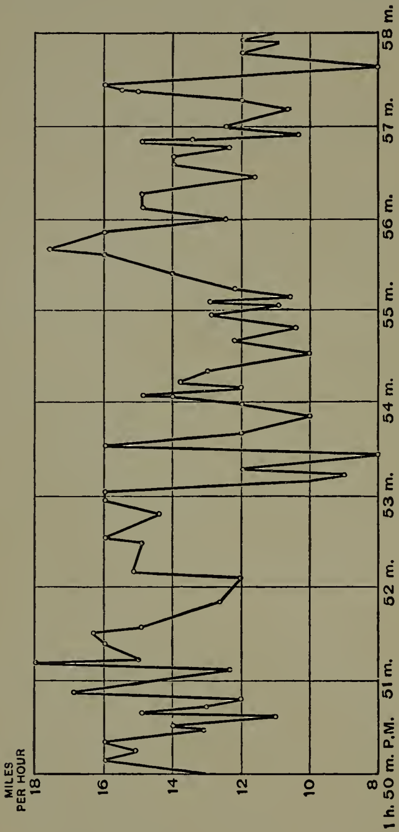

Fig. 40.

Diagram showing change in velocity of wind for successive minutes. The rate in miles per hour indicated by vertical division.

Recent studies have shown that the wind is not a simple onward movement of a regular kind, but a series of pulsations, somewhat like the puffs from an engine. As the air moves forward, it also rises and falls; and it has been found that even in times of strong wind there are momentary calms. We are all familiar with this in a larger way, when the wind comes in gusts; but besides these, which are well known and very noticeable, there are tiny gusts, so slight that delicate instruments are needed to detect them (Fig. 40). The vertical movement of the air which accompanies this wave-like passage of the winds, is believed to be the motive power which such birds as condors and hawks use in their remarkable habit of soaring without the movement of their wings. Perhaps some day men may also make use of this principle in the construction of some air ship.

Measurement of Winds. — Aside from certain delicate instruments for special study of the wind, and from the result of wind studies in the higher air now being made by means of kites, there are two instruments commonly in use for studying the air movement. One of these is the ordinary *wind vane*, which tells the direction. Every one is familiar with the construction of this and with its use. Sometimes, however, it is connected by electricity in such a way as to make an automatic record of changes in wind direction.

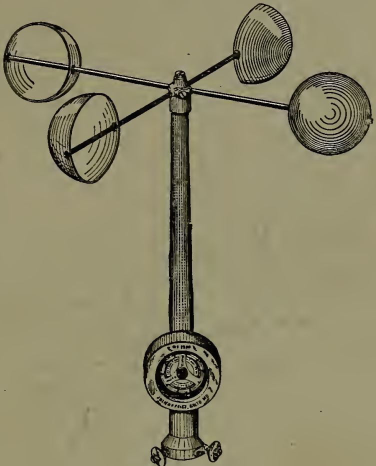

FIG. 41.
An anemometer.

Another wind instrument is the *anemometer* (Fig. 41), which is used for determining the *rate* at which the air moves. This instrument consists of four metal cups which are whirled about by the wind, and each revolution which they perform turns a cog wheel, which in turn moves others, causing a hand to move over a dial upon which are figures representing miles and fractions of miles. A certain number of revolutions of the instrument causes the hand to move over the space marked on the dial as one mile; and therefore by reading this dial, one can tell how fast the wind blows, just as we may tell the time of day by the rate of movement of the hands over the dial of a clock. Oftentimes the instrument is connected by electric wire with a self-recording apparatus, and thus each revolution of the anemometer is automatically recorded.

CHAPTER VIII

STORMS

Weather Changes. — In the central and eastern states, there is a fairly regular succession of weather changes, though with many minor variations. A cool (cold in winter) spell of dry weather is followed by a rise in temperature which accompanies winds from southerly quarters. Gradually the sky becomes overcast, the wind changes toward the east, rain falls, and after awhile there is a clearing, with lower temperature, and wind from the north or northwest. During the summer this change *may be* preceded by thunder storms, and in the Mississippi valley by tornadoes. In winter it is often followed by severe cold weather, when a blanket of cold air overspreads all the eastern half of the country, possibly causing frosts even in Florida.

Every five or six days this cycle is passed through, though perchance the rain may be slight, or may not be sufficiently widespread to affect the entire eastern region. Sometimes, particularly in winter, the changes in temperature are rapid and severe, and at times the force of the wind is great and its effect destructive, while at other times the winds are only breezes. These weather changes need to be studied in considerable detail.

Weather Maps. — The United States government has in its employ a corps of weather observers, stationed at various points in the country, and furnished with thermometers, barometers, and other meteorological instruments, to be used in making observations on the changes in temperature, pressure, wind direction, wind force, etc. These observations, made at the same time of day at all stations, are telegraphed to headquarters, and the information thus obtained from all parts of the country, is placed upon a map, which is called the *weather map*. These are printed and widely distributed, and any one sufficiently interested may obtain them.

Fig. 42.

Chart to show weather conditions January 7, 1893. Isobars (red) and red shading show the pressure, heaviest shading indicating highest pressure. Blue shows temperature, heaviest shade indicating lowest temperature. Areas of rainfall dotted. Arrows point in direction toward which the wind is blowing.

Upon the weather map are lines connecting places of equal temperature, or isothermal lines. By these one may tell what the temperature has been in various parts of the country. *Isobaric lines*, or lines connecting places having the same air or barometric pressure, are also placed on the map. The pressure is marked in inches and tenths of an inch, thus: 30.4, 29.9, etc. Arrows point in the direction toward which the wind is blowing, and circles tell whether the weather is cloudy, rainy, snowy, or clear. A statement of the weather conditions is printed at the bottom of the map, and a prediction for the local weather of the next day is also placed upon it. These maps contain much valuable information about the weather, but in some respects they are unsatisfactory, chiefly because the government does not have as many observers as are really needed for the work.

FIG. 43.

Chart to show weather conditions January 8, 1893. Shading, etc., same as Fig. 42. Path of storm centre shown by a series of arrows.

Comparison of Weather Maps. — If we take a series of such maps for successive days, we are able to see the reason for the succession of weather changes noted above. A series of winter charts will probably best illustrate the points, for then the cycle of change is most typical.

In the series selected for this description (and each winter will furnish many similar series), we start with one in which the word *Low* is placed in the Canadian northwest, north of Montana (Fig. 42). Around the word *Low*, the isobaric lines are arranged concentrically, the lowest pressure being within. Between the word *Low* and the northern boundary of Idaho the pressure varies .4 of an inch, being 29.9 inches in the north, and 30.3 in the south, while further south the pressure is higher. Toward the area of low pressure the wind is blowing from various directions.

FIG. 44.

Chart to show weather conditions January 9, 1893. Shading, etc., same as Figs. 42 and 43.

In the east, near Nova Scotia, there is another *Low*, and here, also, the isobars are arranged around the word, near which is the lowest pressure, of 29.3 inches. Toward this also the wind is blowing from all directions, and the weather in the neighborhood of the low pressure is rainy. The temperature here is between 10° and 20°, while that in the other low-pressure area varies from 10° to 40°.

Twenty-four hours later, the more eastern word *Low* has disappeared, and if our map extended so far, we would find the conditions that caused it out on the Atlantic, beyond Newfoundland (Fig. 43). The western *Low* area has passed eastward to Lake Superior, and with it have gone the conditions of cloudy, rainy weather, and for the winter time, high temperature. In the meantime a *High* area, with clear weather and low temperature, has appeared in the northwest, near where we first found the low pressure; and the next day (Fig. 44) the *Low*, which is evidently a storm, has gone still further east, while the *High* has also moved eastward. A day later the *Low* is over the Bay of St. Lawrence, on its way out to sea, while the clear, cool weather accompanying the high-pressure area, has overspread New York and possibly New England. By this time another *Low* will have appeared in the northwest, and in this way, day by day, changes of similar nature are recorded by the weather maps.[1]

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[1] I would urge upon teachers the advisability of obtaining various sets of such maps, which each student may study, so as to become thoroughly familiar with the *facts* illustrated, before undertaking the study of the *nature* of these changes. Also it is of high value to have the daily weather charts in the school. These will undoubtedly be sent regularly if application is made to the nearest Weather Bureau station, the location of which can be learned by addressing the chief of the Weather Bureau, United States Department of Agriculture, Washington, D.C.

Cyclonic and Anticyclonic Areas: *The Low- and High-Pressure Areas.* — From these observations it is seen, that for some reason, an area in which the pressure is lower than the average, appears in the northwest, and progresses rapidly eastward, passing over the country in from two to four days. No case is known of such an area starting in the east and going westward, though at times they do begin in the southwest, and also in the West Indian region. When this is the case, the low-pressure area moves toward the northeast, and then across the Atlantic toward Europe, which they often reach. So we have as one universal fact, a path which ultimately leads toward the east (Fig. 45); and what is said of the low-pressure areas applies equally to the high. The most common path

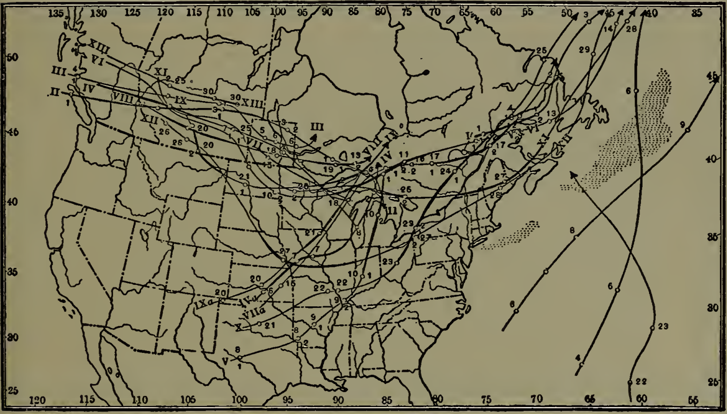

FIG. 45.

Map showing paths followed by low-pressure areas during November, 1891. Order of storms shown by Roman, and dates by Arabic numerals. Figure 1 beneath the line indicates morning, and 2, evening. From these one can tell the direction and distance over which each storm travelled.

for these disturbances of the air is eastward over the Great Lakes, through the St. Lawrence valley, over Newfoundland, and across the Atlantic, toward northern Europe.

In their passage they sometimes die out, and on the other hand they at times rapidly develop renewed energy. In some cases there is only a slight difference in the pressure, while at other times the difference is great, and as these variations occur, there is a change in the velocity of the wind, which, when the difference in pressure is great, sometimes becomes very violent. As the low-pressure area progresses, the wind blows toward it from various directions, and when it is typically developed,

FIG. 46.

Weather conditions April 20, 1893, showing two high-pressure areas and a typical storm. Rain area shaded. 1.4 inch difference in pressure.

the air moves from all sides spirally toward the centre of lowest pressure (Fig. 46). Although the storm moves eastward, it is not to be inferred that the progress of the low-pressure area across the country is a *bodily movement* of the air; for if this were so, there would be extremely violent winds from the west as it passed along. What is really the case in these disturbances of the air, is a low-pressure *condition* moving toward the east, just as a wave moves along the water surface with little real forward movement of the water. Hence the condition is this: an *area* of low pressure constantly progresses eastward with a wave-like movement, and toward this moving area of low barometer, winds blow from all directions.

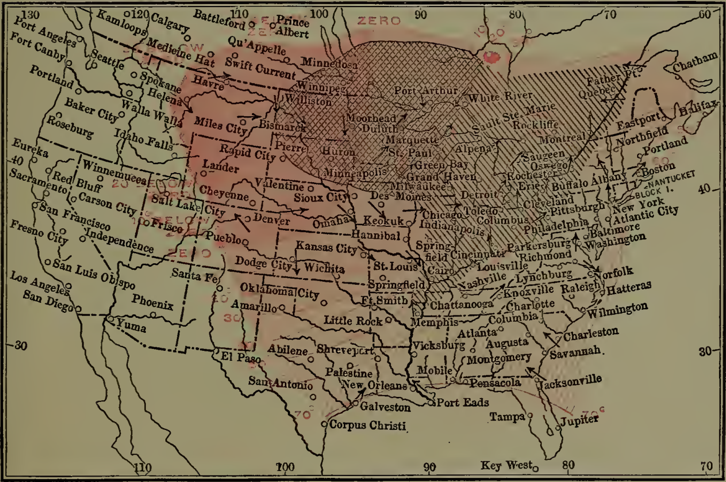

FIG. 47.

Map showing weather conditions November 27, 1896. From a high-pressure area in the west, the winds are blowing outward. In this high area the temperature is very low — temperature indicated by shading.

For the high-pressure area the same holds true, excepting that here the air moves outward (Fig. 47). Other facts to be noted are, that the areas of high and low pressure, while sometimes circular (Fig. 46), are more often elongated or elliptical, and when this is the case, the long axis extends in a north and south direction (Fig. 48). In this case there is an even more notable resemblance to a wave, especially when, as is sometimes the case, the trough of low pressure covers nearly the entire Mississippi valley, from north of the Canadian line to the Gulf. We need also to note the fact, that clouds, rain, and high temperatures generally accompany the low-pressure areas, and that they *always* do so if these are strongly

FIG. 48.

Map showing weather conditions January 12, 1897. Two low and a high-pressure area with isobars extending nearly north and south. Most intense shading indicates highest pressure. Temperature in centre of high, 30 below zero.

developed, while the reverse is true for the areas of high barometer.

Origin of the High- and Low-Pressure Areas.—It was once believed that all of these areas had their origin in differences of temperature, much as in the case of the sea breeze. Such a cause would explain most of the features observed, because warmth would expand the air, and inaugurate a circulation, just as truly as it does in the case of the sea breeze, or the summer monsoon. As a result of studies made in Europe, doubt has recently been cast upon this theory. If the air is warmed, and is rising in the low-pressure areas, the temperature of the atmosphere on the mountain tops in such a centre should be warmer than that of the borders; but the studies mentioned, which were made among mountains, fail to show that this is true. Also the facts that these disturbances of the air are more pronounced in the coldest parts of the year, and that the areas of high and low pressure pass in such regular succession, are difficult to explain on this theory. Therefore, while such disturbances *can* be caused by differences of temperature, and while undoubtedly some are, many meteorologists believe that we must look for some other theory.

No certain explanation can be offered in place of the old theory, but facts point toward the possible truth of the following. In the circumpolar whirl of prevailing westerlies, the air is moving eastward. If in its passage it is thrown into waves, as the sea is, and as we may expect it to be in passing over the irregularities of the land (Fig. 39), troughs and crests of high and low pressure would be produced. These should come in a definite order, high following low, and with these variations appearing at frequent intervals. This will also account for the eastward progress of the areas; and whichever theory is finally accepted, the explanation of the movement *toward* the east, must be that the areas move in the great circumpolar whirl, and hence toward the east.

Explanation of the Winds. — It has already been stated in sufficient detail, that air will move *toward* areas of low pressure, and *away from* areas of high barometer. Hence as such areas move across the country, the winds must blow toward a region of low barometer and away from that of high, in the attempt to equalize the pressure that has been disturbed. Since in the high-pressure areas, air is moving *outward* from the centre, its place must be taken by other air which is pushing it onward. The source of this must be from above, for it cannot be from either side, since the movement is outward in all direc-

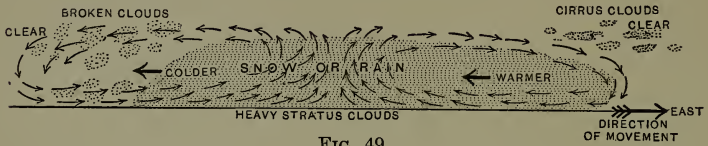

FIG. 49.

Diagram showing theoretical movement of air (by arrows), and other conditions, in a low pressure or storm area.

FIG. 50.

Diagram showing theoretical circulation (by arrows), and other conditions, in high pressure or anticyclonic area. Temperature rises on left.

tions. Therefore in high-pressure areas the air is settling from aloft.

In the low-pressure regions, air moves *toward* a centre which is constantly shifting its position; but as it comes from all sides toward the centre, some of it must find escape, and the only place for escape is upward. Hence here, there is ascending air, not perhaps of true convectional origin, but similar to that arising from convection. Perhaps the air that rises from the centre of the low-barometer area, passing upward, flows along toward the neighboring area of high barometer, and there settles, performing a journey similar to that in the trade-wind circulation (Figs. 49 and 50).

Explanation of the Rain. — The subject of rain does not properly belong in this chapter, but on this point a few words must now be said. It is from the low-pressure areas that northern Europe and America obtain most of their rain supply, and these storms sometimes last for several days. In parts of New England these are called *northeast storms*, because the rainy winds of the storm are from the east and northeast. By meteorologists they are called *cyclones*, cyclonic storms, or extra-tropical cyclones. The diameter of the cloudy and rainy area may be more than 1000 miles; and as the storm moves eastward, the entire country, from the Rocky Mountains to the Atlantic, and from the Gulf states to Hudson's Bay, may receive rain, or in winter, snow.

The causes for these rains are probably several. In the first place, the air is blowing in toward the low pressure, and as it does so it is often obliged to rise over mountains or plateaus, or up the more moderate grade of the interior plains. Since the temperature of the atmosphere decreases with elevation (Fig. 18), this lifting of the air over the rising ground causes it to cool. Also much of the air moves from a southern toward a cooler northern region, and in this way also its temperature is lowered. In a third way the air may become cooled as it rises *in* the area of low pressure.

Vapor can be held in greater quantities when the temperature is high, than when low; and therefore, if at the beginning of its movement toward the area of low barometer, the air was nearly saturated, it may, by being cooled in its passage, be forced to give up some of its vapor, forming clouds (Fig. 49), and rain or snow. This is particularly liable to happen if the winds have come from the ocean, as they usually have when they blow from the south and east, toward the central and eastern states.

To explain the dry, clear air of the high-pressure areas, or, as they are called, the *anticyclones*, because of their contrast with the cyclones, we have but to reverse the statements just made. In these the air is settling, and hence becoming warmer; it is generally moving *down grade;* and it is often flowing from cool to warm regions. Hence by all these causes the anticyclonic air is having its temperature raised, and therefore its capacity to take vapor increased. Instead of clouds and rain, such conditions bring clear and dry weather (Fig. 50).

Explanation of the Temperatures. — When a cyclonic storm area is passing over northern United States, the winds of the country involved are usually from southerly or easterly quarters. These may come from the water, which in winter is warmer than the land, or from southern regions, which are also warmer.

Hence the passage of air toward the low-pressure area is a cause for a rise in temperature. In addition to this, the cloud-covering checks radiation, and hence prevents nocturnal cooling. Also *the condensation of vapor is a warming process*, the so-called latent heat, or the heat that is expended in transforming the water to vapor, is liberated when the clouds form, and raindrops are produced (p. 62). Hence even when a winter storm begins as a cold snowstorm, if the condensation of vapor continues, in time the weather moderates, and perhaps the snowstorm may end in rain. It is also true that this liberated heat *furnishes energy* to the storm, warming the air and making it lighter, thus decreasing the pressure and increasing the wind velocity and rainfall as well as the general intensity of the storm. The storm has become a great engine, which once started increases by the aid of fuel which it supplies to itself.

The coolness of the high-pressure anticyclone, which in winter may produce a *cold wave*, and spread a blanket of ice-cold air over the land, is also due to several causes. The settling of the air from aloft brings down to the earth the high temperatures of the upper atmosphere (Fig. 50). Since the centre of the anticyclone is generally in the north, the air that flows over the United States usually comes from northerly quarters, and hence from colder lands. Since this air is dry and cool, radiation, both of day and night, proceeds with rapidity; and as a result of these several causes, the anticyclone is distinctly cooler than the low-pressure area. When a well-developed anticyclone overspreads the northern states, the rapid radiation of night-time may cause even the summer night to be uncomfortably cool, while in spring, late frosts may come, or in the fall, vegetation may suffer from an early frost.

Hurricanes or Tropical Cyclones: *Time and Place of Occurrence.* — The sailors of the Atlantic believe that a violent storm may be expected at the autumn equinox, near the middle of September; and in reality, during August, September, and early October, the western Atlantic is liable to be visited by one or several very violent storms, which are called *hurricanes* or *tropical cyclones.* Similar storms visit the Indian Ocean and the south Pacific. The *typhoon*, which quite often devastates the Asiatic coast, is a similar disturbance of the air. Such storms are not known in the south Atlantic, nor do they ever originate on the land. They come in the autumn months (the autumn corresponding with our spring in the southern hemisphere), and are practically confined to these. Their birthplace is near the tropics over the ocean.

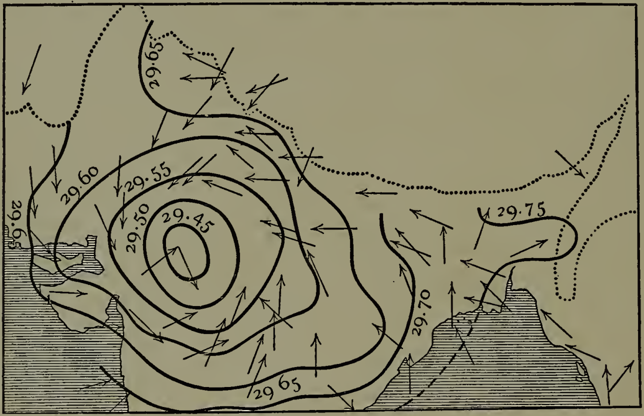

Fig. 51.

A tropical cyclone in India, showing spirally inflowing winds toward area of low pressure.

The West Indian hurricanes have their origin between

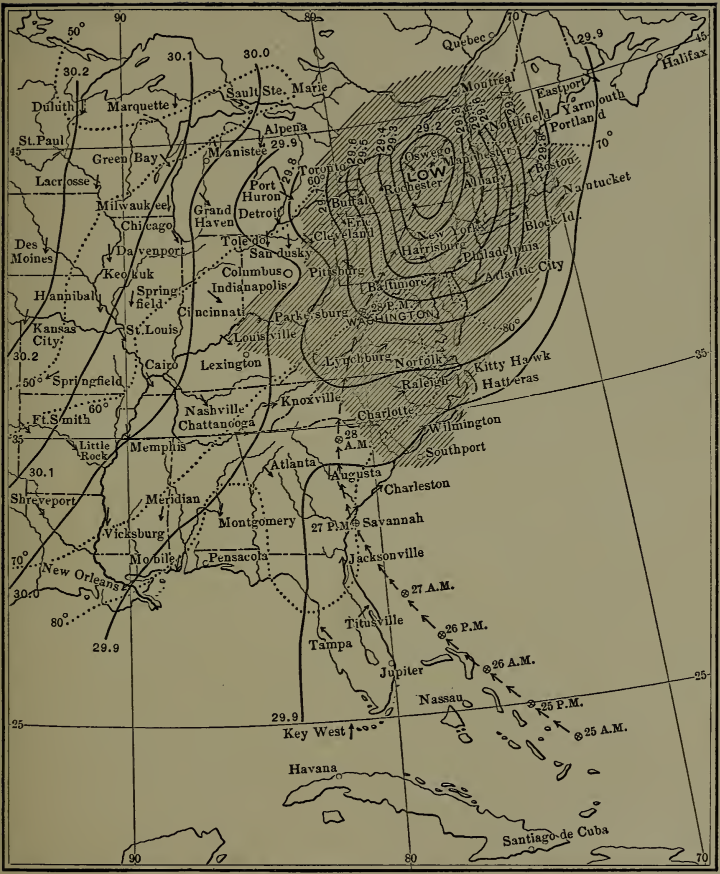

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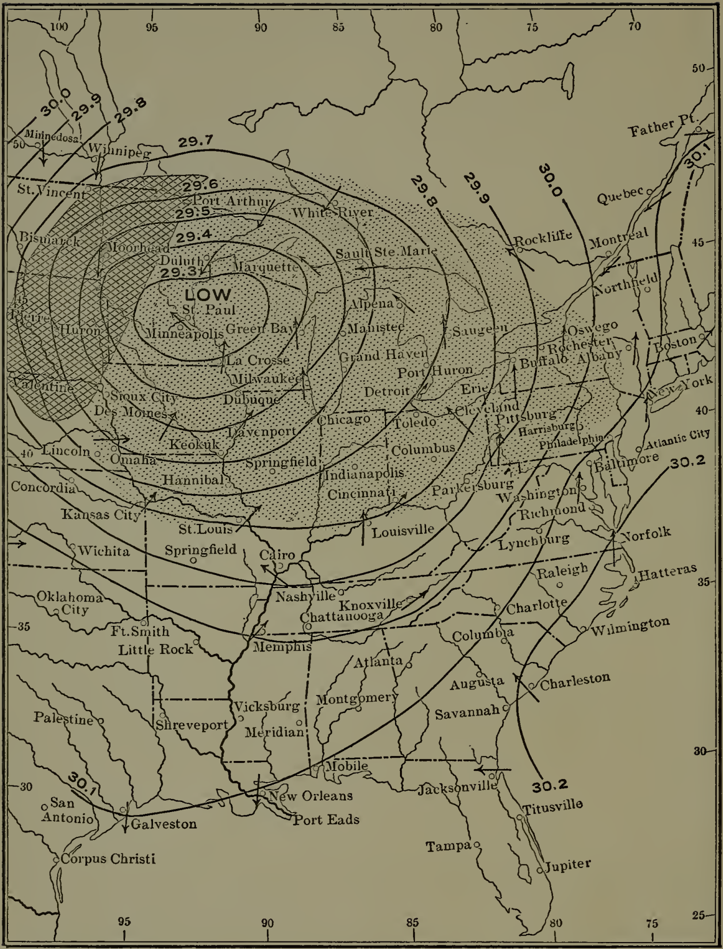
PLATE 10.

B. D. Servoss, N. Y.

A tropical cyclone or West Indian hurricane. Path shown by line of arrows upon which the dates of passage are indicated. Winds, isobars, and isotherms shown. Rain indicated by shading. Path somewhat abnormal.



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R.D.Servoss, N.Y.

PLATE 11.

Map of typical winter storm to show difference in temperature in different parts. Over dotted area rain is falling, over cross-shaded portion, near boundary between cyclone and anticyclone, snow is falling.

Florida and the South American coast, from which they move northward, with the centre generally off our coast (Fig. 45), usually causing terrific gales from Texas to Nova Scotia. After passing along this coast, they cross the Atlantic, approximately along the path pursued by the cyclones, turning toward the east, under the influence of rotation, in exactly the same way that the trade winds are deflected. Sometimes these storms diverge from this path and pass over the land, so that the centre moves over the eastern states (Plate 10).

Characteristics. — Where first noticed as distinct storms, the hurricanes are disturbances much smaller in area than the cyclonic storms which we have been considering. In the centre the pressure is very low, and the isobars are crowded together, so that in a short distance the pressure may change more than an inch. Toward this centre, the air goes from all sides with great force (blowing 60 or 70

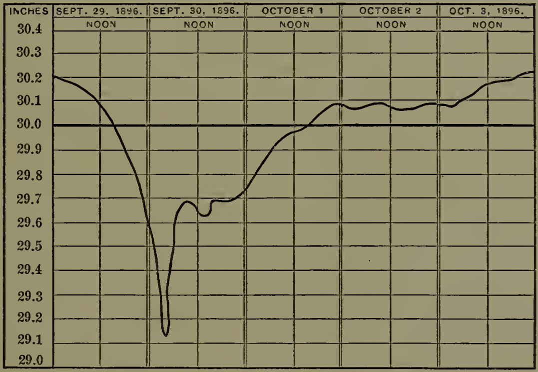

FIG. 52.

Diagram showing sudden fall of barometer at Ithaca, N.Y., during the passage of a hurricane, the winds of which did much damage.

miles an hour), turning spirally as it moves, somewhat as water does in escaping from a basin. Exactly in the centre, the air is rising vertically, and there the sky may be clear, while all around it are clouds, from which torrents of rain are falling. A vessel that has the misfortune to come within the reach of the more violent part of the hurricane, if it escapes at all, does so only after suffering much damage. Seacoast towns over which hurricanes pass, are often devastated, and this forms one of the most violent and destructive classes of storms. As they come out of the tropics, they gradually lose violence, and generally at the same time increase in area.

Explanation. — The origin of hurricanes seems evident from the fact that they always begin in *warm regions*. This points to convection as their cause. Unusual heat brings about conditions as a result of which air must rise, and hence, upon cooling, furnish rain. The heat thus liberated by the condensed vapor, increases the ascent of the air by warming it, and this decreases the already low pressure. Toward this area of ascent, air comes from all sides, forming winds, which move spirally because they are deflected by the effect of rotation. The storm increases, slowly moves, and finally, passing into the cooler regions, loses intensity; for the cooler air that exists in the more northern latitudes, contains less vapor to supply the heat energy with which the intensity of the tropical storm is maintained. Such a storm could not be formed over the land, because the air is not so humid as over the water; and hence the heat caused by the condensation of vapor could not be supplied in such amount.

But much heat reaches the tropical zone at all times of the year; and why then do we not have such storms at all times? and why are none found in the south Atlantic? To explain these two peculiarities, we must recall the fact that the deflective influence of rotation, which gives rise to the whirling movement of the air, decreases from polar to tropical latitudes, and near the Equator is so slight, that the air currents in the belt of calms cannot be turned very decidedly to one side. In the autumn the belt of greatest heat is furthest from the Equator, and hence nearest the region where this deflective effect can produce *decided influence* upon the direction of the winds. Hence at this time *only*, can the winds which blow toward the region of low pressure of the heated belt, start whirling; and without the whirl the storm cannot exist. Since this heated belt never goes far south of the Equator in the south Atlantic, such storms cannot visit this ocean.

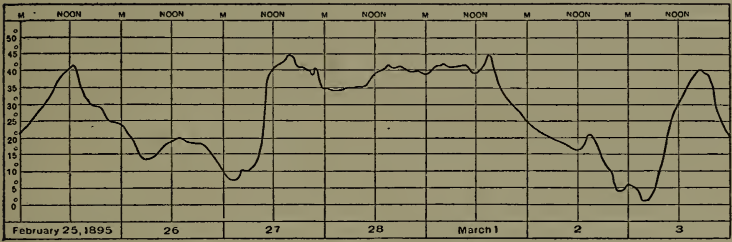

FIG. 53.

Temperature record for several successive days (Ithaca, N.Y.), showing effect of two cold waves, and (in centre) of Sirocco, which brought a high temperature for several days.

Storm Winds. — While the greater part of the United States is within the belt of prevailing westerlies (Chapter VII), so that west winds prevail, the winds near the surface are mainly determined by the passage of the high- and low-pressure areas. The hot summer winds, which come from the south, generally represent air that is slowly flowing in toward a low-pressure area in the far north. They are often muggy winds because their source is from the warm, humid sea. Sometimes these winds blow day after day without cessation, and then the land may be visited by a summer drought. During the winter our *warm* winds are also from the southern quarter, and these likewise are moving toward a storm centre (Figs. 53 and 54). It is such winds as these which cause the winter thaws.

In Europe similar warm winds are called *siroccos*, and this name may also be applied to our own warm south winds.

During the progress of a storm the wind in any particular place may veer through various quarters: the warm south wind may be followed by a warm and rainy southwest or southeast wind, and this by wind from the east, which bears rain, and this in turn by cold air moving from the northwest. The latter illustrates an exactly opposite type from that of the sirocco (Figs. 53 and 54). On the rear or west side of a storm, there are often strong and even fierce west and northwest winds, perhaps accompanied by snow (Plate 11). They represent cold air coming partly from the upper layers of the atmosphere, and partly from the cool interior and more northerly regions. In Texas such a wind is called a *norther*, in Dakota a *blizzard*.

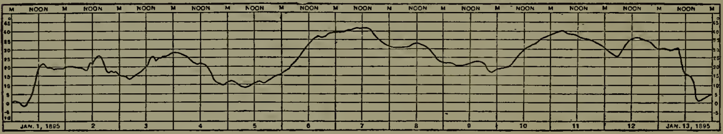

FIG. 54.

Temperature record (Ithaca, N.Y.) showing how for thirteen successive days the daily temperature range was destroyed by cyclones and anticyclones.

Milder types of blizzards occur in New York, and other eastern states, after many of the winter storms. During such a time, perhaps after a rain storm, as the wind changes the temperature descends, perhaps even at midday, cold snow squalls occur, and soon the thermometer has fallen nearly to zero. After this comes the *calm* of the anticyclone, and the land, already covered with a blanket of cold, clear air, cools still more by radiation, until even lower temperatures occur. The cool, dry, and refreshing west wind of summer, which succeeds the sultry weather that has perhaps terminated in a thunder shower, is the summer equivalent of the winter cold wave.

Sometimes in the west, near the eastern base of the Rocky Mountains, in Montana and elsewhere, a wonderfully dry and warm wind springs up from the west, perhaps causing all the snow to disappear from the ground. This wind is known as the *chinook* (Fig. 55), and a wind of the same kind is known in Switzerland as the *Foehn*. Also in Greenland, the air which flows down from the great ice and snow covered interior, is sometimes warm instead of cold, as we should expect. These warm winds are caused by air blowing down the mountain slopes toward a centre of low pressure. When air settles rapidly, its temperature rises as a result of the compression, and hence it reaches the ground much warmer than when it started.[1] The air is made dry, because as the temperature rises, its ability to carry vapor is increased.

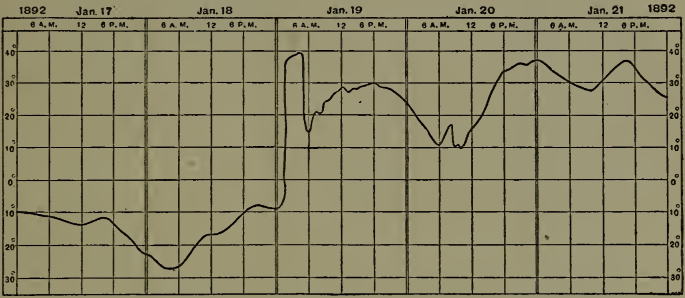

FIG. 55.

Temperature records during the blowing of the Chinook wind in Montana. In less than an hour the thermometer rose from 10° below zero nearly to 40° above — a rise of nearly 50°.

Thunder Storms. — During the summer, after an oppressive day, we look for a thunder storm, and it frequently

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[1] This is a fact of physics, and is merely stated here as a fact, — that descending air has its temperature increased, and ascending air is cooled as it rises and expands.

comes; and often when one does not visit us, they occur to the north or south, and even sometimes so near that we see the lightning and even hear the thunder. In northern United States these storms come from the west, usually in the afternoon or early evening. Following the storm the air is generally fresher, and cool, dry west winds replace the sultry air that has been coming from the south.

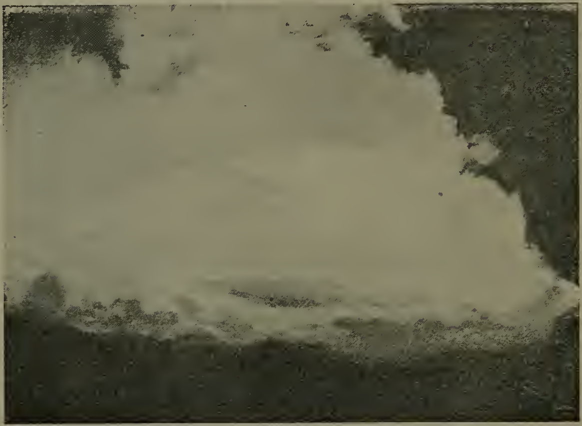

Fig. 56.

Photograph of a distant thunder storm.

Thunder storms are of frequent occurrence within the tropical belt. As the air is warmed by the morning sun, great banks of cloud begin to develop overhead, and finally rain falls, while lightning and thunder appear. Here the cause is evidently the rise of the air by convection; for rising air cools, and if it started with much vapor, some is condensed to form clouds, and later rain, because with a lower temperature some of the vapor must be given up.

Around mountain peaks similar storms are developed in summer, and here also convection is the cause.

The same explanation appears to apply to the thunder storms of the United States, for these come only in the warm months, and when the air is very humid. Moreover, their coming is preceded by the formation of cloud banks, similar to those caused by convection in the tropics.[1] If one will examine the weather map for a day when thunder storms occur, he will find that they have developed in the southern quarter of a low-pressure area, where warm, humid south and southeast winds are blowing toward the storm centre (Fig. 57). They are therefore *secondary storms*, occurring in a larger area of low pressure, and developed mainly because of the heat made possible by the south winds, and of

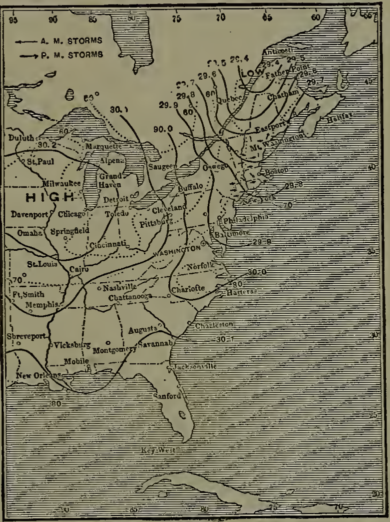

FIG. 57.

Part of weather map July 16, 1892, showing storm over eastern Canada and northern New England. Thunder storms occurred at places marked by arrows.

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[1] That convection is the cause for these clouds is shown by the fact that they often form over the land, and not over the cooler ocean, where there is less convection. In sailing off shore, one often sees a line of these clouds while the sky overhead is clear; and the presence of distant land, which is out of sight, is shown by these banks of clouds.

the moisture, which is due to the same cause. They move eastward in the same direction as the low-pressure area, and sometimes many such storms develop and progress eastward, following approximately parallel paths. Some such storms have travelled from New York across New England, and disappeared upon passing out to sea.

Tornadoes. — Fortunately these terrible storms are uncommon in most of the country, and where they do occur, they extend over only a very small tract. As in the case of thunder storms, they develop in the southern part of low-pressure areas, and move eastward during the afternoon or evening of hot, muggy days, generally in summer. Seen from one side, they consist of a spout of black cloud, spreading out into an umbrella shape above (Fig. 58). Rain and hail fall from the margin, and lightning and thunder accompany the storm. Excepting near the spout the wind is not violent; but *in* this it attains such a velocity that strong buildings are torn apart, trees uprooted, heavy objects lifted and borne away, and many remarkable feats performed.

The wind in a tornado blows spirally toward the centre of the spout, with increasing velocity until the centre is reached, where the air is rising rapidly enough to lift the roofs of houses from their supports. Here no rain can fall, for everything so light must rise. In the centre the barometric pressure is extremely low, and the condition of a vacuum is so nearly reached, that the expansion of the air within the houses sometimes blows the walls outward. The tornado spout is somewhat like the whirl of water which escapes from the outlet of a wash basin. On a small but much more violent scale it is like a hurricane, and on a much larger, and also more violent scale it resembles the tiny dust whirls of the desert, which I shall describe.

On a plain, and better still on deserts, the heat of the sun warms the air near the ground, until its temperature is several degrees higher than the layers above. This is an unstable and unnatural condition, for warm, light air should rise; but the day is so quiet that for awhile nothing causes it to start. Then perhaps the flutter of a bird starts a movement which shall give relief to the unnatural arrangement of air layers. Air presses from all sides toward the place where the ascent is being begun, and soon a slight whirl is started, and the movement of the air is so rapid that the winds carry dust, leaves, and even sticks, which in the centre rise, and spreading out above, fall to the ground on one side of the centre. From all directions the air moves toward this spout, and the little dust whirl itself moves slowly across the plain, so that if one should stand in its path, he would find the wind first in his back, when his hat would rise into the air, and quickly the wind would blow directly in his face, at first briskly, then more gently, until finally replaced by the calm of the desert. On a milder and very small scale this is what is experienced in a tornado.

FIG. 58.
A tornado near St. Paul, Minnesota, July 13, 1890.

During days when tornadoes come, the air near the ground is very warm and humid, while cooler layers of air exist above. Convection causes a whirl to start, and a tornado develops, being no doubt increased in force by the formation of rain, which causes more heat. The reason why tornadoes are more abundant in the Mississippi valley than elsewhere, is that here, over the great plains, the warm air from the south is more easily drawn in *under* the cool air, which is moving from the west in the prevailing westerlies.

CHAPTER IX

MOISTURE IN THE ATMOSPHERE

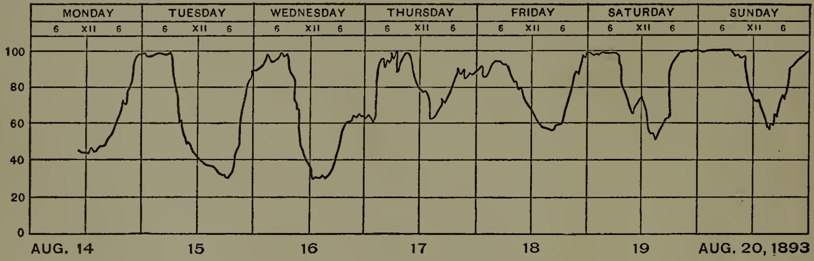
Vapor. — This invisible form of water is always present in the air, and every now and then some of it is being changed from an invisible gas to the liquid or solid form of water. This substance finds its way into the air as the result of *evaporation*, and at nearly all times vapor is being taken from all water bodies in the world, as it is also from damp ground and from the leaves of plants. It is possible for *some* vapor to be held in *all air*, no matter how cold, but there is a limit to the amount that air of any *given temperature* can hold. When the air has so much vapor that no more can be taken, it is said to be *saturated;* hence such humid or saturated air does not have the power to carry on evaporation further. On the other hand, an air that is dry, and *not* nearly saturated, is capable of rapid evaporation. Therefore in deserts, where the air is exceedingly dry, water cannot stand long without being evaporated.

The *rate of evaporation* depends partly upon the dryness of the air, partly on its temperature, and partly on its movement. When the air remains quiet over a pond, it may become saturated, and hence for the time being, evaporation over the water surface may be checked; but if the wind is blowing, there are constant supplies of *new* *air*, and hence evaporation proceeds without interruption. The winds that pass over the great ocean can obtain much vapor, and hence the air of oceans, as well as that of the land near them, is generally more humid than that far away in the interior of continents.

In any given amount of air there is always a certain *quantity* of water vapor; and this is known as the *absolute humidity*, and could be measured in pounds (Chapter III). If we suppose that air with a temperature of 60° has $\frac{3}{4}$ as much vapor as it could possibly contain at that temperature, this $\frac{3}{4}$ would be called the *relative humidity;* that is, it would be *the percentage of vapor actually present in the air, compared with that which might be held at that temperature.* If it contained all that could possibly be held, or was saturated, the relative humidity would be 100%; hence the $\frac{3}{4}$, which we have supposed, would be 75% of the possible, and the relative humidity would therefore be 75%. Should the *temperature* of this same air fall, even without the least change in the *real amount* of vapor, or the absolute humidity, the relative humidity would be *increased*, because cold air is able to carry *less* vapor than when warmer. Indeed, it is possible that the temperature may descend until the *point of saturation* is reached, and if this be so, some of the vapor must be given up either in the form of fog, rain, dew, frost, snow, or hail. This point of saturation, when the relative humidity stands at 100%, is known as the *dew point.*

If, instead of falling, the air temperature rises, the relative humidity will *decrease*, because it can hold *more* vapor than formerly; and therefore, with a higher temperature, the percentage of that held compared with what *might* be carried is smaller. These facts have important bearings on the explanation of the precipitation of moisture from the air. Evaporated and transformed to a gas which no one can see, the vapor passes hither and thither, until finally, by some change of temperature, it can no longer exist as vapor, but must assume its old form, and perhaps return to the very ocean which gave it birth.

Almost any place in moist countries offers frequent illustrations of this change in relative humidity. Perhaps for several days the air of a place has about the same actual *amount of vapor*, or the same absolute humidity, but the *temperature* of the air varies from day to night. As the sun's heat warms the earth in the daytime, the relative humidity of the air decreases, and perhaps by noon there is only 50% as much vapor as can be held at that temperature, and then evaporation is rapid, as may be seen by the fact that clothes on the line dry quickly. In the afternoon the temperature descends, and therefore the relative humidity rises, until perhaps the point of



RELATIVE HUMIDITY
ITHACA

FIG. 59.

Record of relative humidity for a week at Ithaca, N.Y. Nearly every night the dew point is reached, but at midday the relative humidity is only from 30°–60°.

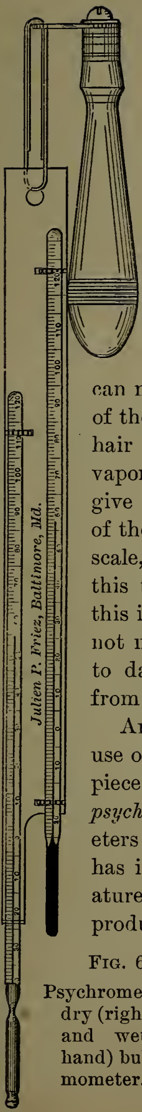


FIG. 60.

Psychrometer or dry (right hand) and wet (left hand) bulb thermometer.

saturation is reached (Fig. 59), and then dew may form; and if clothes have been left out upon the line, they again begin to become damp, although before sunset they were dry. In addition to this *daily change*, dependent entirely upon variation in temperature, there are also changes in the absolute humidity of the air, for some winds are damp and others dry.

Instruments for Measuring Vapor. — Although we cannot *see* vapor, there are various ways in which we can measure the relative humidity. One of the commonest of these is the *hair hygrometer*, which consists of a bundle of hair robbed of its oil. The individual hairs absorb the vapor in proportion to its amount, and as they absorb or give up vapor they lengthen or contract. This movement of the hairs can be made to move a hand across a graduated scale, so that readings of the length may be made, and from this the relative humidity be calculated. The operation of this instrument is upon the same principle that causes hair not naturally curly to lose the artificial curl when exposed to damp air. This results from the absorption of vapor from the air.

Another means for making this measurement is by the use of two thermometers, one having its bulb encased in a piece of wet muslin. This instrument, which is called a *psychrometer*, is whirled in the air, and one of the thermometers records the real *air temperature*, while the other, which has its bulb wrapped in wet muslin, records a *lower* temperature, because the evaporation of water from the muslin produces cold, as evaporation always does.[1] If the air is

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[1] This principle is made use of in dry countries to keep water cool. Water in a porous jar evaporates through the sides, thus cooling the jar and also the water. In travelling in such countries it is customary to carry a canteen of tin,

very dry, the evaporation is rapid, if it is humid, the evaporation proceeds slowly; and hence in the former case the *difference* in temperature recorded by the two instruments, is greater than in the latter. By means of tables made for the purpose (these may be obtained from the U. S. Weather Bureau at Washington) the relative humidity may be calculated, and from them also it is possible to tell at just what temperature the dew point will be reached under all conditions of relative humidity.[1]

The *rate* of evaporation is generally determined by means of a pan of water (called an *evaporating dish*) either placed upon scales, and hence weighed, or else one in which there is a graduated rod. By means of this rod the measurement of the depth of water evaporated is made in inches; and hence, in stating the evaporation, it is customary to say that it amounts to so many inches in a year, by this meaning in the course of a year that evaporation from a water body would lower it just that number of inches. In dry regions, particularly in deserts, the amount of evaporation exceeds that of the rainfall, and the soil is kept constantly dry, because the air is always greedy for more moisture than it can find.

Dew. — During the summer, and at other times when the temperature does not fall below the freezing point, the setting of the sun is often followed by an increasing dampness of the grass and other objects that are near the ground. This dampness we call *dew*, and it may form, or "fall," even before the sun has finally set; or possibly its formation may not begin until late at night, and during some nights no dew forms, especially if the sky is cloudy. Sometimes dew gathers only in certain places, and again,

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covered with a woollen cloth. So long as the cloth is kept damp, the evaporation of water from the surface keeps the canteen and its contents cool, even though exposed to the direct rays of the sun. In dry countries one may, therefore, have cool drinking water even on the hottest day.

[1] There is a similar instrument which is not whirled, but kept stationary. In this a wick leading from a dish of water keeps the muslin damp, the water rising as oil does through a lamp wick.

particularly after a muggy summer day, so much gathers that all vegetation is dripping wet, as if with rain. Shortly after sunrise the glittering drops of dew disappear, being evaporated under the warming influence of the sun.

The production of dew depends upon the change in relative humidity. The air, perhaps very humid, as is sometimes the case in summer, is cooled by radiation after the sun sinks in the west; soon the dew point is reached (Fig. 59), and from the then saturated air, some vapor passes into the form of liquid water, just as vapor in a room may condense on the surface of the cold window. Those objects that have cooled most, receive the greatest supply of dew, and vegetation, which is one of the best of radiators, is most abundantly supplied.[1] With many clouds in the sky, radiation is checked, and the dew point may not be reached; and also if the air is very dry, the cooling at night may not go far enough to reach the dew point, or perhaps only just far enough for a little to collect. Silently it accumulates, *not by falling*, but by condensation from the air upon the surface of those objects that are coolest.

Probably this cause for dew formation is aided by another, which also results from radiation. At all times vapor is being exuded from the damp ground, and particularly from plants, in which it rises from the ground in the form of sap. During the daytime this is evaporated, and does not appear in the form of drops of water which are visible; but at night, when the air is nearly or quite saturated, evaporation cannot proceed, and the dampness accumulates on the surface of the ground and plants, adding to the quantity that comes from the air. This is why dew gathers on the under side of leaves and other objects spread out near the ground.

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[1] This is one of the many beautiful adjustments of nature, by which animals and plants make use of Nature's riches.

Frost. — This condensation of vapor from the air produces frost whenever the temperature of the dew point is 32° or less. Frost is *not* frozen dew, but merely the solid form assumed by the condensation of invisible vapor, at a temperature below the freezing point. It is quite like the formation of frost work on the window, where the frost crystals may be seen to grow as *solid* forms, without any previous deposit of liquid water which can freeze. Therefore the remarks that have been made about dew apply quite fully to frost.

There are many peculiarities in the distribution of frost. Sometimes it is very heavy, and the grass and earth are white with it, but at other times there is only a very light frost in a few places. In the latter case very slight differences in exposure, or in the nature of the ground, will cause differences in amount; and indeed in one place dew may accumulate, while in others frost gathers. The smoke of a fire, or a cloth spread over a plant, will often prevent frost by checking radiation, and thus the cooling. Low ground is visited earlier than the higher land, particularly if the lower ground is damp; for then there is *more* vapor in the air. It is partly for this reason that in autumn the leaves of trees in swamps turn earlier than those on the dry hillsides. There is another cause besides this one; for as radiation proceeds, and the air near the ground cools, it becomes heavy and slides down the hillsides, thus causing movement and a stirring of the air, while in the valleys the cold layers settle and remain much more quiet. Moving air is not easily cooled, because as soon as the radiation from the ground has lowered the temperature of the air near it, it slides away, and other layers take its place.

Fog. — Sometimes, particularly in damp places, the cooling of the ground by radiation chills the air for some distance above it, and lowers its temperature to the dew point. Then vapor must condense, and a veil of fog forms. In the early morning this mist may often be seen spreading over a swamp or a stream bottom. The fog particle is a minute drop of water, so small that one may sometimes walk in a fog without becoming sensibly wet, and so small also, that the particles do not settle to the ground by their own weight. The centre of the fog particle is often, if not always, a speck of dust, and it is believed that one of the main causes for the abundant fogs of London is the presence of innumerable dust particles furnished from that great city, and thus available for the condensation of vapor to form the fog.

There are various ways in which fogs may be produced, aside from that mentioned above. When one breathes into the air of a frosty morning, he forms a tiny fog, because the warm, vapor-laden breath has its temperature reduced by the cold air, until the dew point is reached. On a very large scale nature is making fogs of a similar kind. In the Atlantic, along the path of the European steamers, near Newfoundland, extensive fog banks abound. Here there are two currents of water, one cold and moving southward from the Arctic, the other warm and flowing northward from the Tropics. The former is the cold Labrador current, the latter the Gulf Stream. When winds from the south pass over the warm Gulf Stream, and after becoming warm and humid pass on over the cold Labrador current, they are often chilled until their temperature is reduced to the dew point, when a fog is produced. Sometimes a similar fog is caused on the land, when a warm, humid wind from the south passes northward over the cold land, in autumn, spring, or sometimes even in winter. During such conditions, however, the fog may not extend over *all* the land, but occurs only over low, swampy places or lakes.

On the other hand, a *cold* wind blowing over the warm, humid earth may cause the dew point to be reached in the layers that are near the surface. Some of the fogs of the Gulf Stream region have the same origin as this, when cold air from the Labrador current flows over the Gulf Stream, chilling the warm, humid air that exists there. By one of these several causes fogs may fill valleys, so that from the enclosing hills or mountains one may look down upon a great sea of fog (Fig. 61), through which perchance the church steeples rise, while all else is hidden from sight. The fogs of the land soon disappear before the warm sun, which eats them up by evaporation, as if by magic; but the heavy fog banks of the ocean, or of the Arctic, may remain for days, until a change in the weather causes them to disappear.

FIG. 61.

Upper surface of a sea of fog. Looking down into a valley from a mountain.

Haze. — Oftentimes, particularly in summer and autumn, the air is blue and hazy, so that distant landscapes are softened by a veil of haze which otherwise might not be detected. Sometimes the haze so increases that distant objects are obscured. This phenomenon is generally due to the presence of an unusual number of dust particles; and after dry spells, when forest fires have been extensive, and rains have not come to remove the dust, the air may become exceedingly hazy. In addition to these causes, it seems probable that some haze results from a form of liquefied vapor, in which the particles are even less numerous and more minute than in the lightest of fogs.

Mist. — There are times when the air is filled with a mist of particles larger than those of fog, and yet smaller than the usual raindrops. This *mist* may be due either to the *growth* of the fog particles, until they become so large that they settle to the earth, or else to the *combination* of various such particles, until the same result is produced. The latter may happen when wind is blowing the fog about, so that the movement will cause numerous collisions of fog particles, until they grow so in size that they must sink toward the earth. Then as they settle, they strike other particles, and so increase in size still more.

Clouds: *Cloud Materials.* — A cloud may be formed of smoke, or of steam issuing from a locomotive; but in nature nearly all clouds are caused by the natural condensation of vapor in the air, when the temperature reaches the dew point. Therefore we may expect that clouds will be composed either of fog, mist, rain, snow, or ice particles. Balloonists and travellers among high mountains prove that this is actually the case, for in such journeys, clouds are entered and even passed through. A fog or mist may be truly said to be nothing more than cloud resting on the earth. In climbing a mountain one may see a cloud above him, he may enter it, perhaps finding it to be only fog, and passing above it, and looking down upon its upper surface, he may see the same appearance as that caused by a veil of fog in a small valley. Indeed, during a rain storm, when the clouds rest upon the hillsides, one may easily ascend into them and see exactly of what they are made.

Forms of Clouds. — There is nothing in nature more beautiful than the forms and colors assumed by clouds. Being commonly about us, we perhaps do not give them as much attention as they deserve. They dot the sky in patches or clusters, having every variety of form, and constantly varying in outline. It would seem an almost impossible task to classify and name all clouds, and so indeed it would be, if we tried to find a name for every variety of form. However, there are certain types which are fairly easy to recognize.

FIG. 62.
Clouds upon a cliff in the Yosemite.

Sometimes the sky is nearly or quite overcast by clouds, massed into layers or bands, giving them a stratified appearance. These are called *stratus*, and they generally lie low in the heavens, perhaps with their bases resting against the distant hillside. It is this class that accompanies the cyclonic storms described in the last chapter. Another type is that which comes on a hot summer day, and is commonly called the "thunder head" (Fig. 56). The name for this is the *cumulus* (Fig. 63), and it consists of a bank of cloud particles rising from a nearly level base, whose elevation is several thousand feet above the surface. Above this, domes of cloud masses rise several thousand feet higher. These are among the most beautiful of the clouds, and when seen in the east after a summer thunder storm, especially when lighted and colored by the rays of the setting sun, they furnish a spectacle which may well arouse our admiration. From both stratus and cumulus clouds, rain may fall, and the rain-producing cloud is called the *nimbus*. Both stratus and cumulus clouds are generally so dense, that when they pass before the sun, its rays are cut off.

Fig. 63.

Cumulus clouds.

Oftentimes there are thin clouds, which scarcely or only partially intercept the sun's rays. These are high in the air, and measurements that have been made, show that they are often five or six miles from the earth. Sometimes they are so thin and veil-like that the stars shine through them at night. It is known that these are made, not of fog particles, but of ice spicules, which are so transparent that light easily passes through. They are so high that the liquid form of water cannot exist, because of the low temperatures which occur there even in summer. These, which are often plumed and feathery, are called *cirrus* clouds (Fig. 64), and they are the highest of all. It is in them that coronas, halos, etc., are often developed.

Fig. 64.
Cirrus clouds.

Between these three types there is every gradation: sometimes the cirrus are stratified, and they are then

Fig. 65.
Strato-cumulus clouds.

called *cirro-stratus;* at times the feathery form is replaced by little banks, resembling small cumulus clouds high in the air, and these are called *cirro-cumulus* (Fig. 66), or if they are more like cumulus than cirrus, *cumulo-cirrus.* By combining the three names into similar compound words, names may be formed for most of the common clouds of the sky (Fig. 65).

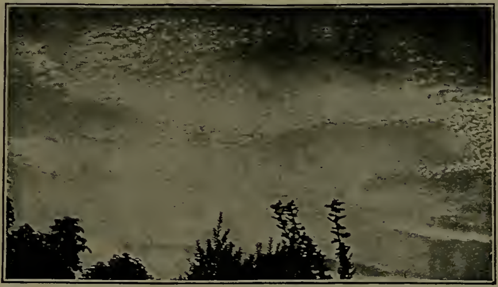

Fig. 66.
Cirro-cumulus clouds.

Causes of Clouds. — Generally the cause of clouds is the same as that of other visible forms of water in the air, — the condensation of vapor. The most common way in which vapor is condensed in the air, is by lowering the temperature to the dew point. This may be caused by convection, and the cumulus clouds are commonly formed by this means. The air near the surface rises upon being warmed, and as it does so, cools (Fig. 18). Starting with a certain amount of vapor, if the rising continues, this cooling must bring about condensation whenever the proper temperature is reached, as it will be at a certain height, the elevation of which will depend largely on the relative humidity of the air at the beginning. This is why cumulus clouds have level bases, for these represent the elevation at which condensation began; and as the air continues to rise, more vapor condenses above this, forming the beautiful piles of cloud banks.

Vapor-laden air, coming in contact with a cool surface, may form clouds, exactly as it may cause fog near the ground. From this cause clouds often gather around mountains and even hills. Or, again, as in the case of fog, air currents of different temperatures may produce clouds. For instance, a cold layer of air moving over a warm and humid layer, may chill the latter near the contact and cause clouds to form. That there are such currents in the air, may be inferred by watching the clouds, when it may often be seen that those at different levels are moving in two or more directions. Probably many of the clouds of the upper air are caused in this way, and it now seems certain that this is one of the causes for the dense layers of stratus clouds in cyclonic storms.

Rain. — If as a result of any one of the causes mentioned above, the condensation of the vapor forms particles large enough to fall through the air, rain is formed.[1] Oftentimes such drops start from the cloud and fail to reach the ground, being evaporated on the way, because not enough drops are produced to satisfy the dryer layers of air through which they are passing. We may often see streamlets of such rain descending from the summer clouds and gradually dying out in the air.

A fog particle may grow to the size of a raindrop by condensation of vapor around it, so that its size constantly increases; and then, starting to fall from the cloud, other particles are added to the drop by collision, until perhaps the raindrop has grown to large size. There is every gradation from these down to the tiny fog particles.

Clouds furnish the birthplace for most raindrops, and their production is merely a continuation of the process which makes the cloud; but a cloud may be formed without going far enough to cause rain, as we all may see from the fact that rain fails to fall from most of them. When the process of raising air by convection, or chilling it by contact with colder bodies, either of air, water, or land, has gone far enough, rain must fall, and this is particularly liable to happen when warm humid air is present, for then there is much vapor to condense. This is the case during the hot days which prevail in the humid tropical belt, and in our own country when thunder storms develop in the

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[1] Provided the temperature is above the freezing point.

hot summer afternoons. The rising air in hurricanes, the air currents in cyclonic storms, and the damp air of the ocean blowing against rising land, along the margins of continents, also bring about conditions favoring the formation of rain.

Hail. — Rarely, in summer, when thunder storms are present, balls of ice fall to the ground, sometimes of such size and with such force as to break windows and cause much damage to vegetation. These are really ice balls made of layers of clear and cloudy ice, and they represent the freezing of water high in the air, where the temperature is low. Little is known of the mode of formation of these remarkable hailstones, but they are an unusual result of vapor condensation, and are apparently formed when the air is in violent commotion, and certainly at an elevation where the temperature is low. They differ from snow in not being made of feathery crystals caused by the solidification of vapor.

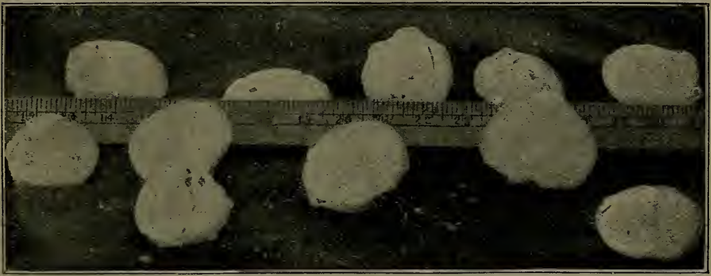

Fig. 67.

Photograph of large hailstones. A ruler, marked in inches, shows the size of the hail.

Snow. — During a winter storm, when the temperature is near the freezing point, a heavy, damp snow may fall, and reaching the ground, cover it with slush. Later, by a slight rise in temperature, the snow may change to rain, although there has been no difference in the appearance of the clouds. After the storm clears, we may see that, while rain has been falling on the low ground, the neighboring highlands have been whitened with snow. During such a condition we may leave the rain, and climbing a high hill, ascend into the region where snow is falling, passing first through the zone where rain and snow fall together.

Fig. 68.
Photograph of actual snow flakes.

Or the storm may start as rain, and gradually, as the thermometer falls, change to snow, until finally the delicate crystals or snow flakes are dry, and as they fall accumulate on the ground. These snowflakes are true crystals of feathery and beautiful form, and they are the result of the operation of a law in nature whose products are well known to us, but whose cause is not understood. This law is, that upon solidification from the liquid or vaporous condition, many substances will take on definite geometrical forms, as quartz and other crystals &c, or as salt may be made to do by allowing a solution of salt in water to evaporate.

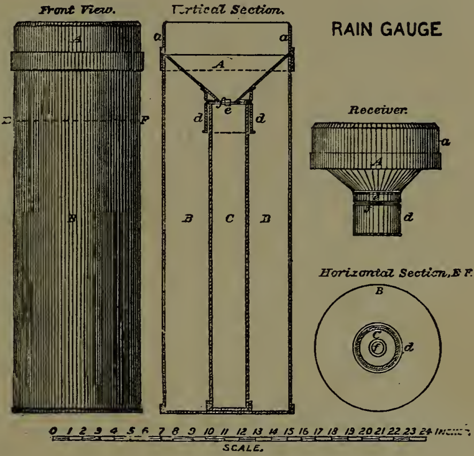

FIG. 69.

Rain gauge. *B*, outer cylinder; *C*, inner cylinder; *a*, *a* (and small left-hand figures), the funnel.

In the case of snow, the vapor is condensed at a temperature below freezing point, and hence one at which water cannot be produced, so that as vapor is given out, it takes the solid form directly. So the snow crystal gradually grows, following the definite laws of crystal growth, until the beautiful snow flake is formed by constant additions of vapor. There is a great variety of form in these flakes, but they all follow the same law of geometrical perfection. Snow crystals are *not* frozen rain, for this would form balls of ice or sleet; but they are truly the result of crystallization of water vapor.

Measurement of Rainfall.—The instrument for measuring rainfall is called the *rain gauge.* This is a cylinder of metal which stands in another cylinder whose area is 10 times as great; and upon it is a funnel whose top has the same area as the larger cylinder. The rain falls upon the funnel in the same amount as it would on the ground, and running down the sides, escapes through a small orifice which opens into the small inner cylinder, where the water collects in the bottom. Since the area of this inner cylinder is $\frac{1}{10}$ that of the area of the collecting funnel, the depth of the water is 10 times as great as it would be if gathered in a cylinder with the same area as the funnel. The object of this increase is to make it possible to measure even small rains, for by this exaggeration of depth, an inch of rain becomes 10 inches deep. The measurement of the depth of the rain is made by means of a stick graduated in inches and tenths of inches. By an inch of rain it is meant that had the rain stayed where it fell, it would have formed a water layer one inch deep. By various means the rainfall may be automatically recorded.

For measuring the snowfall, the rain gauge may be used, the snow being melted, and then the water measured with a stick, as before; or the *depth* of the snow upon a level tract may be measured. Since it is customary to report snowfall in its equivalent amount of rain, it is necessary to convert this measurement of snow depth into rainfall. No perfect rule can be given for this change, because the amount of rain represented in a fall of snow, varies with its dryness or dampness. There is more water in a given depth of damp snow than in an equal depth when it is dry. However, in ordinary snow a depth of about 10 inches is equal to one inch of rain.

Nature of Rainfall. — There is much difference in rain. Sometimes the drops are tiny, almost like fog particles, while at other times they are large. In some cases, especially when the air is very humid, as in summer, the drops are large and very numerous, so that in a short time, perhaps in a quarter of an hour, an inch of rain falls, while in other cases, when the drops are small and not near together, the rainfall of several days may not make an inch. There is also much difference in the snow, some, especially in midwinter, being very dry and feathery, while in other cases, when the temperature of the air is nearly down to freezing point, the snow crystals are damp and matted together.

Distribution of Rain. — As a general statement, it may be said that there is a decrease in the amount of rainfall from the warm tropical belt toward the poles (Plate 12). This would be expected, because the warm air of the equatorial regions carries much vapor, while that of the polar zone has little to give. Hence a slight change in the temperature of the former place will cause more vapor to be condensed than a great change in the colder latitudes. Also there is generally a heavier rainfall on the ocean,[1] and near the coast, than in the interior of continents. This again is easily understood, for the air over the water has more vapor than that far from the sea. In the United States this is very well shown, for the rainfall decreases from the Atlantic and Gulf coasts, westward and northward, until near the base of the Rocky Mountains there is not enough rain for purposes of agriculture. The same difference is shown in Russia, the steppes of southeastern Russia being very much dryer than the climate of western Europe.

This difference between seashore and interior is even better illustrated when the air that goes inland is obliged to pass over mountains on its way, as is the case in the desert and semi-desert region of the Great Basin, between

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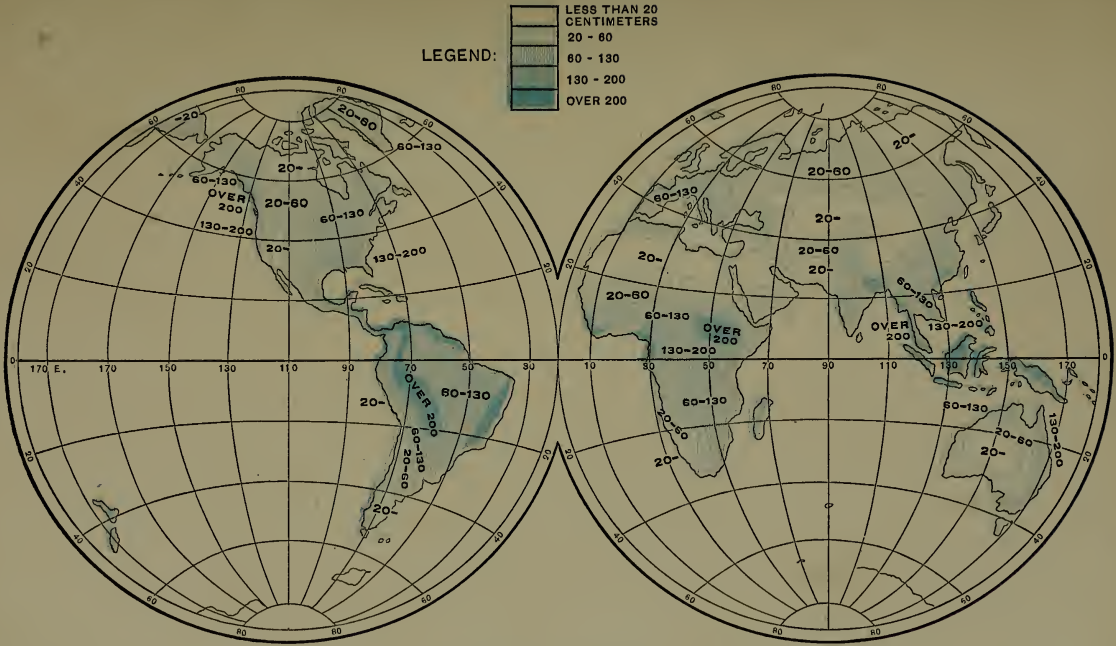
[1] The rainfall on the ocean is known to be heavy, although few measurements have been made there. Vessels move about from place to place, and it is only upon the islands that measurements of rain can be kept for any length of time. Hence the rainfall chart does not include the precipitation over the ocean.

the Sierra Nevada and Rocky Mountains. Here the air, flowing up the mountain sides, is cooled, and hence caused to give up much of its vapor, so that when it descends on the other side, and passes over the plateau, it is dry. This is one of the two most important causes for deserts, and it explains the Great American Desert of Arizona.

Since winds which blow over mountains lose their vapor as the air rises, the sides of the mountain *against* which the wind blows are well watered, and particularly if the air comes from the sea. This is shown in desert countries, like our Great Basin, where mountains rise above the arid plateau. So little rain falls upon the lower ground that trees cannot exist, and other forms of vegetation grow only scantily (Fig. 70); but in the mountains rains are abundant, and forests exist. Even in a distance of a few miles there may be a great difference in rainfall.

In the United States this cause accounts for the heavy rain in the state of Washington, where the prevailing westerlies blow from the warm Pacific water against the sides of the mountains. It is also shown on the world chart, wherever the trade winds blow from the ocean against the rising continents, as in Central America and the coast of South America (compare Plates 8 and 9 with 12).

The best illustration of the effect of mountains that can be found in the world is in India, where the warm, humid summer monsoon wind blows from the Indian Ocean against the mountains. Here is found the heaviest rainfall in the world. In most of eastern United States the rainfall varies from 30 to 60 inches, but there it is 493 inches. The heaviest rainfall in this region occurs during the months of June, July, and August, and sometimes



R.D. Servoss, N.Y.

RAINFALL CHART
OF THE WORLD
IN CENTIMETERS

PLATE 12.

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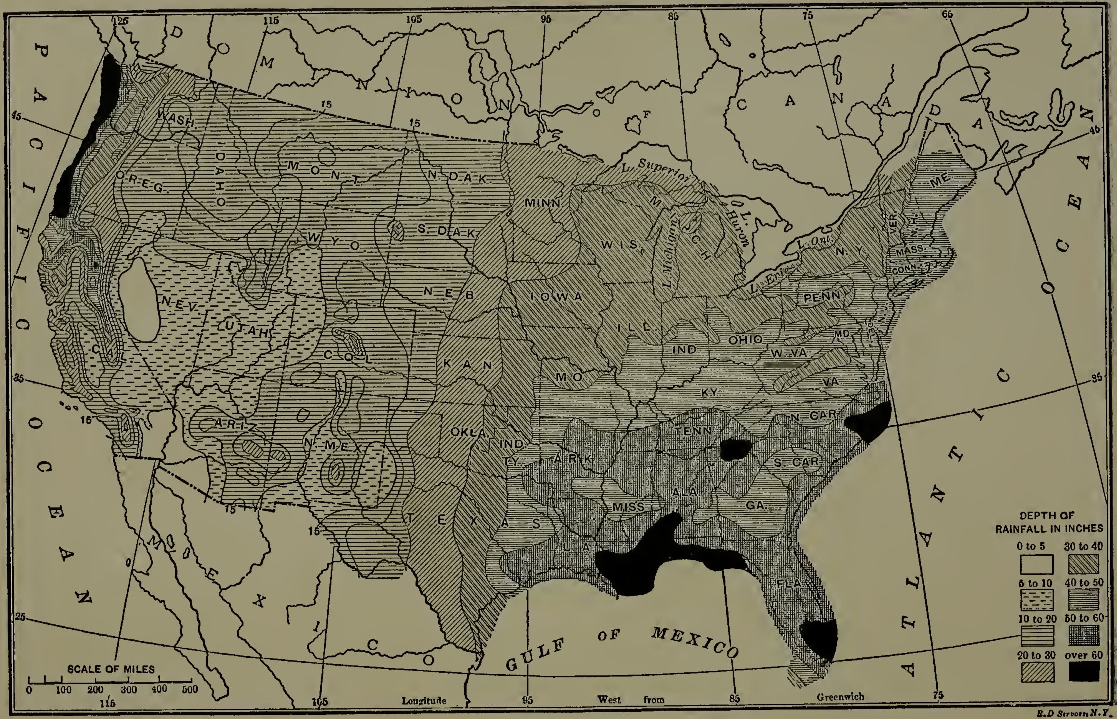

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PLATE 13.

Rainfall chart of the United States.

more rain falls in a single day than we have in a great part of the eastern United States in an entire year. So heavy is the fall of rain that all the soil is washed from the rocks of some of the steep mountain sides.

When the trade winds blow over the land *toward* a coast, the air is coming down grade and becoming warm; and hence, instead of *yielding* vapor, they have their power to *take it* increased. Then they are *drying winds*, and as a result deserts are often produced. This is the reason why some west coasts in the trade-wind belt are arid, as in the case of western South America. The desert of Sahara is explained in a similar way. Here the trades, after rising over the highlands of northern Africa, both descend and go to the southwards, thus having a double cause for warming, and hence for being drying winds.

Where the air rises in the belt of calms, it cools and gives up vapor, forming the copious rains of that belt, which is one of the rainiest in the world. As the belt of calms migrates northward and southward with the seasons (Plates 8 and 9), this belt of heavy rains changes position, and in this way the southern edge of the Sahara region, though dry in one season, is well watered in the opposite.

The rain of temperate latitudes is partly due to similar convectional movement, as illustrated in our thunder storms, partly to air coming from the ocean, and moving both up grade and northward toward colder regions, and partly to the great cyclonic storms, which pass over the country, and which in reality furnish us with most of our rainfall (Chapter VIII). In the belt of prevailing westerlies, west coasts are more humid than east coasts, because the general direction of the air is then from ocean to land.

Distribution of Snowfall. — Over a great part of the earth snow never falls, though everywhere the clouds of the upper air are formed in a zone of perpetual cold, where vapor never condenses in any other than the solid form. Therefore if a mountain peak reaches high enough, even at the Equator the temperature may be sufficiently low to cause snow in place of rain. In the temperate latitudes, freezing temperatures are often found on the high mountains, even during the summer, so that in such places rain rarely falls. Upon these mountains, such as the Alps, there are great snow fields, from which glaciers may extend down into the valleys (Chapter XVII).

Over the greater part of the temperate lands, some snow falls every winter; but it is only in the higher latitudes that much accumulates on the ground. Even though situated on the same parallel, less snow falls in the dry interior lands than near the coast, where the air, though warmer, contains more vapor to furnish snow. Nevertheless there is less snow *exactly* on the coast than at a short distance inland, because though there is more vapor, the temperature is often so high that rain falls, while snow comes over the cooler inland. This is very well shown on the New England coast, where the snowfall is much less at Nantucket and Cape Cod than in central Massachusetts; and in New York, where less falls in New York city than at Buffalo.

Within the Arctic circle most of the precipitation is in the form of snow, though in summer, even as far as explorers have gone, some rain falls over the sea and on the land near sea level. On the higher ground of these latitudes, snow falls both in summer and winter, and so throughout the year this portion of the earth is wrapped in snow and ice, and great glaciers cover most of the land (Chapter XVII).

CHAPTER X

CLIMATE

Meaning of the Word Climate. — Every day there are changes in temperature, and perhaps also in wind direction, abundance of clouds, dryness or dampness of the air, etc. These changes from day to day are called changes in the *weather.* Climate includes and averages these weather conditions. Thus we say that some places have a dry climate, others humid, some variable, others equable. A variable climate is one in which the weather changes frequently, while in an equable climate there is little weather change. Therefore, to consider climate we must look somewhat at the question of weather. The elements of the weather are wind, rain, clouds, sunshine, temperature changes, etc.; and the elements of climate are the same, excepting that less attention is paid to the *single* cases, and more to the *general result.*

Climatic Zones. — One might divide the earth into climatic zones on the basis of rainfall, or any of several features of air change; but it is most common to make temperature the basis. A perfectly natural division may be made according to the altitude of the sun in the heavens, and therefore *according to the latitude* of the place. This gives us the tropical, temperate, and frigid zones, five in all; but in any one of these there is so much difference from place to place, that in each of the zones there are many different climates. For instance, there is a great difference between the climates of Florida and Boston, and between each of these and that of San Francisco, or St. Louis, or Helena, Montana, though all of these are in a single great zone, the north temperate.

There are many variations in climate, and to discuss this subject fully would require several volumes of this size. However, some idea of the *general* climatic features of the world may be gained, if we take only a few places as types. To do this properly, it will be necessary to further subdivide each of the zones into oceanic (or sea-coast and insular), interior, and mountainous. Then also there are desert climates; and within the tropics there are differences between the climate of the trade-wind belt and that of the doldrums.

There is very much less difference in the tropical and frigid zones than in the temperate. In the latter there is an almost interminable variety, and while in each of the former zones there are also differences in climate, these are less, because the tropical zone is *prevailingly* warm, and the frigid, cold, while the places in the temperate zone may be now warm and now cold. Moreover, those portions of the temperate latitudes which are near the tropics, have much higher temperatures and less variation than those near the frigid zones. In the consideration of the climates of the world, we will first take the warm equatorial belt, then the frigid zone, and then the temperate.

Climates of the Tropical Zone: *Belt of Calms.* — This is the zone where the midday sun stands nearly vertical at all times of the year, and it is therefore the warmest belt. Here it is that the air is rising, as the trade winds blow in from either side. Calms prevail here, because the air ceases to move horizontally, and ascends. In this belt sailing vessels may linger for days, and even weeks, without having a wind of sufficient force to drive them through to the zone of the trade winds. On the ocean, where the doldrums are best developed, the air both of day and night is warm and humid throughout the year. The heat of the daytime, although great and oppressive, is tempered somewhat by the ocean, and this is the most equable climate in the world. Because the air is rising, and hence cooling, there is heavy rain throughout the year; and during the day, when the sun shines, and the air rises more perceptibly, clouds form and copious rain falls.

Over the land there is less rain and the temperature is less equable. Because of radiation from the land, the daytime is hot and the nights cool. Because of the absence of ocean water to supply vapor, the air is less humid, and hence the rainfall is less. Also the air is less calm, for over various parts of the land there are differences in temperature, which cause breezes to arise. Nevertheless, even over the land, this is a rainy, relatively calm, and very warm belt. In it are situated the heavily forested rainy districts of central Africa and the Amazon valley. These change gradually to less dense forests on either side, and in Africa gradually give place to the dry desert of Sahara, on which almost no vegetation can grow.

As the belt of calms migrates with the seasons, the position of the heavy rains changes, so that on the margin of the tropical rain belt, there is a climate which is dry in one season and very wet in the other. This is shown in South America, where the llanos of Venezuela are rainy during the summer season, and dry in the winter, and also in the campos of Brazil, south of the Equator, which are well watered in winter and dry in summer.

The Trade-Wind Belt. — There is much more variety in the climate of this zone than in the belt of calms. Being within the tropics, the temperature is everywhere high excepting on the lofty mountain tops, where the climate is almost frigid. Among these mountains one may journey from the zone of perpetual summer, to that where the conditions of spring prevail throughout the year, and then, going still higher, one may rise above the elevation where timber can grow, and finally into a region where the nights are cold and the days cool, and perhaps even as cold as those of the northern winter.

Although in respect to temperature there is a resemblance between these climates of high altitudes and those of the frigid zone, there is this difference, that even though the weather is cold, the sun rises high in the heavens in midday at all times of the year.

Over the ocean the trade winds blow with wonderful steadiness, moving constantly, and with distinct strength, in one direction. They are warm and carry much vapor, taken as they pass over the sea; but since they are blowing from colder to warmer latitudes, their temperature is constantly rising, and hence they are able to take much more vapor. Therefore as they blow over the sea, they do much work of evaporation, and here they are not especially rainy winds; but that the trade winds *are carrying* much vapor is proved by the fact that when the air has its temperature lowered, when rising in the belt of calms, it precipitates quantities of moisture.

When blowing over the land, the trade winds may produce deserts, as they do in the Sahara north of the Equator, and in Australia and South Africa south of the Equator. The desert climate is one of extreme heat in the day, followed by a cool, or in winter really cold, night (Fig. 25).

Because of the dryness of the air, which permits heat to readily reach the ground throughout the daytime, and allows it to be radiated at night with almost equal ease, the temperature range of the desert is great. As the name indicates, a desert climate is one of great dryness, rarely if ever a climate in which *no* rain falls (Plate 12), but one in which there is little precipitation, and this only in certain seasons. In the desert there is not enough rainfall to support any but the most hardy forms of desert plants.

FIG. 70.

The desert vegetation in the far west.

On the land, the direction of the trade winds is often changed as one part of the land becomes warmer than another, causing a circulation as the air attempts to equalize the differences in pressure thus produced. In this way the trade winds are sometimes deflected from their course, and caused to move toward the heated land, as in the case of western Africa (Plates 8 and 9), and also on many oceanic islands, where the sea breeze blows and air is drawn in from the ocean. Then the climate of the trade-wind belt may be changed from one of moderate dryness to one of heavy rainfall (Plate 12); for as the air blows in over the heated land, either passing up the grade of the land, or rising by convection, the dew point is soon reached, clouds are formed, and rain falls. The trade-wind belt is also rainy on many *east-facing* coasts, for as the air blows against the land, being forced to rise, it gives up some of its vapor, causing heavy rains, as in the case of South America both to the north and south of the Equator (Plate 12).

The Indian Climate. — A peculiar climate is found on the plains of India, within the trade-wind belt, where the air movement is modified by the monsoon effect of Asia. Here there are three seasons, the hot summer, the rains, and the winter. The hot summer begins in April and lasts until June, and during this time the air is hot and dry, and the temperature of the day reaches above 100° in the shade, and sometimes 110° or 115°. Everything becomes dry, and it is almost impossible for an Englishman to take exercise, excepting at night and just before the dawn. Everything withers before the scorching west winds which blow from the sandy wastes of the Indus valley.

Then in June there comes a calm, in which the heat, still intense, becomes even more suffocating, because there is no movement of the air; and every one prays for the south and east winds of the summer monsoon, which bring rain and some relief from the steady heat. Finally clouds appear, and rain falls, which during this season, lasting over a month or two, is of daily occurrence. Under the influence of the heavy rainfall, plants flower a second time, having previously been in leaf and flower in February or March. The intense dryness is followed by equally intense dampness, and then, toward the close of the rains, the climate is once more almost unendurable.

By the beginning of October the winter monsoon begins, and from then until December the cool air, blowing from the highlands of northern and central India, transforms the hot plains to a region with a deliciously cool climate, in which the air is clear and dry. Then the weather becomes so cold that fires are needed in the evening, during the months of December and January. In February the warm weather begins, and a sort of spring visits the land, inducing vegetation to break forth; and this is then followed by the hot, dry season, which discourages the thriving vegetation, and causes it to wither until it again bursts forth in the *true* growing season of wet weather.

Climates of the Frigid Zones: *The South Frigid Zone.* — Very little is known about the climates of the south frigid belt, but there seem to be two different climates, that of the ocean, and that of the high, ice-covered land of the Antarctic continent, which appears to entirely enwrap the South Pole. Probably these climates are very similar to those of the Arctic Ocean, on the one hand, and the ice-covered land of Greenland on the other; but they have not been studied.

Near the Arctic Circle. — Within the Arctic there is a progressive increase in the severity of the climate as one proceeds northward. In the extreme southern portion, near the sea level, the summer sun reaches about as high in the heavens as it does in northern United States during the late autumn. At night-time it drops down to the northern horizon, and at midnight the earth is lighted either by the dim sunlight or bright twilight. Therefore, although the sun is low in the heavens, it shines most or all of the day, and the summer weather is cool, but not cold. The storms of temperate latitudes affect this region, and hence there is much variety of weather, with alternately cool and clear conditions, followed by a cloudy sky, perhaps with rainy weather, similar to the changes in the

United States. The temperature is so high that rain falls instead of snow, which is the form of precipitation during most of the year.

In the winter the sun rises high enough to cause twilight at midday, and the night is therefore constant. Then there is a season of prevailing cold. The storms cause cold or warm winds, and clear weather or snow, and these changes are determined, not by the direct influence of the sun, but by outside causes. There is little or no daily rise and fall of temperature, but the variations are mainly governed by movements of the air caused by the cyclonic storms of the temperate zone. Between this season of winter cold and summer coolness, there are two seasons when the sun rises and sets; and then, in addition to the causes mentioned, the temperature changes from day to night. There are therefore four different seasons, with quite distinct characteristics.

FIG. 71.

The midnight sun, northern Norway.

In the Higher Latitudes. — Further north these climates become even still different. The winter night is marked by intense cold, with temperatures generally ranging between 21° and 60° (and probably more) below zero, though now and then rising above freezing point, when a warm wind is caused by some movement of the air. During this season the land is deeply snow-covered, and the sea coated with ice. As the darkness of the winter night is replaced by the spring-time, soon the midday becomes comfortably warm, while the nights are cold. Then the snow begins to melt, and the sea ice to break up and float away to the south (Fig. 72), where it eventually melts in the warmer waters of the more temperate latitudes.

FIG. 72.
The ice-covered sea off Cumberland Sound, Baffin Land, summer of 1896. Steamer Hope in the ice.

After this comes the summer, when plants burst forth into blossom, and the hum of insects is heard, being warmed into life under the influence of the summer sun, that shines by night as well as by day. Though low in the heavens, the sun warms the earth, the frost disappears from the surface, and even at midnight the temperature does not descend to the freezing point. During this season rain may fall even as far north as man has gone. After this comes the autumn, when the darkness of night again appears, and the earth, warmed slightly by day, cools at night, so that the bays begin to freeze, snow commences to fall, and gradually the day becomes shorter, until finally the winter night sets in, and for weeks, and further north even for months, the sun is not seen.

Fig. 73.

A part of the high coast of Greenland, summer of 1896. Latitude 74° 15′.

The same changes of sun occur in the high interior lands; but here, because of the greater elevation, the temperature is so low that even in summer there is never rain, and never warmth enough to melt the snow. Here perpetual winter prevails, and the land is deeply covered with snow and ice, as in the case of the whole interior of Greenland, and probably also of the great Antarctic continent. This climate, which is bitter cold in summer, must become intensely severe in winter; but no one has ever lived there to tell us how low the temperatures descend. We do know that the snowfall is extremely heavy.

FIG. 74.

The Greenland ice sheet showing a part of the Cornell Glacier. Latitude 74° 15′. Taken from an elevation of 1400 feet. Fjord in foreground 3 miles wide, and icebergs in it, in some cases, 75 feet high. The glacier covers all land excepting the island in the ice (nunatak), which is 9 miles distant.

There are other differences in the frigid climate, the most noteworthy of which is that caused by ocean currents. The coast of Greenland is distinctly warmer than that of Baffin Land in the same latitude, because a warm current of water, coming from the south, bathes the former shores, while a cold current, flowing southward, passes Baffin Land and carries to that coast the chill of the ice-laden waters of the north.

Climates of the Temperate Zone: *Various Types.* — Near the frigid zones the temperate climate is quite like that near the Arctic and Antarctic circles; and near the tropics the conditions resemble those described for the trade-wind belt. Between these two extremes are the great temperate belts of variable climates, in which so much of the civilized world lies. These two zones, one south and one north of the Equator, are characterized by prevailing moderate temperature, changing from warm and perhaps hot in summer, to cool or cold conditions in winter. Everywhere there is generally a range of temperature from day to night, and this differs in winter and summer, and also in the two intermediate seasons of autumn and spring. These daily temperature changes are liable to be interrupted by the cyclonic and anticyclonic disturbances which affect the temperate latitudes. The wind and weather changes are influenced by the prevailing westerlies, and mainly caused either by differences in heat effect, or by the low- and high-pressure areas, which pass from west to east over the higher latitudes of the belt (Chapter VIII).

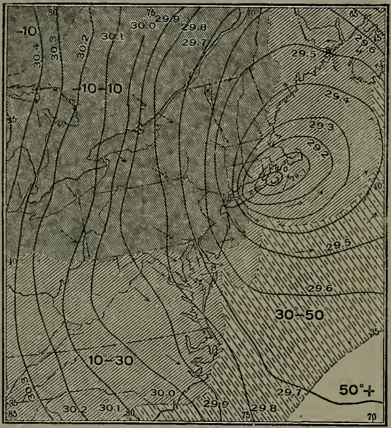

FIG. 75.

A cold wave, March 13, 1888. Temperature indicated by shading. Isobars also shown.

The climates and weather of the south temperate zone resemble those of the northern, excepting in the fact that there is less irregularity, because the southern hemisphere is occupied mainly by water. This allows less range of temperature, and less irregularity of winds, which prevailingly blow from the west. Near the tropics, in both hemispheres, the climate of the temperate zones is modified by the conditions of the horse latitudes, where the air is settling, the winds light and variable, with frequent calms, and the sky generally clear. In this belt of settling air there are some deserts, as for instance on the east coast of southern South America.

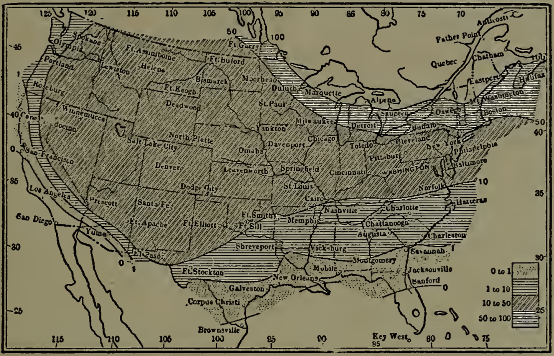

Fig. 76.

Map showing snowfall of United States in inches. All in temperate belt.

United States Climates. — In northern United States, southern Canada, and Europe, we find the characteristic weather conditions and variable climates of the temperate latitudes. This variability has been sufficiently described for the United States in the chapter on Storms, and what is said there applies to Canada and Europe, and in general to other parts of the middle temperate belt. By the passage of cyclonic storms and anticyclones, the daily range of temperature in winter may be replaced by warm spells, or by cold weather, and in summer by hot or by cool spells. A cold wave, overspreading the land, may cause the temperature to drop even at midday, and cover the northern United States with a blanket of cold air, producing temperatures varying from freezing to 40° below zero (Fig. 75). Or on the contrary, warm winds from the south, moving toward a storm centre, may cause the temperature to rise, even at night, and to become so high that a thaw occurs, causing the snow to melt from the ground (Figs. 53 and 54).

As these changes occur, the direction of the wind varies, being now from the south, now from the west, north, or east; and now the sky is clouded, and perhaps rain or snow is falling, and then the sky is clear, and the vault of the heavens a beautiful blue. Day by day, and week by week, these changes occur, and no one can tell what the weather will be from week to week, excepting to know that it will be variable, day after day. This is in striking contrast to the ever dry climate of a desert, the constant winter cold of parts of the Arctic, the uniform humidity of the doldrum belt, or the permanent winds of the lands influenced by the trades.

Difference between United States and Europe. — Within this belt of variable temperate climate there is much variety from place to place. The great city of St. Petersburg is situated in nearly the same latitude as southern Greenland and northern Labrador, — places inhabited only by Esquimaux and a few Europeans who live there for purposes of trade; Berlin and London lie in the latitude of southern Labrador, a sparsely settled region, having a climate of almost Arctic rigor; and New York lies in the latitude of southern Italy and Greece, places with warm and almost subtropical climates.

There are two reasons for these conditions, one the fact that the prevailing westerlies blow over eastern America, after having passed across the land, while those of Europe have blown across the ocean water. The second reason is that the water of the eastern Atlantic, on the European coast, is warmed by an ocean current from the south (the Gulf Stream), while the American shores are bathed by a frigid current (the Labrador) from the icy Arctic sea (Chap. XIII). For similar reasons the western coast of the United States is warmer than the eastern, and also warmer than the eastern coast of Asia in the same latitude; but the difference between the climates of the Asiatic and American coasts is less than that just described, because no cold Arctic current bathes the shores of eastern Asia.

Variation with Altitude. — There are also noticeable differences in the climate of the temperate zone according to altitude. In a small way this may be seen in any mountainous district, like that of New England, where the valleys are very much warmer than the mountain tops (Fig. 31). For instance, Mt. Washington in New Hampshire is enwrapped in cold air even in summer, while the lowlands to the east, in New Hampshire and Maine, are covered with a blanket of hot air; and by autumn the top of this mountain is covered with snow, while in winter the temperatures are exceedingly low and the snowfall heavy. In the same way the Alps, which lie in the latitude of southern France, where the summer is hot and the winter not extreme, are so cold that snow falls upon their summits even in summer, so that there are great fields of perpetual snow and glaciers among the mountains (Chap. XVII).

Differences between Ocean and Land. — Again there is a variation in climate from the sea to the interior. The climate of New York city is warmer and more equable than that of Ohio, and this in turn is less extreme than that of Wyoming, all of which are in the same latitude. The climate of Boston is less severe than that of the interior of Massachusetts, and from place to place along the coast one finds many variations (Figs. 24 and 30).

At Cape Ann, Mass., a point nearly surrounded by the equable ocean, the temperature during the cold midwinter does not descend so far as at places 10 miles inland; and in spring, being surrounded by the *cold* ocean water, vegetation does not so quickly develop as it does at Cambridge, which lies but a short distance inland. The leaves begin to appear upon the maple trees in Cambridge fully a week earlier than at Cape Ann. Throughout the fall, the ocean water, warmed during the summer, prevents radiation on the land from cooling the air over this cape to such low temperatures as those reached a short distance away; and hence some frosts, which occur a few miles from the shore, do not visit the cape.

These same differences in climate are shown near lakes, as for instance along the shores of Lake Erie, in western New York. Here the conditions are so equable, near the lake shore, that an extensive grape-raising industry has developed, while upon the hillsides, two or three miles away, this industry is not possible.

On an even more notable scale the influence of the ocean upon climate may be illustrated by contrasting the Bermuda Islands with central Georgia on the same parallel of latitude. The former, surrounded entirely by warm ocean waters, does not have extremely high temperatures in summer, while in winter the nights are never cold and rarely cool, and frosts are practically unknown. The vegetation has a tropical aspect (Chap. XI), and the Bermudas in this respect resemble the Bahamas and Florida, which lie much further south. In central Georgia, the sun, having the same altitude, warms the land in summer, causing hot days, while in winter, although the climate is not extreme, frosts are by no means uncommon, and the nights are often cold. Thus in the temperate latitude there is an infinite variety in the weather; and equally great is the variation in the climates of different parts of the great zone.

CHAPTER XI

DISTRIBUTION OF ANIMALS AND PLANTS

Zones of Life. — There are three great zones of life inhabited by different assemblages of animals and plants, — the ocean, the land, and the fresh water. In each of these there are subzones in which the animals and plants differ because of variations in temperature. For instance there are very different organisms in the tropical belt from those of the frigid or even the temperate zone, and this applies to ocean and fresh-water as well as to land animals. Besides these there are other zones in the sea and deeper lakes, for the nature of the flora and fauna varies with depth. Also in the larger bodies of water there are changes with distance from shore, and also along the shore, as the nature of the coast varies. There are also numerous subdivisions of the zones of land life. The creatures that live among the mountains differ from those of the plain, while those of the humid seacoast climate bear very little resemblance to those of the desert. The subject of the distribution of animals and plants is therefore a very complex one, which in a book of this scope can be treated only in a brief and most general way.

Life in the Ocean

Plants. — In the sea both plants and animals exist in great abundance, though the latter greatly exceed the former in importance. Excepting at the very coast line, none of the higher flowering plants, so common on the land, are found. Upon salt marshes (Chap. XVIII), there are numerous species of plants, resembling those of the land. On the coast of Florida and other tropical lands, the mangrove tree is able to live with its roots in salt water; and in protected places along these coasts there are veritable jungles of mangrove swamps (Fig. 77), into which the salt water enters.

Fig. 77.
A mangrove swamp, Bermuda.

Elsewhere in the sea the plant life belongs to the lower forms of vegetation, notably the seaweed. Upon that part of the rocky coast of New England which is exposed at low tide, these plants produce a mat (Fig. 78), and the seaweed also grows upon the bottom, near the coast. It is limited to shallow water, because at depths of a few hundred feet not enough sunlight passes through the ocean water to perform the work necessary for plant growth. Therefore, the great expanse of ocean bottom, where the water is deep, is devoid of vegetable life, being in this respect a great desert extending over nearly three-fourths of the earth's surface. Seaweed needs to have a solid base on which to grow, and hence, on the exposed, sandy shores, where the waves keep the sand particles in constant movement, these delicate organisms cannot exist.

There is also much seaweed floating about on the surface of the ocean, especially in the warm waters of the tropical zone in the mid-ocean; and sometimes this gathers over such great areas, that sailing vessels have their progress retarded in passing through them. These are called "grassy" or *Sargasso seas*, like that which lies between Spain and the West Indies, in which the species of Sargassum are most abundant (Plate 16).

Animals. — The abundance of animal life in the sea is marvellous, and there is no part of its surface or bed which is not inhabited. We may recognize three great zones of animal life in the ocean: (1) The *littoral*, or that of the seacoast; (2) the *abyssal*, or that of the ocean bottom; and (3) the *pelagic*, or that of the surface.

Faunas of the Coast Line (Littoral faunas). — The seacoast faunas vary greatly from *place to place.* Some creatures swim in the surf, some cling to the seaweed, many attach themselves firmly to the rocks, others burrow in the mud, and in all of these places many move about from place to place, walking or crawling over the bottom. Hence as we pass along the coast, going from a rocky headland to a sandy beach, and then to a muddy flat in an enclosed bay, we find three entirely different types of animal

FIG. 78.

Seaweed mat. Shore of Cape Ann, Mass. Exposed between tides.

colonies, even though the distance be no more than a mile.

There are also great differences in the animal life according to the *temperature* of the water. Within the Arctic almost no organisms live on the rocky shores, because in winter these are ice-bound, and as the tide rises, it grinds against the shore with such power that no life can withstand its effects. But below the reach of the ice, many animals and seaweeds exist.

These, as well as those of the temperate latitudes, though abundant, are much less so than the myriads of creatures that dwell in the warm waters of the tropics. Moreover, they are much less delicate and beautiful; and in their plain and rugged forms they tell of the struggle against the rigors of winter, to which the tropical animals are not subjected. The latter, bathed constantly in warm water, and at all times furnished with an abundance of food, become marvellously beautiful and varied in form and color. Similar differences are noticed on the land, both in the animal and vegetable kingdoms.

It is within the waters warmed by the tropical sun, and particularly where this water is in circulation as warm ocean currents, that we find the littoral faunas in all their luxuriance of development. These currents not only bear the equable conditions of constant warmth, but also an abundance of floating animals, which thrive in the warm water. The dwellers on the seacoast and shallow bottoms, usually anchored firmly in place, cannot go to seek their food, but must have it brought to them; and therefore warm currents, laden with animalculæ, furnish them with an abundant food supply.

Under these favorable conditions, reefs of coral develop, and one who has never seen a coral reef (Fig. 79), can form no real conception of the vast numbers and wonderful variety of the animal life clustered together in these colonies. Drifting about in a boat, one may gaze down upon a bottom covered with corals of all colors and forms, with millions of mouths wide open and hungry for food that is floating past. The coral reefs are the gardens of the sea, and I know of no better comparison than to a garden on the land, in which plants of various colors and forms are growing in rank profusion. Nowhere else in the world are there so many individuals and species of animals clustered together in a small space, as one may see in the coral reefs of Bermuda, the Bahamas, and many of the coasts of the tropics.

FIG. 79.

A part of the Great Barrier Reef, Australia, showing profusion of coral life.

Animals of the Ocean Bottom (Abyssal Fauna). — It was once thought that no animals could exist on the bed of the sea, where the water has a depth of at least a mile, and often two or three miles, and where the temperature is always nearly at the freezing point, and where a darkness like that of night constantly reigns. Now, however, as a result of much study, we know that this great realm is inhabited by animals not greatly different from those of the ocean surface. Fishes swim about, shellfish crawl over or burrow into the mud, and shrimp, sea-anemones, and many other kinds of ocean animals exist there in great numbers. Some are blind, but others have eyes. Most of the animals dwelling in this zone depend for their food supply upon the remains of animals that lived near the surface of the sea, and upon dying, settled to the bottom. The abundance of animal life on the ocean bed is in large part determined by the amount of food that is thus supplied.

There are fewer differences among the animals of different parts of the ocean bottom, than in any other great area; the temperature is always low, there are no changes with season, and none from day to night, and the temperature is about the same at the Equator as at the Arctic circle, being nearly everywhere below 40°, day after day, and year after year. There is therefore little cause for differences. Nearly everywhere, as the depth of the sea increases, the temperature becomes lower (Fig. 93), and this is one great cause for the variation in the faunas of the deep sea. Sometimes warm currents of water bathe shallow parts of the sea bed, and then, under the more favorable conditions, greater numbers and different kinds of animals live in the shallows, than in the neighboring deeper and colder water.

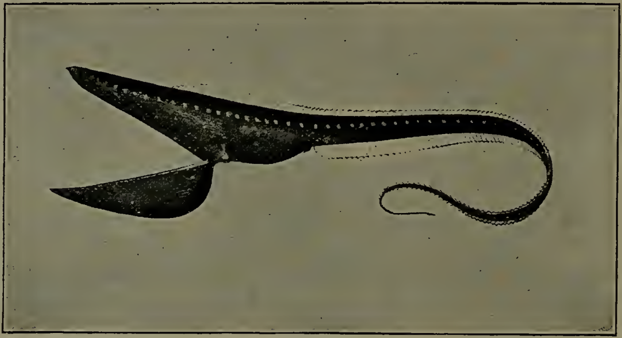

FIG. 80.

A deep-sea fish.

Life at the Surface (Pelagic Faunas). — Here, there is great variety and abundance of animal life. Not merely do the larger fishes swim about singly and in great "schools" or "shoals," containing tens of thousands in a single group, but the water teems with life of minute and even microscopic size. Countless myriads of these tiny creatures occupy the water of all parts of the ocean surface, from the tropical zone to the ever frozen waters of the Arctic. One might sail over the ocean without being aware of their existence, so small are they; but if he will drag the surface with a net having minute meshes, he may gather these animals, and in a dish of sea water examine them at leisure.

FIG. 81.

A deep-sea crinoid.

Now and then, for some unknown reason, these tiny creatures combine to produce a phosphorescent glow on the water surface, and then at night, a gleam of silvery light marks the track of the vessel, or silvery drops fall from the oars. Each animalcule is emitting his share of this strange light. The abundance of these creatures is shown by the fact that the mammoth whale obtains his living from them, swimming through the water with his mouth wide open, and straining the minute animals from the water by means of the fringed whalebones. These monsters obtain food by this means not only in the warm waters of the tropics, but even in the ice-strewn Arctic seas.

There is little reason for difference in the pelagic fauna, excepting in places so far apart, and so different, as the cold waters of the frigid zone and the warm equatorial ocean. Within the tropics, the waters are always so warm, and the conditions so uniform, that the surface animals differ but little; they swim about easily from place to place, or are driven here and there before the winds or the currents, and hence are widely distributed. So also in the frigid zone, the constant cold which prevails in these waters favors uniformity of life. In the temperate latitudes, however, there are somewhat greater differences, and hence greater variety. Near the coast, the water is cold in winter and warm in summer, while further out to sea, the temperature is more equable, and generally higher, because of the presence of warm ocean currents. Therefore there are *zones of life* here.

In the ocean there is therefore the greatest variety of life conditions in the littoral or seashore zone, and least in the great expanse of the deep sea. In each of these zones there is wide distribution, partly because the waters are in nearly constant movement, partly because many of the creatures can swim about,[1] and partly because the temperature variation is not great, excepting in widely separated regions. In the entire area of these three great zones, there is a wonderful variety and abundance of animals.

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[1] Even those which are anchored have a free-swimming stage early in life before settling down to the real condition of maturity.

LIFE IN FRESH WATER

Some of the animals that dwell in fresh water come from the air and land,[1] but there are many species of plants and animals which live and die in the fresh water. As the animals and plants of the land vary, so do those of the lakes and rivers, for among these there are differences from lowland to mountain, and from frigid to tropical zones. Many of the groups of animals of the sea inhabit the lakes; but many, like corals, are never found in fresh water. Some sea fish (such as salmon, alewives, etc.) have a habit of passing up rivers into lakes to breed or "spawn," and hence there is often a difference between the faunas of fresh-water bodies near the sea and those remote from it; for not only do the adults pass up stream to lay their eggs, and then come back again, but the young *remain* in the lakes for a season. Through changes of land and water, animals of the sea have sometimes been obliged to remain permanently in the fresh water, and then sea fish are found in the lakes at all times. Probably many of the lake and river fish have come to inhabit their present homes in a similar way.

In the small lakes, and in rivers, there are only slight differences in the nature of the animal and plant inhabitants from one part to another. There will perhaps be different creatures on the swampy shores from those of the rocky headlands, and between these and the inhabitants of the marshy and sandy shores; but these variations would be slight, because the distance and the difference in conditions are not great. But in large lakes, like the Great Lakes, the fauna and flora vary greatly, and in a way similar to the conditions existing in the ocean, although in lakes there is no such abundant variety of animal life as in the sea. There is here a variable littoral fauna and flora, a pelagic zone, and a lake-bottom zone. In the latter, as in the sea, there is little variety, because the temperature is always low, and the conditions constant and unfavorable to life. Here also, as in the sea, plant life ceases below the depth where the sun's rays cease to be powerful enough to perform the work needed by plants. Although the species are not the same, and notwithstanding many minor dif-

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[1] Such as the young of the mosquito and dragon-fly from the air, and the tree-toad from the land.

ferences, there is a general resemblance between the life zones of large lakes and the sea.

Sometimes a fresh-water lake has its source cut off, as the result of a change in climate from moist to arid, when the water evaporates faster than the rain can supply it; and then gradually a salt lake results, as in the case of the Great Salt Lake and the Dead Sea. As the fresh water changes to salt, many of the animals perish, until finally only a few remain, so few, in fact, that the lake is called a *dead sea.* Even in the Great Salt Lake there are *some* minute animals and plants. The life of the salt lakes is different from that in any other part of the world, the chief difference being in the very limited number of species and individuals, which contrasts so distinctly with the abundance of life in ocean and fresh water.

FIG. 82.

A view in a semi-tropical forest in Florida.

LIFE ON THE LAND

Plants. — The most characteristic life on the land is the plant life, and yet animals are of very high importance. Vegetation clothes the surface almost everywhere, furnishing dwelling-places for many animals and supplying all with food. Animals of the land have not the power of taking food directly from the earth; but plants are able to convert earthy materials into substance which animals can use; and even those creatures which do not take their food directly from plants, do so more indirectly from other animals. Most plants live at the surface of the earth and cling to it, firmly anchored in place.

There is a limit to the abundance of plants in any given place, but this varies with the conditions. Under the most favorable circumstances, as for instance within the tropical belt of heavy rains, the limit is only that of space. As many as can get together and obtain food from the earth, and the necessary sunlight for plant growth, can exist in this place; and here are found tropical jungles of forest trees reaching high in the air, and a tangle of undergrowth, forming an almost impassable mat of vegetation.

Fig. 83.

In the desert of Arizona, showing giant cactus.

On the other extreme, in deserts, even though within the tropics, the conditions of sunlight and warmth are still present, but the equally necessary water is absent, and hence the surface is only scantily clothed with the desert grass, cactus, and other kinds of vegetation which can thrive amidst such adverse conditions (Figs. 70 and 83).

Growing easily, because of the favorable conditions, plants in the humid climates suffer little if attacked by animals; but on the desert the conditions of nature are so adverse that any additional difficulties would be fatal. Hence the desert plants attempt to protect themselves from the attacks of animals, attaining this end sometimes by means of thorns, as in the case of cactus, and sometimes by developing substances in the sap which cause the taste of the plant to be disagreeable, as in the sage brush of the desert.

Equally adverse are the conditions on high mountain tops (Fig. 84), where the temperature is low, or in the Arctic, where not only is there cold, but also a limited amount of sunshine. Approaching either of these regions, we find the trees changing from the deciduous to the evergreens, the forests becoming less dense, and then the trees more and more scattered and stunted, until finally the *timber line* is passed (Fig. 85), and the only forms of vegetation are those that cling to the earth. Within the Arctic regions the willows and other species of trees creep

FIG. 84.

A mountain peak on the crest of the Andes in Peru, above the timber line.

along the ground, raising their leaves and flowers no higher than is necessary; for early in the winter it is vitally important to secure a covering of snow which shall protect them from the intense cold. However, no matter how far north we may go, even to the highest latitude so far visited, grass and flowers will be found in summer, wherever soil exists in a position exposed to the sun (Fig. 86). Upon the bare rocks are innumerable lichens and mosses, and on the hillsides, and in the valley bottoms, are patches covered with flowering plants, but there are never any trees.

FIG. 85.

A view near the timber line in the high Rockies of Colorado.

With change in latitude there are many variations in vegetation; the tropical plants differ radically from those of the temperate zone, being much more abundant, varied, and beautiful. Fruits abound, and Nature is very prodigal in her productions.

Many of the plants of the world are cultivated by man, and even where he protects them, there are distinct belts in which various species grow best. For instance, coffee, bananas, pineapples, etc., cannot be grown in northern United States; and barley or wheat thrive better in the cooler climates. But in the cold Arctic zone it is impossible to raise even the hardiest of crops, for the summer season is too short for any but the native species, which are accustomed to blossom and mature their seed in the short summer of these far northern lands.

Animals. — The animal life of the land may be said to live in three great zones, or else to spend a part of their time in two or all three. There are many that dwell in the air, and this includes many of the insects and most of the birds, as well as some others (such as the bat). Others, and the majority, dwell on the surface of the earth, moving about by one means or another; for on the land the habit of remaining fixed in one place is not common as it is in the sea. An animal that stayed in one place would have little chance to obtain its food supply, for the air is unlike the ocean in this respect. A third group of animals occupies the ground, either living in it all of the time, or spending part of the time on the surface. There are also many of the land animals which leave the dry land, either in some stage of their development, or from time to time, taking to the sea or fresh water for the purpose of obtaining a food supply. Among these there are some which spend more time in the sea than on the land.

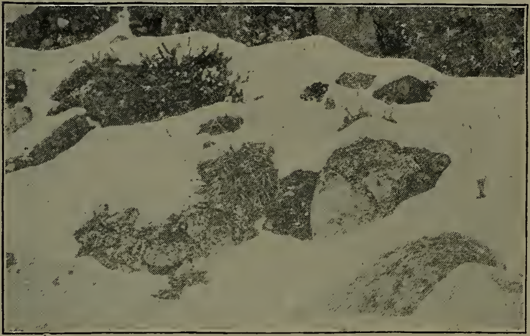

FIG. 86.

A view in North Greenland, showing plants and flowers (Arctic poppies) peeping above the snow.

Among land animals there is much less widespread distribution than among the animals of the sea, or the plants of land and sea. Some, like birds or insects, move so readily that they occupy large areas. For instance, ducks and geese which nest in the Arctic, spend the winter in southern United States and Mexico; but most of the land animals move about so slowly, and with such difficulty, that they are restricted to relatively limited localities. Some species are confined to certain small tracts.[1]

As in the case of plants, so among the animals, there is a very great difference between those of the tropics and those of the colder zones. The *fauna* of the humid belt of calms, rivals the flora in abundance and variety. The tropical forest is alive with creatures of all classes, because food is furnished prodigally by the abundant growth of vegetation. Where this is more nearly absent, as in deserts, animals become scarce.

Upon our western plains the limited number of insects and birds, contrasts strikingly with the abundance of these creatures in the swamps of Arkansas in the same latitude; and the reptiles and higher animals show an even greater diminution. The antelope, the prairie dog, a few burrowing animals, one or two species of rabbit, the coyote, and a few other species, which constitute the higher animal life of the desert, furnish a striking contrast to the scores of mammals which exist in more favorable localities.

In ascending a mountain a similar change is seen, and in a journey to the Arctic, one finds the decrease in abun-

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[1] For instance, the Australian land, surrounded by water, though not far from the large islands to the northward, has animals so different from those of other countries, that it may be said to have a fauna of its own. Nowhere else in the world are the kangaroo, and the many other strange animals of Australia, at present living.

dance of land animal life parallel to that of the plant life. For instance, in central eastern Greenland, with the exception of the mosquito, insects are not numerous or abundant. Reptiles and burrowing animals are entirely absent, because the frost is in the ground throughout the year, and in winter the temperature is extremely low. Birds, mainly those which obtain food entirely from the sea, are abundant along the coast in summer, but most of these disappear with the coming of winter. The chief land birds are the snow bunting, ptarmigan, and raven. Reindeer, foxes, and Arctic hares are the principal land mammals, and these are by no means abundant.

The polar bear, though coming to the land now and then, lives mainly on the floating ice of the sea where he obtains his food. The seal and walrus crawl upon the rocks, but only now and then, for they spend most of their time in the water or on the sea ice. This list of the land animal life of this inhospitable climate furnishes a wonderful contrast to the thousands of species that inhabit the tropical forests. Moreover it is noticeable that the higher creatures of the Arctic live there only by protecting themselves by a thick covering of fur, which keeps out the cold, and that most of them depend not upon the land for their food, but upon the sea. In the great ice-covered wastes of interior Greenland, there is an entire absence of both animal and vegetable life. This is the most absolute desert so far visited by man.

Distribution of Man. — Once was the time when men were distributed in belts, and when races were separated and marked by distinct characteristics; but now, with the progress of civilization and the development of means of transportation, the barriers have in large measure been removed, and before the white race, the others are disappearing or are being rapidly absorbed.

There are still savage or uncivilized races which are kept within certain bounds by natural barriers, as people were in Europe several centuries ago; but most races have reached the stage of development when natural barriers are easily overcome. Rivers no longer present serious obstacles to travel, as they did when the boundaries of some of the European countries were drawn. Seas are no longer crossed with difficulty, as was the case when England, Scandinavia, and other countries developed independently of their neighbors; and mountains are no longer such impenetrable barriers as they were in the time when it was possible for a tiny state, like Switzerland, to exist independently in the midst of greedy neighbors.

The boundary lines of many countries were drawn in the days when even a dense forest was a difficulty of a serious nature. For a long time the Appalachian forests, aided to be sure by the Indian occupants, served as a barrier to the progress of the American people, and caused a concentration along the Atlantic coast; and it is doubtful whether the American Revolution would have been successful had it been possible for the early settlers to have spread themselves over the western territory.

Without serious study one can hardly realize how closely dependent upon geographic conditions has the development of the human race been, although now we have nearly risen above this dependence on natural surroundings. In his advance toward a higher civilization, man has been subjected to many of the same influences that have affected the abundance and variety of plants and animals.

For instance, amid the conditions of the tropics, although savage, his superior intelligence and skill made man the master; but his mastery cost so little effort, and his livelihood was so secure, that he did not advance as rapidly as those who were placed amid the greater difficulties of the temperate zone. Here constant effort was necessary, so that the intelligence and skill were developed which have made the men of temperate latitudes the masters of the world, and not merely of other men, but to some extent of Nature herself. The people of the Arctic have had too severe a struggle, and too little opportunity, and as a result they have developed hardly more than the races of the tropics; yet among uncivilized peoples, one will probably not find a more intelligent race than the Esquimaux of the Arctic.

FIG. 87.

A Bermuda road bordered by cedar groves.

Modes of Distribution of Animals and Plants.— While from place to place there are many variations in the kind of animals and plants, many species are widely distributed. The same species in some cases are found in Siberia and British North America, or in both eastern and central United States. Those animals which live in the air or water are most easily distributed, being drifted about in these media. One may gain an excellent idea of the general subject of the modes by which animals and plants are distributed over the earth, by comparing the fauna and flora of Bermuda with that of the United States; for in the resemblances and differences which are found, the chief causes for distribution are illustrated.

The Bermudas lie about 600 miles from the Carolina coast, which is the nearest land. They form a cluster of tiny islands, absolutely alone in the sea, and have never been connected with North America; but yet the animals and plants are American in kind. Upon their surface we find the cedar (Fig. 87) and other plants from the same latitude in North America, the cactus and Spanish dagger, which on the mainland exist on the arid plains, the palmetto, and other Bahama and Florida plants, the oleander, and scores of other species common in southern United States.

When these islands were first visited, not a single mammal, excepting the bat, was found on the island. Insects of the same kind as those of the mainland are numerous; and birds are also there in considerable numbers, particularly the ground dove, redbird, bluebird, catbird, and a few others. A tiny lizard of the same kind as one in the West Indies is also found there.

Fig. 88.

A bit of Bermuda landscape.

How did these come to this remote island, and why are there no larger animals? One of the most striking facts concerning the fauna of the Bermudas, is that the animal life is chiefly made up of species which can fly; and every year there is proof that it is this fact which accounts for their presence. Robins and other birds of passage stop upon this land during their annual migrations, and during or after heavy storms, many species of birds are seen which do not naturally belong there, and which quickly disappear. They have been blown out to sea by the wind, and the number which have been thus driven away from the land, may be shown by the fact, that although the land birds native to the island number hardly more than a dozen, 185 different species have been found there. Even the tiny humming-bird has been seen in the Bermudas.[1] No doubt for every tiny bird that makes the journey in safety, scores perish at sea. Naturally then, the dwellers of the air, either by direct flight, or driven by accident, may make a journey across the sea, and better yet over the land, perhaps starting a colony in some new place not before occupied by this particular species.

Birds, eating fruit upon the mainland, after arriving at the island, or in fact after making any journey, may drop seeds, which, sprouting, develop into plants that start a growth of a new kind in this place. Also the wind, carrying lighter seeds, may drive them to far-distant lands. The first lizards which came to the Bermudas were, no doubt carried there upon bits of floating wood, moving in the ocean currents, which have also carried the shells now inhabiting the land and the water which surrounds these islands. None of the larger and higher species of animals can take such a journey; for there would be nothing to float them, and in any event they probably could not survive it.

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[1] It may appear strange that so small a bird can make so great a journey; but it must be remembered that there are many logs and bits of wood floating in the sea, and that these will serve as a resting-place for the birds that are forced to make this flight against their will. It is by no means uncommon, when sailing far out of sight of land, to see some small land bird wearily flying toward the ship, where he rests for awhile in the rigging, before taking up his flight in the effort to again reach the land from which he has been driven.

These are the means by which animals and plants are distributed: some make direct journeys, some *come* by chance, and some are *carried* by accident. On the land they move slowly along, spreading out into whatever new territory they may be able to occupy.

This process of extension of species into areas previously unoccupied by them, is well illustrated in the case of many of the weeds, such as the field daisy, introduced by chance into this country during the Revolution, and now one of the commonest of plants; or of the Canadian thistle, which has extended its range so as to become a pest in farming districts. Many insects, like the Colorado beetle or potato bug, and other animals, like the English sparrow, the latter a European species, finding themselves in a new region favorable to their development, have multiplied and spread in a wonderful manner. In Australia the rabbit, introduced from Europe not many years ago, has become a national pest.

Man has now come upon the scene, and has become the most potent of all agents in the distribution of animals and plants. Formerly, by their own or by accidental movements, organisms had spread about over the land, so that the world was divided into fairly definite zones, each species having found a place for itself and occupying a restricted area; but man is interrupting all this, killing off species here, and introducing them there, so that very often it is difficult to say which species are native and which introduced. For instance, in Bermuda, many plants carried there by man have taken such a footing on the islands that in some cases it is almost impossible to say that they were not there before man came.

Barriers to the Spread of Life. — The most effective barrier to the spread of life is temperature. No matter by what means the cocoanut or the coffee berry were carried to northern United States, they could not grow; nor would one of our pines or spruces find the tropical belt a congenial home. There is therefore, on land as well as sea, a limit to the distribution both of animals and plants, dependent largely upon *temperature.* Therefore the species of the north temperate and Arctic belts are not at all the same as those of the southern hemisphere, even where the climatic conditions are the same, for they cannot pass the great *tropical barrier.*

For the same reason *mountain ranges* serve as a partial barrier; for because of the low temperatures, many species cannot cross them, though some of the more hardy species are able to make the journey, and others pass around the ends, so that these elevations are not complete barriers. Organisms accustomed to life in a humid climate cannot survive on a *desert*, and therefore this also serves as a partial barrier. Even a *river*, or a *chain of lakes*, may mark the limit of spread of some species; and sometimes a *forest*, or an *open country*, may serve as a barrier; for the forest-dweller may not be able to endure a journey across the open prairie, or the inhabitant of an open plain may find the passage through a forest impossible.

However, the great barrier is the *sea*, and this has been well illustrated in the case of Bermuda. Only certain forms can make the passage of this barrier, and therefore the land fauna and flora of oceanic islands may differ from those of the nearest mainland by the absence of many species, especially of the higher animals, and oftentimes by the presence of new forms, which have been developed there, and have not yet spread to the mainland. In the far-away islands of the mid-ocean these peculiarities are very marked.

PART III. — THE OCEAN

CHAPTER XII

GENERAL DESCRIPTION OF THE OCEAN

Area of the Ocean. — Upon the earth there are about 145,000,000 square miles of ocean water, covering and hiding from view about three-quarters of its surface. It is not a uniform sheet, but is irregularly distributed in oceans, and between these there are continents, while above its surface there rise numerous islands. Its waters bathe the shores of these lands, and the contact between land and water is very irregular, especially in the northern hemisphere, where the land is indented by many bays and harbors, and even by great enclosed seas. This line of contact is the scene of many changes (Chap. XVIII), for the waves of the sea are incessantly at work in an attack upon the land.

Importance of the Ocean. — The ocean surface is now traversed by ships, carrying the products of one zone to the people of another; but at one time, before our means of navigation had reached such perfection, the sea surface was a barrier to the spread of man, almost as effectual as it now is to animals. Then distant lands were unknown, and even short journeys by sea were hazardous.

The water of the ocean moderates the climate of the globe, and especially influences the land near by; it furnishes the air with the vapor which falls as rain, and therefore supplies our streams and lakes with water, which after a passage over the land, may return to the parent sea which gave it birth. The rivers not only take water to the ocean, but also carry sediment from the land, and so the sea becomes the dumping ground for the waste of the land. This, added to that which is wrested from the coast by the waves, is strewn over the bed of the sea near the land. Last, and by no means least, the ocean is the home of myriads of animals, many of which serve man as an important source of food.

The Ocean Water is Salt. — Unlike most of the water of the land, the ocean water is distinctly salt, and there is a great difference in the percentage of this substance present in it. On an average the amount of salt in the sea varies from 3.3% to 3.7% of the whole, so that more than 96% of the ocean is pure fresh water. Yet so great is the bulk of sea water on the earth, that the total amount of salt dissolved in it, if deposited in a layer over the surface of the land, would make a bed over 400 feet thick.

In rainy belts, such as the doldrums, the constant supply of rain freshens the sea water; and so also, the ocean is less salty at the mouths of large rivers, and near such great glaciers as those of Greenland, which enter the sea and furnish fresh water when the ice melts. On the other hand, where evaporation is rapid, as in the trade-wind belt, the sea water becomes salter than elsewhere; for evaporated water is fresh, and when it leaves the ocean, the salt remains behind, thus making the surface water that remains still salter. Salt water is heavier than fresh, and we say that it is more *dense*. Calling the density of fresh water 1, sea water has an average density of 1.02; but as its saltness varies, the density likewise changes.

Besides the common salt which gives the ocean water its taste, there are minute percentages of other solids in

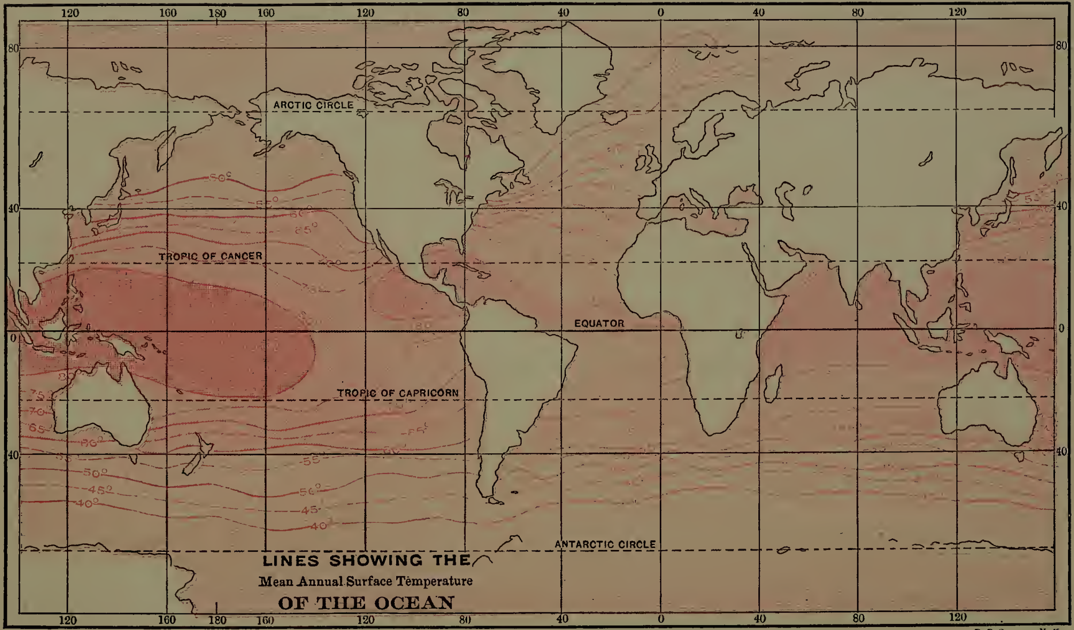

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Plate 14.

Average temperature of the sea.

solution. The most important of these is carbonate of lime, the material out of which corals build their skeletons, and shellfish their shells. They take it with their food and transform it to the solid forms which we know so well, just as the land animals take with their food materials which they build into bone, teeth, etc.

In addition to these solid substances, the sea water carries quantities of oxygen and other gases of the atmosphere, and the fishes take this from the water by means of their gills, very much as we take oxygen from the air by means of our lungs. Without it they would die. Some of the oxygen present in the surface water is furnished by plants, but much is absorbed from the atmosphere, or carried into the sea by rain and river water.

No one is able to say just what is the source of the salt in the ocean. Probably the sea has always been salt, having become so when first the waters gathered on the surface of the globe. If the explanation of the origin of the earth which the Nebular Hypothesis furnishes is correct, the sea in the early history of the globe must have been impure with many substances, for then the earth was hot. As the oceans descended from the atmosphere, in the condition of heated rain, to form the great bodies of water of the globe, they must have contained salt and other substances in solution. Upon this explanation much of the salt now contained in the ocean was then furnished it; but all rivers that flow over the land carry salt, which they have obtained from the rocks and soils, and so the sea is probably becoming salter all the time, just as some lakes without outlet are even now being transformed to salt seas.

Temperature of the Ocean Surface. — Naturally the temperature of the surface of the ocean varies from place to place, for it is warmed by the sun in a manner similar to the warming of the land. Near the Equator the constant warmth produces warm ocean water, and in the Arctic and Antarctic seas, on the other hand, the water is cooled by the constant coolness of the climate. However, the temperature of the sea never descends below the freezing point of salt water,[1] but when this is reached the water congeals and sea ice is formed. Up to this point the water sinks as it cools, for as in the case of air, cooling makes it more dense, and therefore causes it to settle.

The sea-made ice of the Arctic, or the *floe ice*, as it is called when drifting about, forms over the greater portion of the water which surrounds the poles. Far to the north, the surface of the ocean in winter is transformed to solid ice, very much as ponds are in the winter; but the surface of this is very much rougher, for the winds, breaking the ice, pile the blocks one upon another, and the tides and currents moving it hither and thither, crack and break it into blocks, which are sometimes flat, but commonly raised one upon another, so that in many places the Arctic ice is so rough that travel over its surface is almost impossible. The depth of this sea ice is generally not over 10 or 20 feet, though sometimes greater than this.

FIG. 89.
Arctic sea ice, northern end of Labrador.

Since the ocean waters are in movement at the surface, this floe

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[1] This varies with the density of the sea water, but is generally between 28° and 29°.

ice is carried about; and as the movement of the water is mainly toward the south, the accumulation of the winter is in part removed to warmer latitudes during the summer. Both during winter and summer, there is a movement of the sea ice in this direction. Hence it does not increase in thickness as winter succeeds winter, but some goes off to other regions, where, owing to the warmer climate, it melts and disappears. There is a constant procession of this ice past the shores of Baffin Land (Figs. 72 and 89), and in spring and early summer it extends along the entire coast of Labrador, and even as far as Newfoundland.

The difference in the temperature of the sea causes movement to start, very much as the air moves by convection. The warmer water of the tropics is made light by the higher temperature, and hence it floats, while that of the colder regions, being denser, settles, and warmer water takes its place. This is one of the reasons why the ocean waters are in movement in the form of ocean currents, and it is one of the reasons why the surface water changes temperature so slightly; for with a difference in temperature, and hence in density, the water moves about, endeavoring to equalize the differences.

Life on the Bottom (Chapter XI). — For a long time almost nothing was known about the bed of the sea, an area equal to about three-fourths of the earth's surface. It was supposed to be a great barren zone uninhabited by life. People knew that the pressure on the bottom must be tremendous, and that probably no sunlight passed through the great depth of water, and these peculiarities were thought to be sufficient reason for preventing the existence of animals in the depths of the sea.

When it was found to be possible to lay cables across the ocean, it was discovered that animals *did* live in this great zone, and an interest was aroused among scientific men, as a result of which explorations of the sea bottom were undertaken, partly to study animal life, and partly to determine the outline of the ocean bottom, the latter point being necessary in some cases in order to find if it would be possible to lay cables upon it, and in order to select the best lines. It is now known that animals live there notwithstanding the coldness of water, the darkness, and the great pressure; and it is also known that they obtain their food mainly from the death of the creatures with which the surface waters teem.

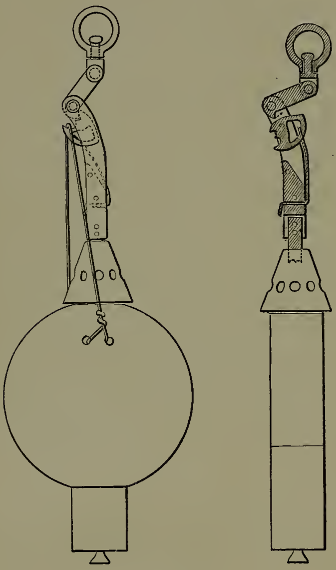

FIG. 90.

Deep-sea sounding machine, with and without the sinker

That there is great pressure on the bottom of the ocean is proved by the fact that fishes brought to the surface often have their skin cracked, their eyes protruding from their heads, and their air-bladders from their mouths. While they are on the bottom there is a tremendous pressure; but it is exerted on every part of their body, just as an air pressure of about 15 pounds to the square inch is exerted on every part of our own bodies. But when these creatures are raised to the surface, the pressure is removed from the outside, and that from within, pressing outward, gives the results mentioned. No doubt the animals move about in the waters of the deep sea with the same ease that their fellow-creatures do in the waters at the surface.

Methods used in Studying the Ocean Bed. — In the study of the ocean bottom there are several sets of facts which are chiefly sought. It is desired to know what animals inhabit these deep recesses, what the temperature is, how deep the water is, and hence something about the outline of the ocean bed. In carrying on the study, the first thing to be learned is the depth.

The sounding is made by means of a small steel wire which is reeled off from a sounding machine (Fig. 90). It is necessary that this shall be small, for the weight of a coil of heavy wire, and its friction in the water, would make it difficult to draw back to the surface what had been lowered. On the end of the sounding wire there is a heavy iron ball which sinks to the bottom, and when it strikes sends a shock through the wire, which causes a spring attached to the machine to jump, and then the reeling of the wire from the wheel is stopped. So delicately made is this machine, that the depth is measured with an error of only a few feet, and we now have many thousand such soundings in different parts of the ocean.

The sounding wire is so frail that it would be impossible to draw the weight back to the surface from the great depths, and hence it is left on the bottom. By doing this it is made certain that the ocean floor has been reached. The iron weight, which is a cannon ball pierced by a hole, surrounds a cylinder,[1] at the top of which is a joint, which when the ball touches bottom, bends and releases a small hook upon which the cannon ball has been suspended by a wire. When this hook drops down, — and it cannot do so until the bottom is reached, — the ball is released, and hence remains on the sea bed, while the wire and water bottle are drawn to the surface.

At the same time the *temperature* of the water is obtained. A thermometer is attached to the sounding wire near the water bottle, and others at different points between the surface and the bottom. These are so constructed that when the sounding wire is drawn in,

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[1] This is the *water bottle*, which by automatic contrivances remains open on the way down, and becomes hermetically sealed by means of a tiny screw which revolves when the wire is being drawn up. Therefore the water bottle brings to the surface a sample of the water from the ocean bottom. It is worthy of mention that this water is charged with gases under great pressure, so that when the bottle is opened at the surface, the water escapes as soda water does from a fountain.

they turn upside down, being allowed to do so by a little screw wheel which is unscrewed by the upward movement through the water. When the thermometer overturns, the temperature at that particular time is recorded by the height of the mercury column, and this is not afterwards disturbed unless the instrument is turned right side up again. Therefore the temperature for any depth may be obtained.[1]

After a sounding has been made, a dredging is often undertaken for the purpose of obtaining some of the deep-sea animals. The *dredge* or *deep-sea trawl* is an iron frame with a long bag net attached. This is lowered by means of a strong wire rope, and then dragged over the ocean bottom, taking whatever chances to come in its way, and a dredge rarely comes from the bottom without containing some of the deep-sea creatures. It is necessary that the frame shall be dragged *over* the bottom, and to do this, much more rope is needed

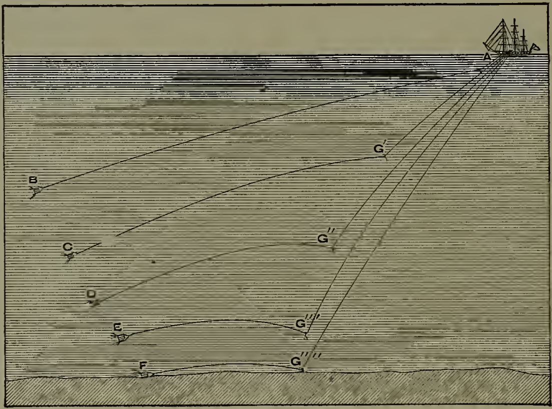

Fig. 91.

Lowering a deep-sea dredge to the ocean bottom.

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[1] Other facts are also obtained, one of importance being the determination of the nature of the materials covering the bottom. This is done by placing some soft substance, like soap, on the bottom of the water bottle, and to this the mud or sand of the sea floor will cling and be brought up to the surface.

than in sounding, for if an extra amount were not allowed, when the steamer began to drag the dredge it would simply be towed through the water. Sometimes a weight is attached to the rope in order to cause it to sag (Fig. 91); but in real deep water the great amount of heavy wire rope used is sufficient for this purpose.

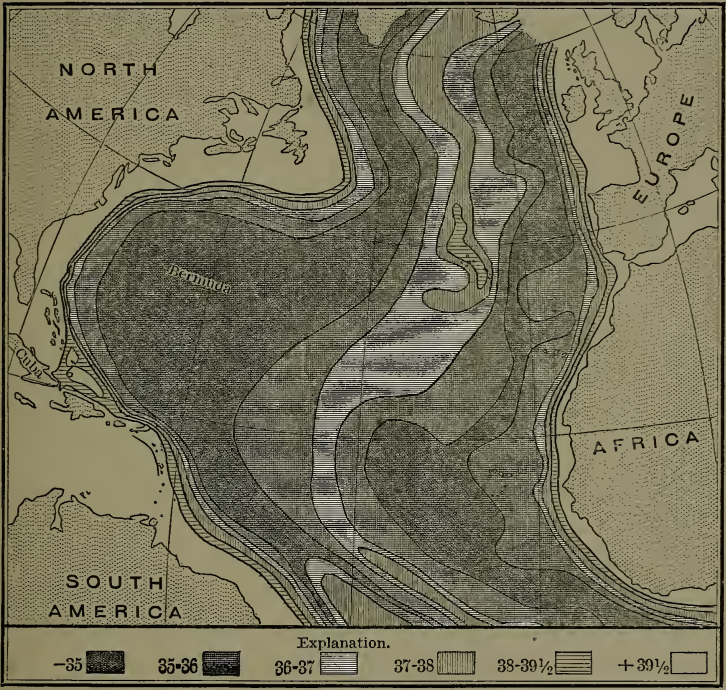

FIG. 92.

Map showing temperature of the bottom of the north Atlantic.

Ocean Bottom Temperatures. — As might be expected, the water of the bottom of the sea is cold. Excepting possibly in the Arctic seas, the temperature of the water decreases as the depth becomes greater. This is because the sun warms only the surface layers; and whenever, either during the winter or the night, the water at the surface is cooled, it sinks, because it then becomes heavier. So there is a *settling* of the cold water, and therefore the temperature at the bottom of the frigid seas is about at the freezing point of salt water. Between Iceland and Norway the ocean bottom temperature is below 30°; but similar cold water is also found at the bottom near the Equator; and over a great part of the sea floor, in its deepest portions, the temperature is between 32° and 35°, even within the tropics. Manifestly this cannot be due to the sinking of water *in* the warmer zones, for the temperature of the sea surface within the tropics is rarely below 70° (Plate 14). There are various reasons for believing that these cold waters have come to their place as a result of the slow movements of ocean currents along the ocean bottom, from the frigid zones toward the Equator (Chap. XIII).

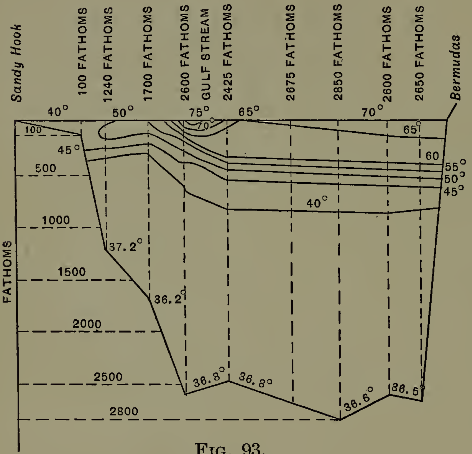

FIG. 93.

A section of the ocean from New York to Bermuda, showing the temperature at various depths (fathom = 6 feet).

Generally the temperature of the ocean descends rather rapidly just below the surface (Fig. 93), particularly in the tropical zone, where the upper layers of water are warm; but after passing from this upper zone, the temperature descends more slowly. At first, a depth of a few hundred feet makes a difference of several degrees, and then this rate becomes less, until near the bottom there may be a change of not more than 1° in a thousand feet. In other words, the ocean water is stratified into layers having different temperatures, the highest at the top and the lowest at the bottom. Therefore, as a general rule, the greater the depth, the lower the temperature.

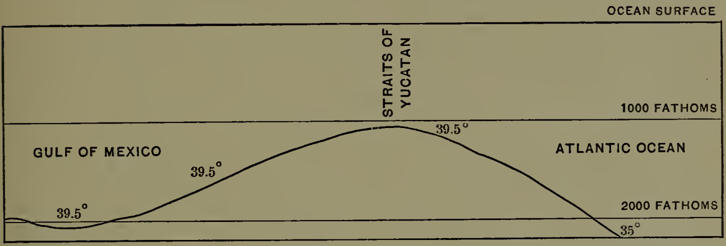

Fig. 94.

Section of part of Gulf of Mexico and Atlantic Ocean, showing depth and temperature.

There are several exceptions to this, most of which are found in such partly enclosed seas as the Mediterranean and Gulf of Mexico (Fig. 94). In the latter, for instance, the temperature decreases normally until it reaches about 39.5°; and then there is no further decrease, while outside, in the open Atlantic, where the ocean depth is no greater, the temperature decreases to 35°. Such a difference must have a special explanation; for if there were chances for free circulation, the cold water of the deeper Atlantic would flow in and displace the warmer water that overspreads the deeper parts of the Gulf of Mexico. The explanation for this peculiarity is found in the fact that there is a rise in the sea bottom which makes the bed of the Gulf a basin with the rim higher than the centre. The coldest water that can enter is that at the level of the top of the rim, which in the open Atlantic is about 39.5°.

The same condition exists in the Mediterranean, where the temperature of the bottom at a depth of 12,000 feet is only 55°, while in the open Atlantic at the same depth it is 20° lower. The temperature at the bottom of the Mediterranean is the same as that in the Atlantic at the same level as the bed of the Strait of Gibraltar.

The Depth of the Sea. — The deepest part of the sea so far discovered lies to the south of the Friendly Islands, which are in the south Pacific, east of Australia. There the depth is over 5000 fathoms, or 30,000 feet, more than 5½ miles, being greater than the elevation of the highest land above the sea level, which is about 29,000 feet. The deepest known point of the Atlantic is 4561 fathoms, within 70 miles of the island of Porto Rico. Not only are parts of the ocean deeper below the sea level than the highest land rises above it, but its *average* depth is very much greater.

Near the continents, and in some of the partly enclosed seas, the ocean is not very deep; but over nearly its entire area, beyond a score or two of miles from the land, and frequently much nearer, the depth is a mile or two, and very often more. Surrounding most of the continents there is a shelf of varying width, from a few miles to over 100 miles, over which the sea is shallow; but beyond this the depth rapidly increases, until the great ocean abysses are reached. The best way to gain an idea of this difference is to make two sections, one from New York to Bermuda, the other from New York to Great Britain.

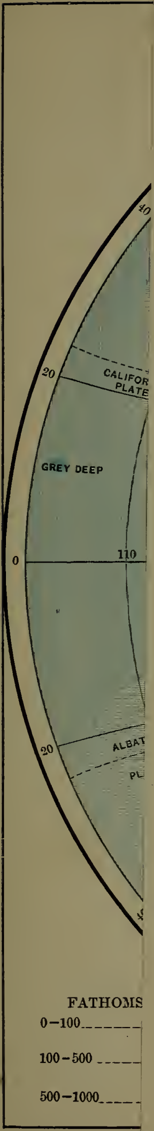

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PLATE 15.

Map showing depth of the sea in the Atlantic Ocean.

Starting from western New York at an elevation of 1000 or 2000 feet, and passing over undulating ground, we come to the seashore, where by a further moderate descent, the land passes beneath the sea and the depth of the water gradually increases (Fig. 95). Twenty-five miles away the depth is perhaps 200 or 300 feet, and the water continues to deepen very gradually, until at a distance of about 75 miles from New York the depth is 100 fathoms, or 600 feet. Between New York and this point, the temperature of the ocean-bottom water varies with the season, being warm in summer and cold in winter; but at the outer limit the temperature is always somewhat high, being kept so by the influence of the water of the Gulf Stream.

This zone of shallow water rests upon the *continental shelf;* and going further we find the depth of the water rapidly increasing, so that within a few miles from the edge of the shelf, the depth has increased from 100 fathoms to 1000 fathoms, or more than a mile. This region of steep slope, which borders the entire continent at varying distances from the coast, is called the *continental slope*, and the descent upon its face is about as rapid as that of a moderate mountain slope. Along this the temperature rapidly decreases, until at the depth of 1000 fathoms it is 38°. Then the depth of the sea becomes gradually greater, until the deepest point of over 3000 fathoms is reached, well toward the Bermudas. Here the temperature of the sea is 34°.

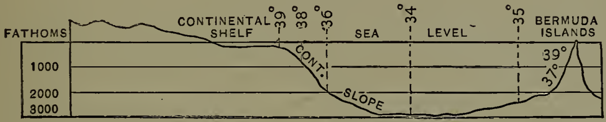

FIG. 95.

Section of ocean from New York to Bermuda, showing depth and temperature.

Within sight of the Bermudas, not more than 30 miles away, the bed of the sea begins to rapidly ascend, and in this short distance rises more than two miles, so that if one could stand on the sea floor 30 miles from the Bermudas, he would see a lofty conical mountain, quite like a volcano in form. As the depth becomes less on the sides of this cone, the temperature increases, at first slowly, then rapidly, until the temperature of the surface, about 70°, is reached. On the opposite side the descent is similar to this, and soon the cold, dark depths of the sea are again found.

Passing from New York toward England, the first part of the journey would be similar to that just described. The great ocean depths that are reached beyond the edge of the continental shelf are nowhere interrupted by shallows, but continue until near the mid-Atlantic, where the bottom rises in a great, broad swell, forming a ridge which divides the Atlantic in a somewhat disconnected way from the northern part to the south Atlantic. Generally the depth of this *mid-Atlantic ridge* is 1000 or 2000 fathoms, but the water is shallower here than on either side, and upon its crest the temperature is higher than in the greater depths to the east or the west (Plate 15).

Beyond this, toward Europe, the bottom again descends, reaching a depth of nearly 3000 fathoms, and then, at a distance of 50 miles from the British coast, the continental slope rises steeply, as on the American side; and with this rise the temperature increases. Then, from the crest of this to the shores of England, the water, at first about 100 fathoms deep, becomes gradually shallower; and here, as on the American side, the temperature changes with the seasons.

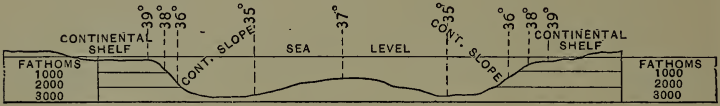

FIG. 96.

Section to show, in diagram, the conditions of temperature and depth in the Atlantic. Depth and width of continental shelf greatly exaggerated.

Topography of the Ocean Bottom. — These two sections are characteristic of the ocean floor in various parts of the world. Bordering the continents there are plains covered with very little water, and varying in width, terminating in steep slopes facing toward the sea, beyond which are extensive plains covered by deep water and extending over nearly three-fourths of the earth's surface. These plains of the ocean bottom are the most extensive in the world, forming great monotonous expanses of ocean-bottom clay, the surface of which no doubt rises and falls in gentle swells and is here and there relieved by single peaks, like the Bermudas, or groups of peaks, like the Hawaiian Islands, some rising to the surface, and some not reaching so far. Here and there also there are mountain ranges, like the chains of islands forming the East and West Indies; and in some parts of the sea, as in the south

Fig. 97.

A part of the Jones Model of the earth, showing a part of the ocean bed and the continents and islands. Copyright, 1894, by Thomas Jones, Chicago, Ill.

Pacific, numbers of disconnected peaks rise from the great ocean-bottom plain (Fig. 97).

There is a distinct difference between the outline of the sea floor and that of the land. In both there are volcanoes and mountains, and in both there are plains and plateaus; but on the land the action of the weather and the running water have gullied and carved the surface into an exceed-

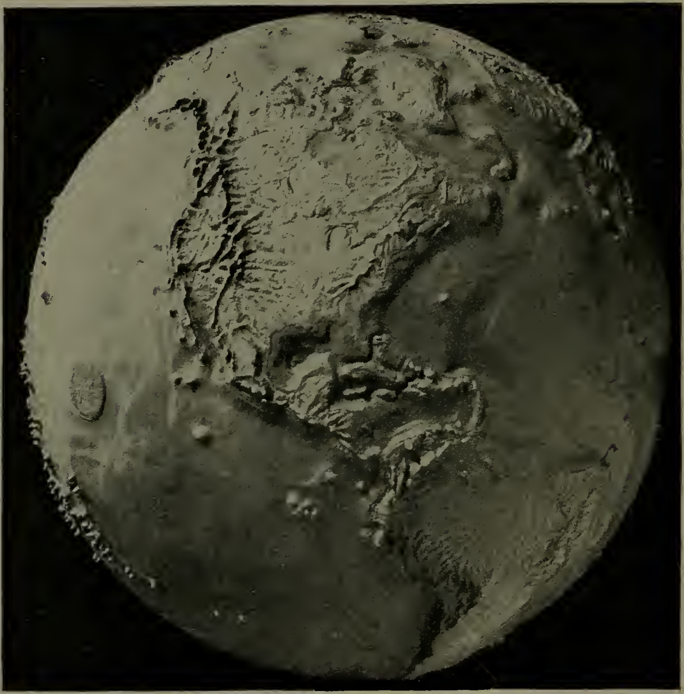

Fig. 98.

North and South America in relief with neighboring ocean beds — showing continent elevations, mountain ranges, and ocean basins. Copyright, 1894, by Thomas Jones, Chicago, Ill.

ingly irregular outline, not only with great elevations and depressions, but also with minute hills and valleys.

On the sea bottom however, these agents of land erosion are absent, and the plains and plateaus are level, while the mountains and volcanoes rise steeply, with smooth, uncut sides. Not only are the causes for the land irregularities absent, but there is also a constant rain of sediment, some brought to the sea by rivers, some wrested from the shore by waves, and much formed by the death of animals which have taken carbonate of lime from the water and built it into shells and skeletons, which when they die fall to the sea bottom and accumulate. This steady supply of materials, distributed over the sea floor, tends to smooth out all the smaller irregularities which naturally exist. For these reasons the main feature of the sea bottom is levelness, broken here and there by steeply ascending and smooth-sided peaks and mountain chains (Plate 15 and Figs. 97 and 98).

The Ocean Bed. — The land surface is either bare rock or soil. The sea bed is nearly everywhere soft clay or muddy ooze. Near the land, gravel and sand are distributed over the bottom, being furnished by rivers and waves; but these fragments are too heavy to be carried far from the coast, and they therefore settle near the shore, so that the further we go from it, the finer are the materials covering the sea bed. Even 100 miles from the coast there are some minute bits of clay floating in the surface waters.

Globigerina Ooze. — But in the open sea these materials settle to the bottom in very much smaller quantity than the shells of the minute and almost microscopic animals which live in such abundance in the surface waters, and which upon their death sink to the bottom. Therefore over most of the sea floor the bed is made of an ooze, chiefly composed of remnants of these shells.

Among the shell-bearing pelagic animals some of the most common are species belonging to the genus Globigerina; and hence over great areas this makes an accumulation of what is called *Globigerina ooze*, which is somewhat like the chalk of England and France. Since they have been falling to the sea bottom in the open ocean for ages past, they must have formed a great thickness of this ooze, though to make a layer a foot in depth must require many centuries, since each grain represents the life and death of an animal whose size is less than that of a pin-head. In parts of the ocean other minute species, such as Diatoms and Infusoria, are more common than the Globigerina; and on the bottom of these seas the ooze is called *diatomaceous* or *infusorial*, according to which form predominates.

Red Clay. — Covering even a larger area than this (about 51,000,000 square miles), is a still more remarkable deposit called *red clay*. This is a red mud occurring in the deeper parts of the ocean, below the depth of 2000 or 2500 fathoms. In it are found bits of meteoric iron, representing the partly burned-up meteors, fragments of pumice, and the more indestructible parts of sea animals, such as the teeth, which are less easily dissolved than the carbonate of lime which forms the shells. Because of the presence of gases (especially carbonic acid gas) held under the great pressure which exists there, the shells have been dissolved in the sea water.

Every shell contains something else than carbonate of lime, such as minute quantities of iron and silica, which are not so easily dissolved as the carbonate of lime. Hence, while the latter is taken into solution, these remain behind; and it is of this *insoluble residue* that the red clay is formed, its color being due to the presence of the iron. Therefore, while the Globigerina ooze is very slowly formed by the accumulation of many minute shells, the red clay is gathering with infinitely greater slowness as a result of the accumulation of minute remnants of these tiny shells.

CHAPTER XIII

THE MOVEMENTS OF THE OCEAN

Wind Waves. — A slight wind disturbs the surface of the sea, causing ripples to start on the water. Thus the surface rises and falls as one ripple succeeds another, passing in the direction toward which the wind is blowing; but an object floating in the water does not move along as fast as the tiny wave does. From this it is seen that the wave is not a *bodily* forward movement of the water, but a disturbance of its surface, just as a series of ring waves move outward in all directions from the centre, when a stone is thrown into the water. The wave form consists of two parts, an elevation and depression, the top or elevated part being called the *crest* of the wave, while the depression between two crests is called the *trough*.

The cause of the wave is the friction of the wind on the water, just as we may raise a tiny wind wave in a basin of water by blowing over its surface. This friction not only causes the water to rise and fall, but it really does drive a very small amount forward, so that a floating body not merely rises and falls as the wave passes under it, but actually floats slowly forward. This surface movement of the water constitutes a gentle current, a *wind drift*, at the very surface. Therefore everywhere that wind is blowing over water, there is a gentle current moving slowly along before the wind.

If the wind continues, and especially if it freshens, the waves become higher, for the cause is increased because then there is more friction.[1] In addition to this, the height of the wave is increased as one wave catches up with another, so that two combine to form one higher than either of the others. This increase may continue until waves reach "mountainous height," which is an exaggeration due to the great apparent height of the wave seen from a small ship.[2]

When a wind wave attains these dimensions, its effect is felt to a depth of 200 or 300 feet, and it then becomes such a powerful movement of the water that it may last for a long time after its cause has disappeared. If one throws a stone into the water, the ripples which it starts extend perhaps for scores of feet, and gradually die out; and so it is with the great ocean waves. Not uncommonly, on a perfectly calm day, when the water surface is smooth and glassy, it heaves with great *swells* or *rollers*, which have originated in some distant part of the sea, and have passed far beyond the place in which they were formed.

In the open ocean the waves are usually doing little work excepting to cause the surface to rise and fall. Vessels pass over them, being lifted and lowered as the waves pass by, but not being injured, excepting rarely, when in violent gales the surface of the sea is lashed into a broken mass of whitened wave crests between deep,

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[1] This may be illustrated by blowing gently on the surface of the water in a basin, and then blowing with much greater force.

[2] Large ocean waves rarely rise more than 20 or 30 feet from trough to crest, but some have been measured which rose 46 feet, and it is believed that some reach the height of 60 feet from the lowest point of the trough to the highest part of the crest. Those having a height of 40 or 50 feet travel as much as 45 miles per hour, and the distance from the crest of one wave to that of another may be over 700 feet; but one may travel on the sea for a long distance without finding such huge disturbances.

narrow troughs. Then small vessels, tossed violently about, are sometimes foundered, and larger ones at times seriously damaged. When they come to the coast, the waves change their habit, and dash upon the exposed shores with resistless fury.

On the coast the wave form is destroyed, for as the water becomes shallower, the great waves have their movement interfered with, and the motion of the bottom part is partially checked as it comes in contact with the sea floor. The upper portion of the wave, being less checked in its movement, progresses, so that as a result of this the crest gradually changes, first becoming steeper on the land side, and then falling forward in the form of a *breaker*, which rushes violently upon the coast, no longer as a mere wave movement, but as an onward flood of water, furiously hurled against the coast. Upon the beach the surf rushes far above the average water level; and against the cliffs the waves strike a blow which causes the rocks to tremble, and sends a roar through the air, while the spray dashes high upon the coast.

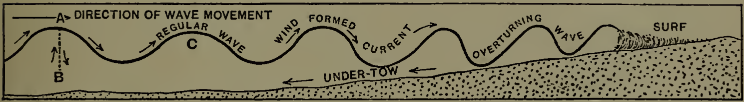

FIG. 99.

Diagram to show approach of a wave upon a beach.

During these times of violent waves there is great work of destruction being done. The sand of the beach is washed backward and forward, or the pebbles are rolled about, causing a deafening roar as they are ground together. This constant grinding wears them slowly away, rounding them and finally reducing them to bits of clay or sand.[1] The beaches are the mills in which the rock fragments, driven ashore by the waves, or wrested by them from the rocky headlands, are ground to form the sediment which is being strewn over the ocean bed. The violent waves not only work here, but also against the cliffs of hard or soft rock, which they are also wearing slowly away. Sometimes the power of the waves becomes so great, that blocks tons in weight are wrested from their beds and moved along the coast.

But if the waves merely *destroyed* the coast, they would soon lose their power to cut into the land, for as the cliffs crumbled, and the débris accumulated at their base, they would be protected from further attack, and the waves would expend their energy on the fragments which they had wrested from the land. Some of these must be *removed*, so as to leave the cliffs open to the further attack of the waves. As the boulders and pebbles are ground to pieces by the waves, particles are worn off which are so fine that they can float away in the moving water. The tidal currents help in this removal, and so also do the wind-formed currents of surface water which move before the winds.

Then also, when the waves come upon the coast diagonally, as they often do, the surf, instead of running directly along the coast, passes not only *toward* the land, but for some distance *along its margin*, so that as wave follows wave, the sand and pebbles are washed along the shores in the surf. Fragments are thus carried over con-

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[1] So rapid is this work of destruction that bricks which have been washed ashore upon the beach, are ground to tiny pebbles in the course of a few years.

siderable distances in the direction toward which the waves move. Also when the waves run upon the beach in the form of surf, the water must return to the sea. This return movement, which begins when the wave has worn itself out against the shore, and is interrupted when the next wave comes, continues below the immediate surface in the form of a current along the bottom. This, which is known as the *undertow*, is an outward-moving current, flowing with such force that bathers are sometimes caught in it and drawn down and held near the bottom until life is extinct.[1]

By these several means the particles which the waves take from the coast are slowly ground up and carried away, some out to sea, where they settle in the more quiet water, and some along shore, until an indentation is reached, where, being driven into the more quiet water of the protected bay, it settles to the bottom. While it is necessary for much of the material to be carried away, in order that the waves may continue their attack upon the land, it is also important that some fragments should also remain in their grasp; for the work of the waves is made effective, not so much by the direct action of the water, as by the battering of the pebbles and sand which they hurl against the shore. These are the tools with which the wave does its work.

This attack of the waves produces different results according to their violence, the exposure of the coast, its form, or its rock structure; and it is performing a great work of change, as a result of which the coasts of the

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[1] When swimming in the ocean surf it is necessary to keep near the surface, and if the feet are allowed to sink toward the bottom the entire body may be drawn under.

world are not only varying in outline, but are being constructed into certain definite forms. The study of these changes may be deferred until we have gained a little more knowledge of the land (see Chap. XVIII).

The Tides:[1] *Nature of the Tides.* — In most parts of the ocean the water surface rises twice each day. The water slowly advances, and a person standing upon the coast is driven from his position as it rises. Then for a little more than 6 hours, it retires as slowly as it came, when it again begins to rise; and this is repeated again and again, so that every 12 hours and 25 minutes there is a high tide, with low tide between. The rising tide is called the *flow;* the falling, the *ebb.* If one watches the tide with care, he sees that it does not rise to the same level day after day, but that there is considerable difference in its height.

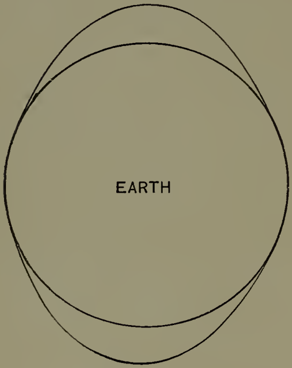

Fig. 100.

Diagram to illustrate the distortion of the ocean by the attraction of the moon, the distortion being of course greatly exaggerated.

Again, from one place to another there is a variation in the height to which the tide rises. At Key West, and on oceanic islands, the rise is only 2 or 3 feet; in Hudson Straits, north of Labrador, it reaches an elevation of 30 feet; in parts of the Bay of Fundy the high tide is often 30 or 40 feet above the low, and in

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[1] From necessity this subject is treated briefly here. The teacher who wishes to expand the subject will find some material for this in my *Elementary Physical Geography*, as well as in other books.

some places is said to reach 50 or 60 feet. In Ungava Bay, in the northern part of the Labrador peninsula, the tide rises about as high as it does in the Bay of Fundy.

Causes of Tides. — From an examination of the tides it is evident that they are waves of rising and falling water, and we know that all ocean shores are disturbed by them. The tides reach greater height in V-shaped bays than on exposed oceanic islands, and this is evidently due to the influence of the land. When a wind wave approaches the beach, it is caused to change its habit and to reach higher than the natural level of the sea. It is piled up; and so is the tide wave as it enters the narrowing bay.

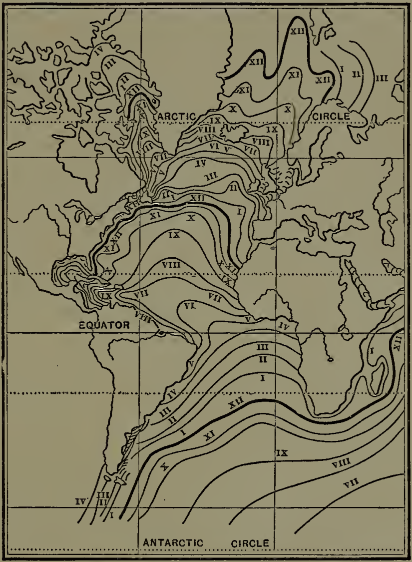

Fig. 101.

Diagram to show advance of tidal wave in the Atlantic. Figures represent hours of the day; heavy lines, noon.

If we observe the variation in height of the tide at any single place, we find that its change corresponds with the variations in the phases of the moon, and this would lead us to believe that in some way the tide is caused by the moon.

The moon, the nearest of the heavenly bodies, is at all times exerting a pull upon the earth, just as this is upon the moon. This pull is the attraction of gravitation, by which the bodies of the solar system are bound together, and it is something like that which holds the air to the earth and causes a stone to fall to the ground. If the moon and earth could cease revolving, they would come together as certainly as a stone will fall to the earth if it is dropped from the hand. Therefore the moon is endeavoring to draw the earth toward it, and to a slight extent is really succeeding in drawing the liquid part of the earth. Therefore a wave is raised in the ocean, and as the moon passes through the heavens, the tide wave follows it. By this attraction one wave is formed under the moon, and one on the opposite side; but they do not pass around the earth *directly under* the moon, for they lag behind, and hence follow it.

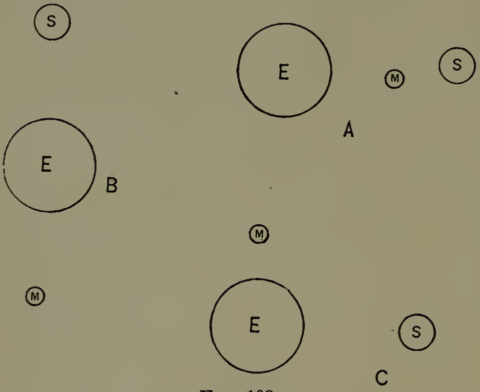

FIG. 102.

Three diagrams to show (A) the sun, earth, and moon in line at new moon; (B) the same at full moon; and (C) the moon and sun in opposition during the quarter. In the first two cases the waves of moon and sun are formed in about the same place; but in the third they are formed in different places and hence the tidal rise is less.

What the moon is doing in this respect, the *sun* is also doing; but this body, though much larger than the moon, is so much further from us that its influence is less, because the attractive force varies not only with the mass of the body, but also with its distance. Therefore four waves are formed, the two larger ones by the moon, and two much smaller waves by the sun. At new and full moon, the sun, earth, and moon are nearly in line, and then both the lunar and solar tides are raised in about the same place. Then the two combine to form a larger wave than usual, giving the *spring* tide. When the moon is in the quarter, the sun and moon are exerting their influence in directions nearly at right angles to one another, and the two waves are therefore somewhat in opposition, so that a lower or *neap* tide is caused. Therefore, as the phases of the moon change, the height of the tide varies.

There are other causes for variations, one of the most important being the difference in distance of the moon. This body travels around the earth once in a lunar month, not in a circle, but along an elliptical path with the earth at one of the foci. Therefore at one part of the lunar month, the moon is much nearer than at the other times. When nearest to us the moon is said to be in *perigee*, and when furthest in *apogee*. The attraction varies greatly with the distance of the body; and hence when the moon is in perigee, the tide is made high, particularly if the moon is full or new.[1]

Effects of the Tides. — Sometimes the tides, instead of being merely the rising and falling of water in true wave form, become real *currents*. Then navigation is checked or aided, sand and clay are drifted about, bars are formed at the mouths of harbors, and the waves are

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[1] An especially valuable lesson in tide variation may be given by a careful study and plotting of the tide height at various places, as given in the *Tide Tables for the Atlantic*, published by the United States Coast Survey, Washington, D.C.; price 25 cents.

aided in moving the sediment either along the coast or else out to sea. These currents are caused by the approach of the wave over the shallow bottom, in a manner similar to the approach of the wind-wave surf on the beach. As the tide rises, the current moves one way, and the outgoing tide in the opposite direction. Sometimes these tidal currents are so strong that navigation is impeded, and oftentimes it is impossible to row a boat against the current. In parts of the Bay of Fundy, where the tide rises to such great height, the currents or *races* become as violent as a rapid river current, and it is unsafe to attempt to navigate these waters unless one is perfectly familiar with all the peculiarities of movement. There the tide, advancing over the low mud flats, moves as rapidly as a man can run.

There are many special causes for these currents. Sometimes the tide rises higher on one side of a peninsula than on the other, and then, if there is a strait between the two bays, with the rising and falling tide the water moves backward and forward through it. Again, after passing through a narrow arm of the sea, the water may enter a broad bay; and then, when the tide falls, this great mass of water rushes out through the narrow channel with the velocity of a river. On the other hand, the tide may sometimes lose its height and velocity, when after passing through a narrow entrance it reaches a broad sea, as the tide wave does after passing through the Strait of Gibraltar into the Mediterranean, where there is almost no rise and fall of the tide.[1]

This silent and regular rising and falling of the ocean surface is one of the most interesting features connected with this great expanse of water. On the open sea one might travel for thousands of miles, never knowing of its existence; but along the land margin it becomes very apparent and important.

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[1] Here, however, a separate tide of small size is generated by the same cause which makes the great ocean tidal waves. In fact, even in large lakes there are slight tides of this origin, besides the more irregular fluctuations of the surface due to winds and changes in the air pressure, and known under the name of *seiches*.

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Diagrammati

6.

ocean currents.

Ocean Currents: *Differences in Temperature* — When speaking of the temperature of the sea (Chap. XII), it was stated that there are reasons for believing that there is a circulation in the ocean, consisting of sinking water in the colder latitudes, and rising in warmer belts, with bottom currents moving toward the Equator, and surface movements away from it. This conclusion seems necessary as a result of the fact of greater warmth in the one place than in the other, and there are other facts pointing to the same conclusion. The temperature of the deep sea can be accounted for only on this explanation. Moreover, if there were no such circulation, how could the deep-sea animals obtain the oxygen which they need? If the waters were quiet, these creatures would have no source for this necessary element; but a slow circulation along the bottom, supplied from the surface, would furnish it.

On this theory the ocean is somewhat like the air, and the great movements of ocean currents are similar to the circulation of the atmosphere; but there is one very important difference: the air is warmed from below, and being made lighter near the ground, rises in the warmer belts, while it cools and settles in the colder regions. But the sun's heat does *not reach* to the bottom of the sea, and the warming of this is therefore confined to the surface layers; hence the comparison with the air is not strictly correct. There are actual movements of the ocean similar to those which this theory demands, but they seem to be more powerful than this cause alone could produce; and although nearly every one believes that differences in temperature cause a *slow* circulation of cold water along the ocean bottom, and aid in the production of some of the currents at the surface, another explanation seems to be necessary for the more powerful of the surface currents. Before stating this theory let us look briefly at the actual conditions of oceanic circulation.

Atlantic Currents. — For illustration of these ocean movements we may select the north Atlantic, in which the ocean currents are as well developed as anywhere, and much more carefully studied.[1] There is a slow circulation of the sea, both north and south of the Equator, moving toward the belt of calms in the direction followed by the trades, — that is, southwest on the northern side of the Equator, and northwest to the south of it. In the doldrums, between the trade-wind belts, this drift of water moves westward until the coast of South America is reached, where it divides into two unequal parts, the larger journeying northward along the northern coast of South America, the smaller southwards. The former passes as a slow *drift* of water, partly into the Caribbean, partly between the West Indies, and partly outside of these islands in the open sea. The latter, turning to the right under the influence of the earth's rotation, circles eastward, then southeastward, and finally, passing along the coast of Europe and northern Africa, again comes within the zone of the trade winds. Hence it circles around, forming a great eddy of slowly moving surface water, and this is found in all the oceans that are crossed by the Equatorial belt, turning to the left in the southern seas and to the right in the northern.

That part of the *Equatorial drift* which passes into the Caribbean Sea, circles through it, becoming warmer, enters

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[1] Although some of the conditions on the ocean bottom have been investigated, it has not been found possible to determine the *rate* of movement of the cold bottom water.

the Gulf of Mexico, and passes out of it between the end of Florida and Cuba, where it emerges as the *Gulf Stream* (Fig. 103). This current, flowing rapidly at first, as a narrow stream, loses velocity as it passes along and becomes broader. Off the Florida coast it is a distinct stream in the sea, flowing at the rate of four or five miles an hour; but by the time the latitude of Cape Cod has been reached, its velocity is reduced to less than two miles an hour. For a while it flows near the American coast, then, about in the latitude of Cape Hatteras, it slowly turns to the right, leaving the American shores and crossing the Atlantic to Europe, being deflected in this direction by the earth's rotation. Against the European coast it divides, some turning southwards toward the Equator, and some going northward past Scandinavia into the Arctic.[1]

FIG. 103.

Diagram to show the currents of the eastern north Atlantic. Figures tell rate of movement in miles per hour.

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[1] Nansen has proved that there is a current in the Arctic from the northern shores of Asia to the region between Greenland and Spitzbergen.

In the north Atlantic there is a cold current called the Labrador current, flowing from the Arctic. This comes down from the north, between Greenland and Baffin Land, past Labrador, and as far as New England, where it disappears in the Gulf of Maine.[1] It hugs the American coast closely, being turned to the right by the deflective effect of the earth's rotation.

Aside from similar currents in the several oceans, there is a drift of water in the southern hemisphere, south of Africa, South America, and Australia, where the water moves in the direction followed by the prevailing westerlies. These movements constitute the great ocean currents of the globe, and as a result of them the waters of the sea are almost constantly in motion in certain definite directions.

The Explanation. — It will be noticed that where they start, the currents have the same directions as the prevailing winds,[2] and this is believed by many to be the most prominent cause for the surface ocean currents. Water is always drifted before the wind, and small currents of this origin may be seen along the coast, not only in the ocean but in many lakes. Drifted along, turned by the land, and by the effect of rotation, the water circles through the seas, giving the great oceanic circulation.

No doubt there is also a great but slow movement caused by differences in temperature; but this seems to be a less important cause for surface currents than the winds.

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[1] The gulf enclosed between Nova Scotia and Cape Cod.

[2] The Labrador current is possibly started by the north winds, but probably is a partial return of the water that is sent into the Arctic by the Gulf Stream, and the fresh water that enters the Arctic from the great north-flowing rivers of Asia and North America. Even the Gulf Stream is aided in crossing the Atlantic by the prevailing westerlies.

There are several reasons for this conclusion, but the most prominent one is, that the ocean currents are less pronounced in the southern than in the northern oceans; yet southern oceans are open to the cold Antarctic, while those north of the Equator are more nearly closed to the cold Arctic waters; and particularly is this true of the north Pacific. If the oceanic circulation is chiefly due to differences in temperature, it should be most pronounced in the southern oceans, where there is a greater chance for this difference to express itself; but the reverse is true.

Effects. — Ocean currents are chiefly important in modifying the climate. By them the ocean itself, and the neighboring lands, are made either warmer or cooler. The currents do not cut the shores as do the waves, nor are they moving rapidly enough to carry much sediment, as are some of the tidal currents; but they are performing a great work in nourishing large numbers of marine animals, which float in these waters, and which furnish food to the larger animals. The warm ocean currents are food bringers for the colonies of corals which exist in the warmer portions of the ocean, and they therefore *aid* in the building of many lands in the sea. The Bahamas, the Bermudas, the southern end of Florida, and the multitudes of islands in the south Pacific, are coral islands made from the skeletons of creatures nourished in the warm water of the ocean currents.

PART IV.—THE LAND

CHAPTER XIV

THE EARTH'S CRUST

Condition of the Crust.[1]—Nearly everywhere at the very surface of the land there is a soil covering, beneath which, at depths usually not more than a few feet, though sometimes 200, 300, or even 400 feet, there is solid rock, and this continues to as great a depth as man has pene-

FIG. 104.

A rock made of horizontal layers of different kinds.

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[1] At this point I would suggest a review of a part of Chapter I, particularly pages 7–13.

trated into the crust. These rocks are of many different kinds, and when seen in a river gorge, or any other cutting, they are usually found to be in layers, and in many cases these are arranged one on another, generally in horizontal beds (Figs. 104, 136, and 139), but sometimes in layers tilted at various angles (Chapter XIX), perhaps even vertically. Some of these are made up of fragments, such as grains of clay or sand, some of shells of animals, forming limestones, and some are made of distinct minerals, and these are called *crystalline* rocks.

Minerals of the Crust:[1] *Elements.* — When subjected to chemical analysis, it is found that in any rock there are certain elements.[2] Chemists have so far discovered about 70 elements, but only a very few are really common in the earth, the three most abundant being oxygen, silicon, and aluminum; and the others, that are less abundant, though still important in the crust, are iron, calcium, magnesium, potassium, sodium, carbon, and hydrogen. Oxygen forms 47% of the earth's crust, silicon 27%, and aluminum 8%, so that these three constitute about 82% of the known rocks of the earth's crust. In many of the

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[1] No attempt can be made here to treat the subject of mineralogy. A very good elementary book is Dana's *Minerals and How to Study Them;* and in his larger works will be found a more complete treatment. The only way for students to really understand minerals is to examine them and study their characteristics from actual specimens. I would suggest the introduction of some simple laboratory work in the study of minerals, preferably taking up only a dozen or twenty of the most common, which are selected not so much for crystal perfection as to show the other characteristics.

[2] An element is the simplest form to which man has been able to reduce matter. Gold, for instance, cannot be made simpler, nor can mercury, nor the oxygen of the air; but each of these may be made to combine with other elements to form some *chemical combination.*

rocks, such as those made of clay, the elements are often in complex and indefinite combination; but frequently they are present in distinct combinations, known as *minerals.*

Definition. — A mineral may be defined as a *homogeneous solid of definite chemical composition, occurring in nature, but not of apparent organic origin.* There are perhaps 2000 minerals known, but most of them are so rare that they are found only in the larger mineral collections. One or two hundred may be considered fairly common, but less than a dozen are really important in the rocks.

Quartz. — By far the most abundant of these is *quartz*, a mineral composed of the two elements silicon and oxygen (SiO_2), and found in all granites and sandstones, as well as in many other rocks and most soils. It is so hard that it cannot be scratched with a knife, and it will cut glass. Very often it is found in perfect crystalline form, being bounded by smooth glassy planes, which form a six-sided prism, while on one end, or perhaps on both, there are hexagonal pyramids. More commonly the quartz crystal is less perfect, and in fact most of the quartz of the world occurs in grains, generally of small size.

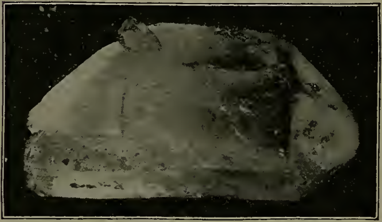

Fig. 105.

Quartz crystal, showing three of the prism sides and three of the pyramid faces.

Quartz may be told from the single grains of other common minerals by its hardness, and by its glassy surface, which reflects light as glass does; and for this reason it is said to have a *glassy lustre.* It resembles glass also in its fracture, for when it breaks it has a shelly, rounded surface quite like broken glass. This is called the *conchoidal* or *shelly fracture*. Being hard, quartz tends to make rocks durable, for it is not easily ground down by the agents which are cutting rocks (Chapter XV). It is more durable than other minerals for another reason,—when exposed to the air it does not change and crumble, as some minerals do, but throughout all the attacks of the weather remains pure, clear quartz. Quartz, when compared with the mineral next described, is about as gold is to iron. In the air gold remains fresh, but iron soon rusts and becomes soft. Quartz is also slightly soluble, and the water flowing over the land always carries small quantities of it; but in this respect it is much less soluble than calcite, and more so than feldspar. Therefore in most respects this is a very durable mineral.

Feldspar. — This mineral is another exceedingly important component of the crust. With quartz it occurs in granite, and this rock is chiefly made of these two minerals. Feldspar sometimes occurs in crystals, though much more rarely than quartz. When it is found in grains together with quartz, the two can generally be told apart by the fact that feldspar is duller and whitish, and has a much less glassy lustre. Besides this, a fractured piece is found to be smooth, like the side of a crystal. This is because the mineral is cut by many minute planes, extending parallel to one another, which are known as *cleavage planes* (Fig. 106); and when the mineral is broken, it splits most easily along these planes. Therefore, although nearly of the same hardness (quartz being a little harder), these minerals may be easily told apart.[1]

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[1] Excellent observation lessons may be given by means of small chips or pebbles from a stone yard or stream bed.

Although nearly as hard as quartz, and not a soluble mineral, feldspar is not nearly so durable. This is because when exposed to the air it slowly changes and gradually crumbles. Really fresh feldspar is glassy and looks quite like quartz; but this kind of feldspar is not common excepting in recently cooled lavas, in which there has not been time enough for change. The dull opaqueness of most feldspar is due to the beginning of this change; and when it has gone far enough, the formerly hard mineral is changed to a crumbling clay or *kaolin*, just as hard iron or steel may rust to a soft, yellow, clayey mass. Air and water cause many changes among the minerals, and hence they slowly crumble when exposed to the action of these agents. Since feldspar is so easily altered, it is an element of weakness in any rock.

Fig. 106.

A piece of calcite, showing cleavage faces and cleavage cracks.

Calcite, another common mineral, forms the marbles and limestones, and is present in small quantities in many other rocks. It illustrates still other mineral properties. Like feldspar it has cleavage, but this is much more distinct in calcite, and one can rarely find a piece of it in which the smooth, shiny cleavage faces do not appear.[1] In color it varies greatly, as do the minerals described above. While quartz and feldspar cannot be scratched with a knife, calcite is easily cut. Moreover, unlike these two minerals, it is *readily*

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[1] For instance, in the white marble used for monuments in cemeteries.

carried in solution, and the water of the land and sea always carries it.[1] One may see the proof of this by visiting a cemetery in which the stones have stood for some years. The surface of the marble headstones is often etched by the rain, and sometimes the inscriptions are nearly obscured.

When exposed to the action of the air, calcite does not change or decay, though it may be carried off in solution; but if water bearing some acid comes in contact with it, a chemical change immediately takes place, and the calcite slowly disappears. What happens then may be seen on a very much more extensive scale, by placing a bit of calcite or marble in a weak solution of hydrochloric, or other acid, when an effervescence begins and carbonic acid gas escapes, until finally the calcite is entirely gone. Because this mineral is soft, easily dissolved, and changed when acids come in contact with it, rocks that are made of calcite are not nearly so durable as those made of quartz or feldspar, or of these combined.

There are numerous other important minerals in the rocks, but the three above mentioned, together with the clays, etc., which have been formed from their destruction, constitute considerably more than one-half of the earth's crust. The other more common rock-forming minerals are the micas, some of which are colorless and others black, while all are characterized by a remarkable cleavage; hornblende and augite, dark brown, green, or black minerals; and some of the compounds of iron, which give the red and yellow colors to soils and many rocks.[2]

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[1] It is this which makes it possible for animals to build shells.

[2] The study of these and a few other minerals, in which each student is expected to handle the specimens and determine the lustre, cleavage (if present), fracture, color, hardness, crystal form (if present), specific gravity, etc., will be of great disciplinary value, particularly if in studying mineral specimens, some of the crystalline rocks are furnished them to study and to identify the minerals of which they are made.

Rocks of the Crust: *Igneous Rocks.* — Rocks like those found on the land are even now forming on the earth's surface. Whenever a volcano breaks forth in eruption, and lava flows out at the surface, a new rock is being added to the crust, and at all times in the past, similar lavas have come from within the earth, and upon cooling have formed hard rocks (Chapter XX). Upon the flanks of Vesuvius and other volcanoes, we find such lavas which have recently cooled; and in former times, volcanoes existed and sent forth molten rock in parts of the earth which are no longer the seats of eruption.

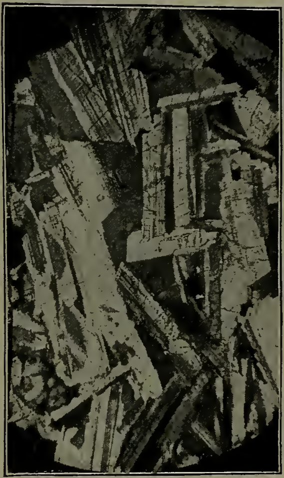

Fig. 107.

Section of diabase (Plate 17) enlarged under the microscope, showing the minerals.

If we examine a solidified lava, either one that has just cooled, or one that was formed long ago, we find that it is made of minerals, though the mineral grains may be so minute that none can be distinguished by the eye. (Compare Plate 17 (diabase) and Fig. 107.) The minerals that are most common in these beds are feldspar, quartz, hornblende and augite, and the grains vary greatly in size. When the lavas are melted, they are made of elements which are not definitely combined; but as they cool, and begin to form hard rock, these elements come together and form definite compounds, or minerals, somewhat as salt crystals are produced when a solution of hot salt water is cooled. If the lava cools very slowly, the

Facing page 227.

PLATE 17.

Specimen of fine-grained igneous rock (diabase) on left, coarse-grained igneous rock (granite) in middle, and banded gneiss on right.

crystals have time to grow to large size (Plate 17); but if the cooling is rapid, they may be so small that the unaided eye cannot distinguish them; and indeed the rock may even become a glass, like obsidian, in which even the microscope cannot detect crystal grains.

Some lavas which are thrust *into* the earth, and which have not reached the surface, have cooled so very slowly that the mineral grains have all grown to good size. This is the origin of the granites (Fig. 108); and such a rock is seen at the surface only when the layers beneath which it was formerly buried have been removed by the agents that are always at work wearing away the crust (Chapter XV). Not only are there these differences in *texture*, but some lavas are porous, others dense, and in fact some are so porous, that like pumice they will float on water. The pores are caused by the expansion of steam in the cooling lava, for all of these molten rocks contain water. There is also a difference in *chemical composition* of the lavas, and hence in the *kind* of minerals which grow as they cool. As a result of this, some rocks contain quartz and others have none of this mineral, some have hornblende, some augite, etc. As these differences occur there is a variation in the color, some being black and some nearly white. In accordance with these differ-

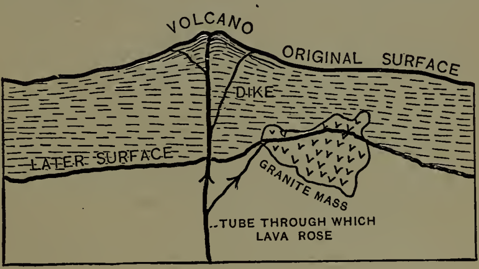

FIG. 108.

Diagram to illustrate the way in which granite is thrust into the earth and later reached.

ences the *igneous* rocks (those formed from the cooling of lava) are classified and given different names.[1]

Sedimentary Rocks. — When exposed to the air, lavas and all other rocks are subjected to changes, resulting from the decay of some of the minerals (like feldspar, augite, and hornblende), the solution of others, and the breaking up of the grains by action of frost, etc. (Chapter XV), so that in the course of time the rocks slowly crumble. As a result of this, there are quite different products of the changes in such minerals as feldspar. New chemical compounds are produced, some being soluble and others insoluble. The former may pass off in the water, which is always sinking into the ground, but the latter remain behind, generally in the form of fine-grained clay, like kaolin. A third product is the *unchanged* mineral, like the grains of quartz. All of these, taken by the water which flows over the land, find their way into the rivers, then from these either into lakes or the sea. Here the waves take the fragments, adding other substances which they themselves rasp from the coast, and strew them over the bed of the sea near the land. The beds of rock thus formed are called *sedimentary*, and upon the land there are great areas of these, which were once formed in the sea, but are now raised above it.

The soluble substances, like salt, gypsum, or carbonate of lime, may in some rare cases, as for instance in salt

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[1] It is impossible to introduce into this book a more complete statement concerning these rocks; in fact it would not be profitable to do so unless the student were supplied with specimens for individual study. This form of laboratory work I would strongly urge. A more complete statement about the rocks of the crust is contained in my *Elementary Geology*, where the teacher will find the necessary information concerning kinds of rocks, names, places where specimens may be purchased, etc.

lakes, be precipitated from a saturated solution, forming layers of *chemically deposited rock.* There are salt and gypsum beds in the west which have been formed in this way;[1] and in some of the salt lakes of the Great Basin of the west, beds of carbonate of lime are even now being precipitated. Or the carbonate of lime may be taken from the water by animals and built into their shells, which later gather into layers of carbonate of lime, forming limestone. The Globigerina ooze and the beds of coral limestone, which are accumulating near coral reefs, are instances of these rocks, which are known as *organic* sedimentary beds. Coal is another illustration of this class; but in this case the beds are made of plant fragments which have taken substances from the air, as well as from the water of the ground. In every tree there are mineral substances, and it is these which form part of the wood and coal ash.

FIG. 109.

A pebble bed, a part of a beach formed in the coal or Carboniferous period, now exposed at Cape Breton Island, Nova Scotia.

But by far the most important group of sedimentary rocks is the *mechanical* or *fragmental*, which are made of rock fragments of all kinds, which the waves and currents have carried and deposited in layers or *strata* on the sea bed. These fragments vary in size from the very finest clay to coarse pebbles and even boulders. Sometimes, when the waves are very strong, the *latter* may be carried;

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[1] This is the origin of many of the beds of rock salt which are now mined.

but later, when the sea is more quiet, only the smaller fragments can be transported. Near the coast line, where the waves are violent, the deposits are of coarse pebbles or sand (Fig. 110); but in quiet bays, and far out to sea, the finer clay, which can no longer be kept afloat by the currents, settles to the bottom and forms beds of clay. Therefore among these rocks there is a variation in texture from pebble beds to clay rocks; and the members of this group are named upon this basis, the pebble rocks being called *conglomerates* (Fig. 109), the sand beds *sandstones*, and the clay layers either *claystones* or *shales*. Like the lavas, the fragmental rocks are unconsolidated when first formed; but as they are not hot they do not become solid by cooling. When found upon land these strata are generally in the form of hard beds; and by examination it will be found that the grains of which they are composed are held together by a *cement*, somewhat as we may cause sand grains to cling together by means of mucilage. The cement of these rocks is deposited from solution by the

Fig. 110.

A sand beach, pebbly at one end, Cape Ann, Mass.

water which is percolating between the grains. The most common rock cements are silica, carbonate of lime, or some salt of iron, — substances which are being carried in solution by most of the water which is flowing over the surface of the earth, and sinking into the ground. Sometimes the cementing has only gone far enough to cause the grains to adhere very slightly, but more often a hard and very dense rock is formed by means of this cement. This process of cementing may often be seen in gravel beds and on shell beaches, like those of Florida, where the shell fragments which are thrown up by the waves, soon become transformed into a rock called *coquina* (Fig. 111), which is used for building houses in these regions. Between the clay or sand bed and the solid rock there is every gradation.

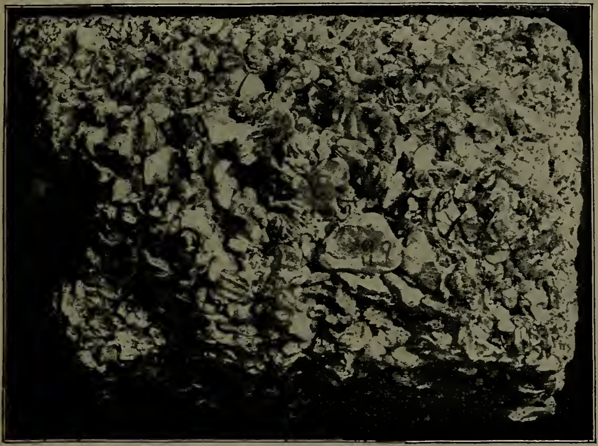

Fig. 111.
A specimen of coquina.

Metamorphic Rocks. — Igneous rocks are made of minerals which are fine crystals, and always have a crystalline structure, though sometimes not possessing a perfect crystal outline. The chemically deposited sedimentary rocks are also frequently crystalline; but the sedimentary beds proper, when first formed, are made up of *fragments* of minerals, and are *not crystalline.* However, the rocks of the crust of the earth are subjected to many changes. The water passing through them alters them so that beds of shell may become crystalline calcite; or the heat of a lava mass passing through the rocks, or the heat which exists in the earth, may also cause change. Besides this, among mountains the strata are often folded, and sometimes even crumpled (Fig. 113), as we might crumple sheets of paper; and this also causes heat and change. The heat results from the friction of the rock particles as they glide over one another during the folding, as we may warm two rocks by rubbing them together, or by pressing them against a grindstone that is revolving.

From these various causes a third great class of rock beds is formed, to which the name *metamorphic* is given. These resemble the igneous in being crystalline, and some of them look quite like granite. Here however, the minerals have been formed *not* by melting, but by some change, or metamorphism, in which heat and heated water have caused minerals to change in kind and form. The limestone becomes a *marble*, the clay rock a *slate*, and perhaps even a *schist;* and metamorphism may produce a coarse-grained granitic rock, called *gneiss* (Plate 17). These metamorphic beds are much more common in mountainous regions than elsewhere, because here the cause for heat has been more pronounced. They exist over great areas in Canada, New England, the highlands of New Jersey, etc.

Position of the Rocks. — Lavas may exist in any position, but they are commonly found either in nearly horizontal beds or in steeply inclined sheets (Figs. 108 and 112). The reason for this is evident; for they come from deep within the earth, and cut through the rocks nearly vertically in reaching toward the surface, where if they come to the air, they flow out over the land in nearly horizontal sheets, as any pasty liquid would. These may later be buried beneath other rocks, or the wearing away of the crust may reach down to a buried lava mass. The sheets that cut *through* the strata are called *dikes* (Figs. 108 and 112); and in every eruption of Kilauea, in the Hawaiian Islands, dikes are formed on the flanks of the volcano, as the lava wells out from a fissure and flows down the mountain sides (Chapter XX).

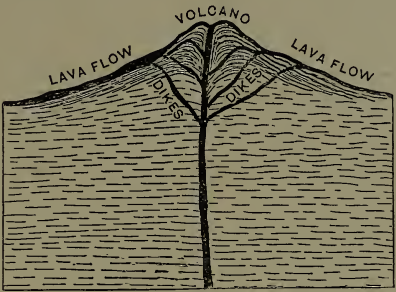

Fig. 112.
Diagram showing a volcano in cross section.

In the sedimentary rocks the *original condition* is nearly horizontal beds of different kinds. Great sheets of sand or clay are formed over the bed of the sea, and the grains settle to the bottom, forming layers parallel to it, which are nearly horizontal, because this is the outline of the greater part of the ocean floor (Chapter XII). The layers vary in kind and in texture, for as time elapses there are many changes. The currents vary, the velocity of the waves changes, and the very level of the land fluctuates. These changes in conditions may cause the deposit first of a sheet of clay, then of sand, then another of clay, then one of limestone, etc.; and these layers may be thin seams (or *laminæ*) or great *beds*. These variations in kind of rock produce *stratifica-*

Fig. 113.
Crumpling of rock.

tion, and the different beds are called *strata* (Figs. 104, 136, and 139). This difference of stratification is one of the most characteristic features of the sedimentary rocks, which in consequence are often called *stratified*. When raised into a dry-land condition, these beds are most commonly so uplifted that they still remain nearly horizontal, as in the great Mississippi valley between the Appalachian and Rocky Mountains; but sometimes they are folded, as in the case of these mountains (Chap. XIX).

Metamorphic rocks also vary in position, for very often they are altered beds which were originally stratified into layers of different texture and composition; but they are rarely horizontal, for they have been metamorphosed as the result of changes in which folding has been of importance. Indeed, the metamorphic rocks are usually most complexly bent and twisted (Fig. 113); for when, by the movement of the earth's crust, these contortions of the rocks occur, they are so folded and changed that they are no longer sedimentary or igneous, but become members of the metamorphic group.

Movements of the Crust. — The study of the rocks proves that the earth's crust has been in movement in the past. On the land, even on the tops of mountains, there are strata which are the same in kind as those now gathering on the sea floor; and in them are found entombed the shells or skeletons of animals that once lived in the sea. Hence these rocks tell us that the land where they now exist was once a sea bed, and that then there came an uplift, as the result of which they have been raised perhaps as much as 10,000 feet above sea level. Sometimes this uplift has been such as to leave the rocks still in horizontal sheets; but in other places the strata have been folded and broken, especially among mountains (Chap. XIX).

Not only has the crust of the earth been in movement in the past, but it is *even now* changing position. During the earthquake shocks in 1835 the land on the coast of Chile was lifted four or five feet, and during many earthquakes similar movements have occurred in other places. The shores of Baffin Land have risen so recently that pebble beaches formed by the waves, and now lifted above the sea level, have not been exposed to the air long enough to have been covered with moss and lichen growth. There is *historical* proof of change in level (rising) of the coast of Hudson's Bay; and on the shores of New England and New Jersey, tree trunks now standing below sea level show a recent sinking. On the coast of Sweden part of the land is slowly rising and part sinking, as has been proved by careful measurements made under the supervision of the government. Scores of similar instances might be introduced to show that the crust is rising here and sinking there; and from equally conclusive evidence geologists have proved that in the past, these changes, occupying long periods of time, have produced not only the mountains of the land, but even the continents.

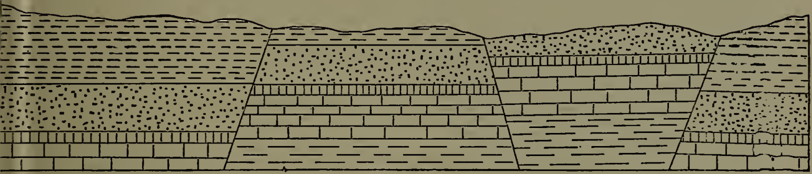

FIG. 114.

A section of horizontal rocks showing three fault planes.

When the rocks thus moved are disturbed very much from their horizontal position, they either bend or break. When breaking, they may move only a few inches, or perhaps thousands of feet, along the plane of breaking, or *fault* *plane* (Figs. 114 and 115). Faults are very common among mountains, and in fact some mountainous elevations are caused by them, the broken blocks being raised and tilted. In folding there may be an up or a down fold (Fig. 116), the former being called an *anticline*, the latter a *syncline;* and while these are sometimes very symmetrical, they are often irregular, and sometimes they are even in the form of overturned folds. In fact, the folding of rocks may proceed so far, that as among the metamorphic series, the beds are actually *crumpled* (Fig. 113). In an anticline the rocks dip in two directions away from a central *axis;* but there is a fold, the *monocline* (Fig. 117), in which the strata dip in only one direction.

FIG. 115.

Photograph of a small fault near Sydney, Cape Breton.

Age of the Earth. — Various attempts have been made to state the age of the earth in years; but all have been far from the truth, because it is impossible to find any means of telling how long it takes for Nature to perform

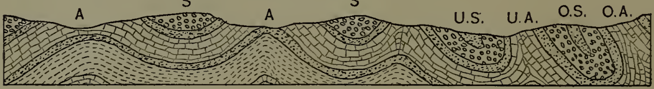

FIG. 116.

Section of folded rocks showing anticlines (A), synclines (S), unsymmetrical anticlines and synclines (U.A. and U.S.) and overturned anticlines and synclines (O.A. and O.S.).

her tasks in changing the earth's surface. In some places there are 30,000 or 40,000 feet of sedimentary strata, one layer upon another, that have been deposited in the sea during some past time; and we know that the action of the agents of the sea would require many scores of thousands of years to form these miles of rock.

Some volcanoes have been watched for one or two thousand years, and they have not grown much in size; yet in previous times they have been built to very nearly their present great height, which in some cases is a mile or two above the base. Not only this, but in some parts of the earth great volcanoes have been built, then have become extinct, and then slowly been destroyed, until now only a few remnants of the lofty pile of lava remain to tell the story. Such great changes require much time; and so also does the formation of the deep river valleys, like the Colorado, which in a lifetime do not appear to change, yet which have been cut out of the rocks by the slow action of the river water.

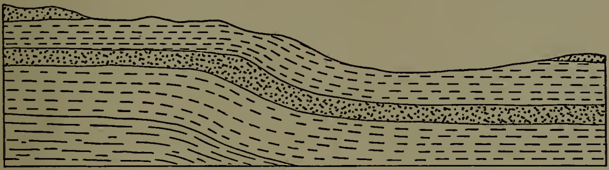

FIG. 117.
A monocline.

The difficulty in attempting any estimate of the age of the earth comes from the fact that the changes are very slow, and the time since they began to operate very great, while our lifetime is short. Compared with the time which has elapsed since the beginning of the geological history, a human life is but a fraction of a second. One thing is noteworthy: all who have tried to estimate the age of the earth during recent years have placed it as *millions of years*, and some, hundreds of millions.

Geological Ages. — While we cannot tell the age of the earth *in years*, we have been able to work out its general history, and to divide this into *stages* or *periods*, just as we divide the early history of man into stages (the paleolithic and neolithic), before he began to leave written records, which can be used to tell the *actual time*. These geological stages have been made out from the records left in the rocks by the animal life of the past. Slowly, throughout all past time, animals and plants have been changing, being first of simple and lowly forms, and gradually changing as higher groups appeared. For instance, at first there were no true fishes, reptiles, birds, or mammals; then fishes appeared, and then reptiles, then birds, then mammals, and finally, highest of all, man himself. Careful studies have revealed this history of change, and we are now able to divide the earth history into stages or *ages*, and say that certain rocks, in which are found animal and plant remains of certain kinds, belong to an earlier or later period than other beds in which *different* organic remains, or *fossils*, occur.

To these divisions of the history certain names have been given, and we have a kind of rough chronology, or *time scale*. In the table, the most ancient periods are placed at the bottom. These are merely the names for the *larger* divisions; but geologists have carried the chronology much further, and there are many names representing subdivisions of these larger groups.[1]

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[1] A more complete statement of the basis for this chronology will be found in most geologies.

TABLE OF GEOLOGICAL AGES

CENOZOIC TIME. **Age of Mammals.**	*Pleistocene or Quaternary.*		Man assumes importance, particularly in the upper part. In the first half the Glacial Period prevailed.
	NEOCENE.	*Tertiary.*	Mammals develop in remarkable variety, and to great size, while reptiles diminish.
	EOCENE.		
MESOZOIC TIME. **Age of Reptiles.**	*Cretaceous.*		Birds begin to become important, reptiles continue, and higher mammals begin. Land plants and insects of high types.
	Jurassic.		Reptiles and amphibia continue to be predominant.
	Triassic.		Amphibia and reptiles develop remarkably. Mammals of low forms appear.
PALEOZOIC TIME. **The age of Invertebrates.**	*Carboniferous.*		Land plants assume great importance.
	Devonian.		Fishes begin to be abundant.
	Silurian.		Invertebrates prevail.[1]
	Cambrian.		No forms higher than invertebrates.
In part AZOIC TIME. **No fossils known.**	*Archean.*[2]		Mostly metamorphic rocks, perhaps in part the original crust of the earth.

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[1] Invertebrates of course continue down to the very present; but until the Devonian they were the most important group. The same is true of fishes, which begin to be abundant in the Devonian, but continue down to the present.

[2] From this group, some of the upper beds have been given a new name, the Algonkian, occurring just below the Cambrian.

CHAPTER XV

THE WEARING AWAY OF THE LAND

Entrance of Water into the Earth. — When rain falls upon the surface, a portion of it runs directly away, and a part soaks into the ground. Each of these portions is engaged in the slow work of wearing away the rocks of the earth's crust. That part which sinks into the soil carries with it some of the oxygen and carbonic acid gas of the air, and perchance it also takes some substances from the decaying vegetation at the surface. When plants decay, carbonic acid gas is produced; and in the humus that is formed, there are substances, which when dissolved by water, transform it either to a weak acid or an alkali. Wood ashes are often used in making soap because of their alkalies, and these are among the materials which the water obtains from the decaying vegetation.

Sinking through the soil, the water may encounter a dense stratum, and while most will be turned aside from its downward path, some sinks gradually into the rock, for in every case the rocks of the surface are crossed by minute crevices. Some beds are much more porous than others, and some parts are more easily entered than others. Therefore there are *paths* along which more water runs than elsewhere. This is why wells dug in one place may not find a good supply of water, while those near by encounter seams which furnish a permanent supply. Generally these water-producing seams are not the result of actual underground streams, but instead, are places in which water trickles through and between the rocks more readily than elsewhere.

There is much difference in the permeability of the beds forming the crust. If water is poured upon sand, it quickly enters and disappears; but if upon clay, the surface becomes wet, and very little water passes into the mass between the compact clay grains. Yet if we could examine these minutely, we would find that some actually did enter. Even a dense rock like granite allows water to pass between and through the minerals.[1] Water exists all through the earth's crust as deep as man has explored; it is trickling through the strata, not only along the cracks and joints, but also into the very heart of the beds themselves.

FIG. 118.

Section of rock (gneiss) enlarged by microscope and showing cracks along which water percolates.

In its underground journey, water near the surface remains cool; but it may pass near a lava which has been intruded into the crust, or it may settle down below the cold upper crust into the warmer portions, and in each case its temperature is increased. Laden as it is

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[1] If a small piece of this, or nearly any other rock, be carefully dried for hours and then weighed, and afterwards soaked in water and weighed again, it will be found that it has become heavier as the result of the absorbed water.

with foreign substances (see above), the water, even when cold, may do much work of solution and change; but when warmed it has its power in this respect greatly increased, for warm water dissolves more easily than cold.

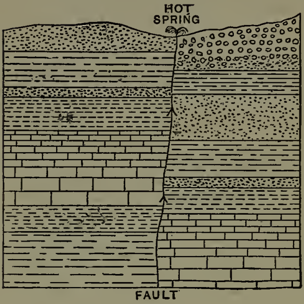

Fig. 119.

Diagram showing condition existing in some hot springs.

Return of Underground Water to the Surface. *Springs.* — After a certain journey some of the water returns to the air. Perhaps it has gone far enough to have been heated, and then, when it flows out at the surface, its temperature may be as high as the boiling point. We then have a *hot spring* (Fig. 119), or if the water escapes by intermittent eruption, a *geyser*. Such springs have come to the surface from considerable depths, passing along a great break in the earth or a fault plane (Fig. 114).

More commonly, however, the water seeps slowly to the surface, and it is this gradual *seepage* that supplies the rivers. Indeed, if the rain that fell flowed away directly, the rivers would be violent floods at

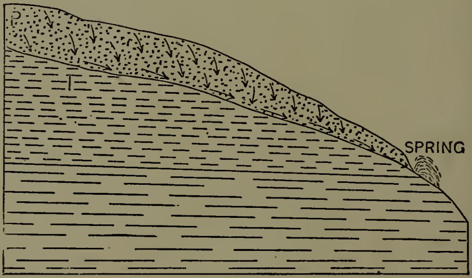

Fig. 120.

Conditions existing in hillside spring. P, porous rock; I, impervious layers. Arrows indicate direction of flow of water.

one time, and then as soon as the rain ceased, dry river channels. But a part of the rain water is stored in the earth, and *gradually* turned over to the streams after a short underground journey. Here and there, where the conditions favor, the water comes out as a *spring* (Fig. 120). There are many ways in which springs may be caused, but the most common is where water, passing through the soil, or a porous rock, encounters a less porous bed, along the surface of which it flows until it reaches the air. Such springs are very often located on hillsides, and sometimes the line of contact of sand and clay beds is marked by boggy places where the water is slowly escaping.

Artesian Wells. — Men sometimes make springs artificially, and these are called *artesian wells*. Water, encountering a porous stratum which dips into the ground, follows it; and if it is prevented from escaping by means of a more impervious layer, it may pass on down the incline. Such a stratum becomes a water-bearing layer, from which, if a well is bored to it, the water rises, perhaps reaching the surface as an artesian well. The water is unable to escape because of the overlying beds which prevent it from rising, while the underlying impervious layers prevent it from sinking. It is therefore under the pressure of the water above it in the inclined water-bearing stratum. That is to say, the pressure is great enough to force the water up through the well boring, nearly as high as the surface of the porous layer where the water has entered. Hence if a well is bored to this layer from a level below that where the water has

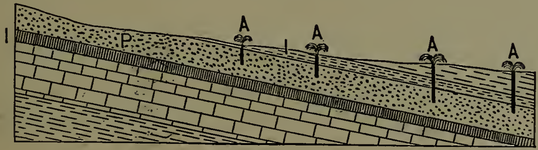

FIG. 121.

Diagram showing conditions favoring artesian wells (A) in inclined layers; porous (P) and impervious (I).

entered the ground, the water will not only reach the surface, but will rise into the air as a fountain.

These are the conditions under which artesian water is most commonly found, and there are thousands of such wells in this country, and many more in which the pressure is not quite strong enough to force the water out into the air, when it is necessary to raise it a short distance by pumping. A much rarer, but even more favorable condition, is that where the rock layers are bent into a syncline; then there are *two* heads of supply, and *no escape* down grade; for the fold forms a saucer-shaped depression, while in a singly inclined layer the water may pass downwards along the porous stratum which is dipping into the earth. In artesian wells the water may come to the surface scores of miles from the place where it entered. In eastern New Jersey and eastern Texas there are such wells, the source of whose water is scores of miles to the westward.

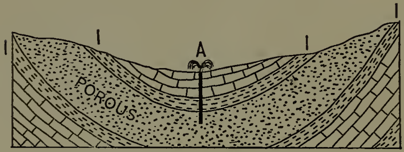

Fig. 122.

Conditions favoring artesian wells (A) in a syncline with porous and impervious (I) layers.

Mineral Springs. — Many waters reached by wells or artesian borings, and many that come out as natural springs, have mineral properties. In other words, they have minerals in solution, and sometimes these are so abundant that the water has a very disagreeable taste. On the land, around many springs, deposits of minerals are being precipitated, because when coming out into the air, the water can no longer hold them in solution. One may find iron deposits of this origin around many iron springs; and surrounding hot springs, where the water cools when it reaches the air, and therefore can no longer hold so much mineral in solution, there are sometimes extensive beds that have been precipitated, and to which additions are constantly being made. For instance, the hot springs of the Yellowstone Park are depositing extensive beds of carbonate of lime (Fig. 123); and from the water of the geysers, in the same region, silica is being precipitated (Chapter XX).

This shows that in its journey, underground water is doing work of solution. Laden as it is with carbonic acid gas and other substances, it attacks the minerals and takes many substances away. These examples, which are impressive because they appeal to the eye, are in reality only extensive cases of exactly what *all* underground water is doing. Not a drop of water passes into the ground, and escapes, without bringing to the surface a small load of dissolved mineral.

FIG. 123.

Hot Springs, Yellowstone Park.

It is this which makes water *hard;* and a chemical analysis of any spring or river water will reveal some iron, limestone, or gypsum, or all of these, and other substances as well. It is this which supplies the animals in the sea with the carbonate of lime which they need; and it is this which supplies the cement for the grains of the sedimentary rocks. One of the most important lessons taught by this solvent action, is that water in a river is *always* carrying something away. Every year, each large stream is bearing seaward thousands of tons of dissolved mineral; and this means that much solid matter is taken away from its drainage area. In the course of the countless ages of geological time this small work amounts to a grand total of land destruction.[1]

Limestone Caves. — As there is a difference in the solubility of minerals, so there is of rocks, some of which contain an abundance of soluble minerals. This is the case with limestones in which caverns are being hollowed out by water action. Water, when sinking into the rocks, chooses some natural break or joint as the easiest way of entering the earth; and slowly it enlarges this by solution. Then, perhaps coming to a more impervious layer, it passes along this, dissolving the limestone as it goes. At first

Fig. 124.

Howe's Cave, New York, showing stalactites on roof. Copyright, 1889, by S. R. Stoddard, Glens Falls, N.Y.

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[1] The Mississippi River annually carries into the sea 150,000,000 tons of dissolved minerals.

the water slowly seeps through the rock along the numerous joints; then as these become enlarged, and the passage of the water is easier, the conditions may in time change until there is formed a veritable underground river, flowing in a great cavern which the water has dissolved out of the rock[1] (Fig. 124).

Fig. 125.
The Natural Bridge, Virginia.

In a limestone country, like Kentucky near the Mammoth Cave, much of the water sinks into the earth, and small surface streams are rare, because the drainage is mostly underground. The surface water runs down into little saucer-shaped depressions, or hollows, where it cascades into the earth to take up its underground journey, emerging, perhaps after a journey of miles, as a spring on the bank of a river. Gradually the surface of the land is being worn down, and in time these caverns are partly opened to the air, and may be entered, as are the Mammoth, Luray, and many others. In time this would go so far that the underground river becomes a surface stream, because the roof of the cave has disappeared; but before this open-stream condition, there might be a *natural bridge* formed, where a part of the cave wall, firmer than the rest, has been left standing as a bridge across the valley, the last remnant of the old cavern.

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[1] This is the case in Mammoth Cave, where not only is there a river, but one in which fishes live.

The water also slowly percolates into the limestone rock through many smaller crevices, and enters the cave through the roof, dropping from this to the floor. On this journey through the rock it has taken some of the carbonate of lime into solution; but upon entering the cave, some of the carbonic acid gas, which permitted the water to dissolve the limestone, escapes into the air, and the water is then unable to hold all of the lime in solution, and is therefore forced to deposit some of its mineral load, either upon the cave roof or upon the floor below. Little by little these deposits grow, forming pendent icicle-like columns, or *stalactites*, from the roof (Fig. 124), and smaller *stalagmites* from the floor. In time these may unite, forming *columns* (Fig. 126); and the weird and even beautiful way in which these deposits increase, often ornaments the caverns so that they become places of distinct interest and beauty, as in the case of the remarkable Luray Cave.

Fig. 126.

Column in a cavern, caused by union of stalactite and stalagmite.

Breaking up of the Rocks. *Methods Employed.* — By the action of solution described above, rocks are being slowly disintegrated; but there are other actions co-operating to cause the rocks to crumble. If this were not so, much of the earth would be in the condition of bare rock, instead of a soil-covered land; and the rivers would not be furnished with sediment to transport to the sea. The strata that form the land are hard, and they must be softened and divided into bits before they can be worn away and carried from land to sea. This process of decaying, softening, and crumbling the rocks is commonly called *weathering*, because it is due to the action of the weather.

One of the most potent agencies of rock disintegration is *water*. This is at work *changing and dissolving* as it passes through the crevices of the rock. Every bit that is taken away in solution weakens the mass, for then the minerals are less firmly supported, and in time they may fall apart. As it passes along, the water finds many minerals ready for change, as iron is when exposed to dampness. Sometimes they need oxygen, sometimes carbonic acid gas, sometimes water, and very often two or all of these, and perhaps other substances which the water is bearing. In this way hard minerals are softened and rocks crumbled. The changes that take place in the minerals are very complex, and one of the results of these is that substances are produced which the water can then take away in solution.

Fig. 127.
Effect of frost action on mountain top in Colorado.

In cold climates, and particularly on high mountain tops, and in the high temperate and Arctic latitudes, water in the rock crevices sometimes freezes at night and thaws in the daytime. When ice is formed, an expansion takes place, and being confined in small crevices, the ice presses with great force against the enclosing walls, with the result that tiny fragments and even great pieces are sometimes pried off. Not only does this prying apart of the rocks break them up directly, but it opens cavities into which water more readily enters, and this increases its power of dissolving and changing the minerals. *Frost action* is everywhere at work where rocks and soil are exposed to the air in cold climates; but below the depth of a few feet it loses its importance, because the changes of temperature do not extend far into the earth. Therefore the soil, even though no deeper than two or three feet, serves as a blanket to protect the rock below.

In hot countries the *change of temperature* from day to night causes expansion during the day and contraction at night; and this, which is necessarily different in different parts of exposed rocks, causes bits to snap from them. On a much larger scale this action may be seen when a fire is built against a stone, or when a brick or stone building burns.[1]

Plants are also helping to destroy the strata. In their sap they take mineral substances from the soil, and upon dying they furnish carbonic acid gas, humic acid, and other substances to the water, which sinks into the earth through the mat of vegetation. They are also aiding *mechanically;* for as they grow, their roots and tiny rootlets ramify through the soil, and even enter the rock itself, which they pry apart as they grow. Every tree, every blade of grass, and every lichen that clings to the surface of a boulder or ledge, is engaged in pulverizing the rock or the soil.

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[1] Or it may be illustrated by placing a lighted candle beneath a piece of window or bottle glass, or even a chip of rock, which will soon crack because of the unequal expansion in different parts.

Difference in Result. — There is a great difference in the power of this weathering. Some strata are so *porous* that water easily enters and causes the changes mentioned; but others are dense and difficult to penetrate. Many are made of *insoluble* or nearly insoluble minerals, and others are easily destroyed by *solution.* Some rocks, neither porous nor soluble, are made of minerals which *decay* rapidly. Where a rock is porous, and has some minerals that can be easily dissolved, and others that are readily changed or decayed, the rate of weathering becomes much more rapid than where only one or none of these conditions are favorable. Hence since rocks differ in composition, one sees, side by side, layers that are worn away rapidly and beds that resist the weather.

This is one of the most important principles of the physical geography of the land; and it accounts for many of the hills, mountains, and valleys. For instance, Mt. Washington, the peaks of the Adirondacks, Pike's Peak, and many other elevations, are made of granitic rocks which are more durable than others surrounding them; and while neighboring strata have been crumbled and carried away, *they* have resisted and stood up, ever becoming higher above the neighboring country, not so much because they were *lifted* there at first, as because they have *remained* more nearly at the elevation to which they were raised. In the same way the ridges of the Appalachians are often made of durable sandstone and conglomerate strata, while the valleys are frequently located in beds of more easily removed shale and limestone; and all over the earth's surface similar illustrations, great and small, may be found.

There are also differences according to the *conditions* *which surround* the rocks. *Climate* is one of the most important of these (Figs. 128 and 129). A moist region furnishes more water to perform the work than does an arid climate, and hence the rocks melt down less rapidly in the latter than in the former regions. Moreover, vegetation is more luxuriant in a moist climate than in an arid one, and this furnishes to the water the tools with which it works in rock decay. In a very cold climate frost is active and weathering rapid. In a warm country this condition is absent; and although there is more water action, its effect is not equal to that of frost.

FIG. 128.

Effect of weathering upon a hill in the arid regions, where the horizontal strata have been carved by rain action because of the absence of protection by plants.

In such cold lands as the Arctic regions, or the high mountain peaks, *altitude* is another modifying condition. Upon a mountain top, where the winds are violent, and where the slope is so great that the rain and melting snows run down the mountain sides with great velocity, the tiny bits of rock, broken off by weathering, are quickly removed, and so the rock remains bare and open to the full effect of the weather (Fig. 127). When this is combined with a cold climate, the rate of weathering is greatly increased.

The *slope of the land* is another feature. This has just been mentioned in speaking of mountains; but in this place, we may also contrast the precipice with the gently sloping hillside. In the former case, every piece that is loosened by frost, or any other cause, falls from the cliff, leaving the face bare to the attacks of the weather; but on the more gently sloping hillsides many of these fragments remain, and soon, by accumulating, form a soil which to some extent protects the rocks from the action of the weather (contrast Figs. 136 and 139 with 142 and 143).

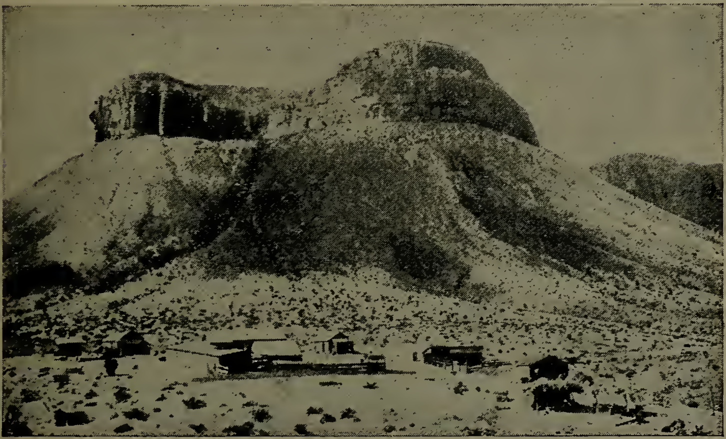

Fig. 129.

A mountain (a butte) in western Texas, showing cliff exposed to weather in an arid climate where vegetation is scanty.

Effects of Weathering. — We may watch a cliff or a rock for years without seeing any notable change; yet if one looks at its surface it is seen to be rough and crumbly, while within, the rock is fresh and hard.[1] Many stone buildings have crumbled at the surface in the 200 or 300 years since they were built; and the obelisk, brought to the damp, changeable New York climate, has been disintegrating so rapidly that it has been found necessary to protect it from the weather. Taking into consideration all the time during which these agents have been at work, not merely a few years, but tens of thousands or even hundreds of thousands of years, the slow work of weathering becomes very important in its effect. It is revolutionizing the outline of the land; and again and again mountains have been raised and worn down, valleys have been dug where hills once existed, and the face of the land has been changed, and is even now very slowly varying in its features. In this work of change the wind and rivers have aided, but weathering has been of prime importance. If weakness exists in rocks, this delicate tool will find it: and while the weak part is rapidly destroyed, the hard portions stand out in relief. Therefore one of the most important effects of weathering is the *sculpturing of the land.*

A second important effect is the *supply of materials* to the rivers and the ocean. In a gorge the rock fragments

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[1] This may be best seen in a quarry by contrasting the fresh rock, that is being quarried, with the decayed surface. Probably the outside is discolored, perhaps by an iron stain, because by the decay of the minerals which contain iron, this change becomes visible, while others, perhaps even more important, are not noticed. By *direct observation* one may see that these rocks are crumbling; and geologists find abundant evidence that all have been and still are being disintegrated.

are constantly dropping to the bottom of the cliffs (Fig. 130), where they either enter the stream, and are taken along with the current, or if more material is supplied than can be carried, or the fragments passing down the cliff fail to reach the stream, accumulate at the base of the precipice, forming a *talus* deposit (Fig. 134). A sea cliff furnishes débris to the sea in the same way. We can *see* the importance of this, and hence it appeals to us; but more important still is the slower and less perceptible down-sliding of the soil fragments on the more gently sloping land. It is not more important because more rapid, but because the area of such slopes greatly exceeds that of steep cliffs. Every rain is washing some material down the hillsides which border the river valleys. This

Fig. 130.

Crumbling of rocks on a mountain side, showing the sliding down of the fragments which fall from the cliffs.

is why the streams become muddy with sediment after heavy rains and during the melting of the snow.

This load of sediment is important for several reasons. First, it keeps the weathered material from accumulating on the rock and protecting it by a deep blanket. Hence *the removal aids weathering;* for if some were not removed, the rock would soon be covered to such a depth that frost and plants would produce no effect, and even percolating water would not be of great importance. It is also important because it gives sediment to the sea, where it is built into the beds of rock, which later, raised to the surface, form such notable elements of the land. Then too, the preparation of material by weathering furnishes streams with tools with which to work in cutting their valleys. Water by itself has little power to cut the rocks; but armed with pebbles, sand, and clay, the stream rasps at its bed and slowly deepens its channel (Ch. XVI).

Fig. 131.

Decaying granite, Maryland. Fragments of rock and clay, formed by decay, surround blocks not yet reached by weathering, and hence fresh enough to be quarried.

To man the most important effect of weathering is the *formation of soil.* The crumbling of the rocks furnishes an accumulation of soil fragments into which plants can easily thrust their roots; and the decay of the minerals furnishes substances which are needed in plant growth, and which, being soluble in water, are taken from the soil in the sap. This soil which is formed by the decay of rocks, and which is the most common one in the world,[1] is called *residual soil.* It is one from which many of the soluble substances have been removed, and is hence composed chiefly of the *insoluble residue*, particularly kaolin clay and silica. In such a soil the surface portions are very fine-grained clay, grading downward to fresh rock, passing first through a zone of partially decayed rock fragments in a clay matrix, and then to soft and partially decayed beds, not yet pulverized to fragments. Such soils may reach 100 or 200 feet in depth, though they are commonly much less.

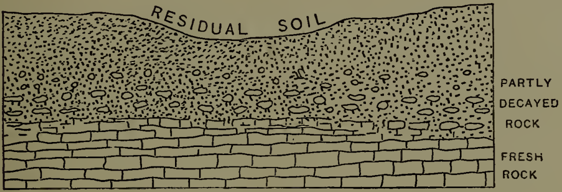

FIG. 132.

Diagram to show the conditions in a region covered by residual soil.

Erosion of the Land. — The land is being destroyed by other agents, which grind down the surface and remove the fragments by *erosion.* Here and there *glaciers* pass over the land (Chapter XVII), and as they slowly move along, dragging soil and rock fragments with them, they scour the beds over which they pass, grinding them down and carrying the pieces thus wrested to their ends, where they may be left on the land or carried away in the streams

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[1] In northern United States and Europe the soil has been brought by glaciers; and along rivers there are soils which have been accumulated by the water. Some are also formed by wind action, and some were once deposited in the sea, and have since been raised above it.

produced by the melting of the ice, or often, where the end is in the sea, be borne away by icebergs. Another agent of erosion is the *wind*, particularly in arid countries, where the soil is not held in place by abundant plant life (Fig. 133), and where, because of the dryness of the climate, the soil particles do not cling together. Along the coast line the *waves and tides* are ever at work destroying the land and removing the fragments (Chaps. XIII, XVIII). Because of the great activity of the destructive agents in the sea, this is one of the most rapidly changing parts of the land.

Fig. 133.
Rain-sculptured Bad Lands of South Dakota.

On the land, water is also active in erosion. Every heavy *rain* removes some material from the surface and carries it to the rivers. The raindrops, first striking a blow upon the soil, gather into tiny rills, and these form streams; and from the first impact of the raindrop, the water may be engaged either in the removal of loose particles, or the grinding of hard rock. The erosion by rain itself becomes more important when vegetation is not present to check the force of its fall and to hold it, preventing its rapid escape. Therefore, in roads, ploughed fields, and in the great desert and semi-desert countries, rain erosion becomes very noticeable (Figs. 128 and 133).

Gathering into *rivers*, the rain-water becomes more concentrated, has its power increased, and the beds of the streams may, therefore, be places of very rapid erosion (Chapter XVI). Valleys are cut, and gorges and even deep cañons are carved in the rocks. This is one of the most potent agents in the sculpturing of the land. This work of rivers goes hand in hand with that of weathering; for the latter, by causing the rocks to crumble, furnishes rivers with tools and materials to carry.

Much of the rain that falls on the land sinks into the ground, and while there it not only dissolves and changes, but also accomplishes much mechanically, as an agent of erosion. The *underground water* lubricates the soil particles so that they slide down the hillsides; and this is one of the most important of the effects of percolating water. Gradually the soil migrates down hill even if the slope is not very great.

Also, water percolating along the contact between a porous and a clayey layer, makes the surface of the latter slippery, so that if the slope is steep, the porous bed may commence to slide, perhaps forming a tiny *landslip*, or *landslide*, though sometimes, on steep mountain sides, a great and destructive *avalanche*. These slips of the land, which sometimes carry thousands of tons of soil and rock, are often caused when the frost is coming from the ground and the earth is then made damp. Or perhaps a heavy fall of snow will increase the weight of an unstable part of the hill or mountain side, causing an avalanche,

Destruction of the Land. — The combined work of weathering and erosion is called *denudation.* By these agents, slowly operating but ever at work, throughout the long periods of time during which the land has been exposed to the air, the most profound effects have been produced. Not merely has the land been sculptured into its present outline of hill and valley, but great mountains have been reduced to lowlands, and thousands of feet of rock have been removed from the surface. Denudation is engaged in the great task of destroying the land and transporting to the sea the materials thus derived; and if it had been permitted to work uninterruptedly throughout all past time, the land long before now would have been reduced to a nearly level surface.

But it is *not* permitted to work without interruption. The land is rising here and falling there; and as a result of the contraction of the heated globe, the land surface is steadily rising, though now and then locally sinking, while the bed of the ocean is gradually becoming deeper. Therefore, while the land is being attacked by denudation, it is also rising; and we may be certain that this uplift has been more rapid than the downcutting caused by denudation, otherwise the surface would be less rugged and the level lower. The two are in conflict, and so far denudation is the weaker of the combatants; but as a result of the conflict, the face of the land has been battered and carved into the irregularities of seashore, plain, plateau, hill, valley, and mountain. It will be interesting to look a little more closely at some of the methods employed in this battle, and at some of the results which have been produced.

CHAPTER XVI

RIVER VALLEYS, INCLUDING WATERFALLS AND LAKES

Characteristics of River Valleys. — Rivers occupy valleys, and among these there is an extremely great variety of form. Some are narrow, some broad, some deep, and some shallow. In every single case there is a certain relation between the conditions surrounding the river, and the form of its valley. In such an elementary book as this we can do no more than understand some of the simplest principles, though geologists studying a river valley can generally find out why it has its particular form. Some valleys are situated in easily destroyed rocks, some in durable layers, and some cross first one and then another. Many are situated on plains, others in mountains and plateaus, and some exist in moist, others in arid, climates. In many cases rivers have occupied their valleys for a very long time; but a few have existed for only a short period. With all of these variations, there is a resulting variety in river-valley form; but there is one characteristic of all rivers, — *that they flow in some kind of a valley.*

Another universal fact is that at some time *all river valleys contain water.* In most of them *some* water is *always* present, sometimes a very small amount, sometimes veritable floods; but there are some valleys which contain water only for a very short time during the year, and others which may remain dry for many years. That is to say, while water is in every case *sometimes* present, in *all* cases the amount varies from time to time. The *velocity* of the stream differs with the slope of its bed, and some have steep, others gentle slopes; but with any *given grade*, the velocity of the water also varies with the *amount* of water. To prove this let any one examine a stream that flows quietly along in ordinary times, and contrast this with the torrent that rushes over the same slope after a heavy rain, or when the snow is rapidly melting. In all rivers this water supply comes partly from the direct fall of rain, and partly from underground water which once fell as rain, and then entered the earth.

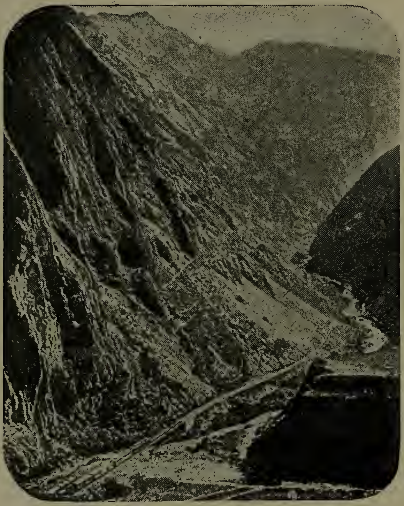

Fig. 134.

A typical river valley in mountains (the high Andes of Peru), showing gorge cut by rapidly descending stream, and also talus supplying débris from the valley walls.

All rivers have tributaries, but these vary in number and kind. Perhaps some tributaries are great rivers, like the Ohio where it enters the Mississippi, but most are only tiny rills which exist during rains. Every river occupies a certain *basin* or *drainage area*, and the combination of all the streams in this area forms the *river system*. Here too, there is great variety in form, size, and condition.

Two neighboring river systems are separated by a line, or more commonly by an area, known as a *divide* or *water parting*. This may be a sharp mountain ridge, or much more commonly, a gently rounded hilltop, or even a swampy plain.

Most of these features are ever changing; for the valleys, valley walls, tributaries, divides, and areas of the river systems are caused to be what they are by the combined action of running water and weathering. That this is so, is proved by the fact that all rivers are at some time, and many are at all times, carrying loads of minerals in solution and rock fragments in suspension. A river is nothing more than a drainage line on the land, by which the surface water is passing from high to low ground, generally toward the sea.[1] In its course, because of the co-operation of weathering, and by its own action, the river is obtaining mineral matter to remove from the land (Fig. 134). Hence it also becomes a *carrier of fragments* obtained from the waste of the land. Incidentally, because of these two facts, the river is *grinding* a valley. That is to say, the water flows down hill, and is furnished with rock fragments; and with these in its grasp it scours its bed, ever deepening it when this is possible. Therefore, according as the slope, volume of water, amount of sediment, kind of rock, and length of time in which the work has proceeded, vary from place to place, the form of the river valley also varies. This point of river variation from time to time and from place to place will be considered in some detail.

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[1] In enclosed basins, like the Great Basin of the west, or the Dead Sea, the water flows into an interior area and hence not necessarily toward the ocean.

The River Work. — When water gathers into a stream, and courses along down a slope, it cuts into its channel by two kinds of action. It dissolves such substances as it can, and it scours its bed by dragging rock fragments along. The rate at which it will do this varies with the velocity of the water, the amount of sediment, and the kind of rock over which it flows. Limestone is dissolved with greater rapidity than granite, and a soft clay bed will be worn away more rapidly than a hard rock.

FIG. 135.

A stream bed in the Adirondacks, showing boulders that are moved by the floods.

To do this work most rapidly the stream should have *sediment* with which to wear away its channel; but some streams have *too much* sediment, in fact more than they can carry along; and then some of the load must be deposited in the bed instead of being able to cut into the rock. The Platte in Nebraska for instance, although flowing down a moderately steep grade, is not cutting a valley, but is building up its bed. On the other hand, Niagara River, above the Falls, has so little sediment that it is not able to scour its channel. When this river flows out from Lake Erie, it starts as clear lake water, and as a result of this, the stream below Buffalo flows almost at the surface of the plain.

FIG. 136.

View in Enfield gorge near Ithaca, N.Y., showing young stream deflected by joint planes. Part of a circular pot hole in the foreground.

A stream that flows over a gentle slope is less able to cut into its channel than one that passes down a steep grade, because it hurls rock-bits against its bed with less force; and since the velocity becomes greater when the volume of water increases, it can cut into its bed more rapidly when in flood than at other times. To appreciate this, one has but to watch the rushing torrent which courses down a stream valley in the spring, and see it carrying along pebbles, and even boulders, which under ordinary conditions it would not be able to move, and which, when the flood subsides, are left standing in the channel (Fig. 135). The greater part of the cutting done by most streams during the year is accomplished during the few days when the water flows as a torrent. For the remainder of the year, though a small amount of work is done, the stream loiters and rests from its labors. In a year there has been no perceptible deepening of the stream channel; but in a few centuries rapidly working streams will make changes; and in the great ages of geological time, vast results in valley formation have been accomplished.

If we should go to any stream valley, where the water is flowing over the bed rock, we would find that in certain places, perhaps where the rock is soft or much jointed, the channel had been turned aside for some distance (Fig. 136), or that the water had cut into those places more deeply than elsewhere. Perhaps in places where the flow was increased for any reason, circular *pot holes* had been dug (Fig. 136). These are carved at the base of waterfalls or in an eddy of the stream, where the swirling waters have whirled the pebbles about (Fig. 139). In such river beds there is proof that the stream is really cutting into its channel; for one can see that a hole has been dug, or that blocks have been cut out; and one may also see that softer rocks are more rapidly worn than harder.

Most valleys have greater breadth than depth, and the width of the *valley* is very much more (perhaps miles) than the width of the *stream channel.* So far as we have gone in this study, we have seen only that the stream cuts its bed; and if this were the whole truth, a river valley should be narrow, its width being about that of the stream itself (Fig. 137). Evidently therefore, there are other facts to be understood. One of these is that the river does not flow over a straight course, but meanders about (Fig. 138). This is true of all streams, and it is also true that in meandering they change their position from time to time. Commonly the place of greatest velocity of a river is in the middle; but when it begins to swing, the place of greatest velocity shifts first to one side of the valley, then to the other. Hence the current strikes *against the bank* (Fig. 138), and in addition to the *vertical* cutting in the stream bed, there is a certain *lateral cutting* against the valley walls. Since the swing of the river changes from time to time, different parts of the side are successively attacked, and so by this action the valley is slightly broadened (Fig. 138).

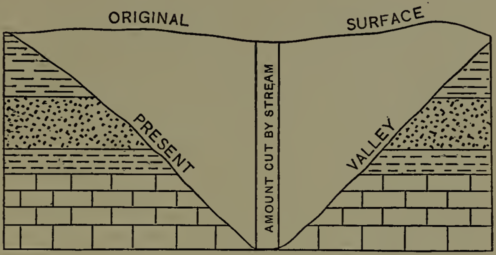

FIG. 137.

Diagram to show relatively small amount of rock actually cut out by the stream, compared with the width of the valley as broadened by weathering.

The really *great widening* of valleys is that done by the very slow action of weathering (Fig. 134). This is always at work, and little by little the rock crumbles, passes into the stream (Fig. 130), and is whirled off toward the sea. Every block that falls from the cliff, every mud-laden rill that courses down the hillside, and every bit of dissolved substance brought to the surface by underground water, represents a small contribution to the grand sum total of valley broadening. To appreciate this we must remember that the valley has been developing, not for a century only, but for many tens or even hundreds of thousands of years.

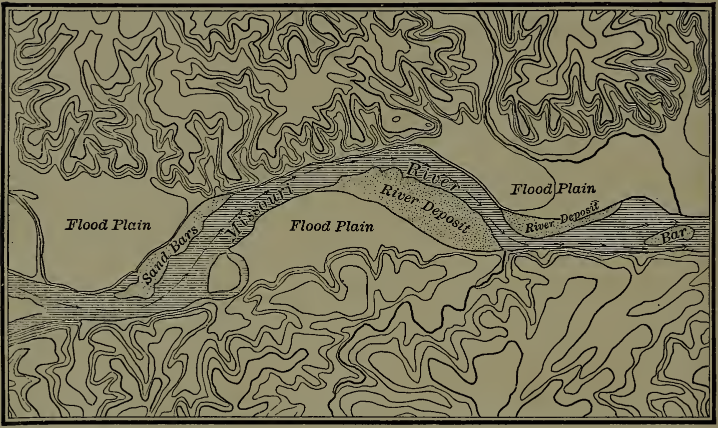

FIG. 138.

Part of map, showing meandering river cutting against bluff on one side and depositing on opposite. Arrows indicate the strongest current.

History of River Valleys. — If a river were supposed to begin upon a new land, the water would take the lowest course, and along this [1] would commence to dig a valley. Weathering would of course immediately begin to co-operate; but for awhile the work of the river in cutting its channel would be more rapid than the action of weathering in widening the valley, because the body of water moving

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[1] Called the *consequent* course, because it is chosen in consequence of the topography.

along the narrow channel is a more powerful agent than the very slow action of weathering and rain wash. Consequently the valley would be narrow and its sides steep, because the river carves the rock with such relative rapidity (Fig. 137). Such a stream valley would be a *young valley* (Figs. 134, 136, 139, and 145); and wherever we find a gorge or cañon, we may be certain that it has not existed long enough for weathering to widen it.

A young river valley may have a very irregular course, for it has taken the lowest line, following it wherever that may lead; and many young streams pursue a very roundabout path to their mouths. It may also have lakes in the course, for there may have been depressions in its bed which had to be filled up before the river could proceed. As time goes on, these will be destroyed; for each

Fig. 139.

A young valley being cut in the shale rock of central New York.

stream that enters a lake, brings sediment which is slowly filling it; and at the same time the outlet stream is cutting its valley down, and therefore lowering the lake level. In time the combination of these causes succeeds in removing the lake, and hence lakes are not liable to be found in valleys that have passed the youthful stage. Waterfalls also may exist in the course of a young stream, where its path has led it down some steep slope;[1] and falls may be developed as the river cuts its bed, passing over hard or soft rock. Therefore a gorge valley, with lakes and waterfalls, is characteristic of young streams.

Fig. 140.

Diagram to illustrate base level (B E) and profile of equilibrium (P E).

After awhile, as the stream valley becomes older, and reaches the stage of *early maturity*, there are differences in the conditions, and therefore in the form of the valley. There is a level below which the stream cannot cut. At its mouth, where it enters the sea, this is the sea level, and it is commonly called the *base level of erosion* (Fig. 140). The sea level is the *permanent base level* of streams, but temporarily there may be a base level above this. For instance, so long as a lake exists in the course of a stream, its channel cannot be cut below the *temporary base level* of the lake surface. While a stream may cut its channel

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[1] As in the case of Niagara. See latter part of chapter.

down to sea level near the sea, it can never do this far inland, for the river must maintain a slope down which the water can run, and at the same time transport its sediment load. This line, sloping down toward the sea, may be called the *profile of equilibrium* (Fig. 140).[1]

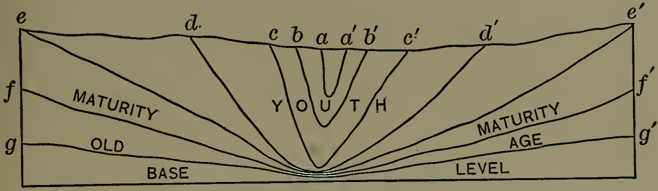

Fig. 141.

Diagram to illustrate the development of a stream valley from original surface (*ee'*), through youth to old age (*gg'*).

Fig. 142.

A broad, mature valley, Ithaca, N.Y.

When a stream in its down-cutting has reached nearly to this lowest possible slope, the profile of equilibrium,

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[1] Called this because it is the profile in which an equilibrium is maintained between water and sediment supply, and river slope.

its power to cut further is very greatly diminished, and finally, when the profile is actually reached, it ceases to be able to cut into its channel. But weathering still continues, and so while the valley is no longer being deepened, it begins to grow broader, and the gorge or cañon gives place to a valley with rounded sides (Fig. 141). This is characteristic of the stage of maturity (Fig. 142).

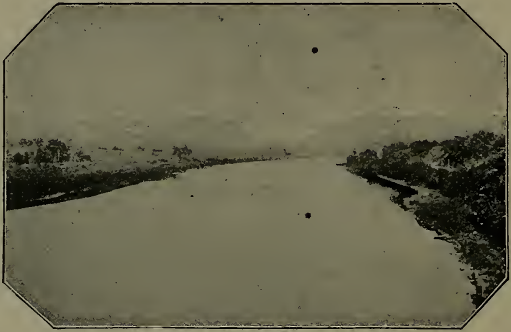

Fig. 143.

A view on the Delaware, showing the Water Gap in the background, where the rocks are hard conglomerate, and the broad, gently sloping valley in the foreground, where the rocks are softer limestones and slates.

The length of time which it will take to reach maturity varies greatly, as it does in animals and plants: in some climates weathering is slow, in others rapid; in some places the stream begins high above sea level, and therefore has more slope, and more work to do, than others which begin on low plains; and some work in hard, others in soft rock. Indeed, two neighboring parts of the same stream may show different stages of development, one being in soft rock, the other in hard, and hence one having a more rounded outline than the other (Fig. 143). Also the headwaters of a stream will be less mature than the lower portions, for these are higher, carry less water, and have more work to perform. Moreover, they cannot be developed *faster* than the lower portions, for they must wait for these in order that they may have the necessary slope down which to carry their sediment supply.

There are other ways in which a mature valley differs from a young one. Waterfalls cannot exist, because the slope is the easiest one possible, and all falls have therefore been destroyed. Nor can lakes exist, for they have all been filled. The river course may have become quite different from the original, for in time rivers adjust themselves, and often gradually alter their direction. Also at first the divides may have been very indefinite and the tributaries few;[1] but the tributaries increase in number, and during maturity the divides are so definite, that all water falling on the land finds a slope down which to flow, and a valley in which to join with other water to ultimately reach the main stream.

After the profile of equilibrium is reached, the operation of weathering slowly continues to broaden the valleys and lower the hilltops, until if everything is favorable, the country will be reduced to the condition of a plain (Fig. 141). There can be no doubt that there has been time enough for this; but there are no such *old valleys;* and here is an illustration of the combat between the elevating and destroying forces. The land is rising faster than denudation can remove it, and hence there are no really old lands. This which has been stated is the

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[1] This is well illustrated in both the Red River valley of the North, and in Florida, which are young plains. Here the divides are great, nearly undrained swamps, and the water that falls scarcely knows which way to flow. In time, as definite courses are chosen, other streams develop, and gradually the divides become more sharply defined.

normal or *ideal cycle of change.* In reality rivers are subject to many interruptions, which may be called *accidents*, and these will now be considered.

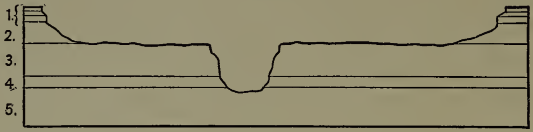

Fig. 144.

Diagram to show young, inner, and older outer gorge of Colorado River.

Accidents interfering with Valley Development. — The country in which a valley is being formed may be raised, and this gives to the stream new power to cut, for it increases the slope. By this the stream is *rejuvenated* or *revived*, and the gorge condition may be prolonged, or a gorge may be cut in the centre of the mature valley, as in the case of the Colorado River of the west (Figs. 144 and 145). Here the river had cut down to its profile

Fig. 145.

A view in the Colorado cañon, showing inner gorge and outer broad valley.

of equilibrium, and the valley sides had wasted back, forming a fairly broad valley. Then there came an uplift of the land, since which the Colorado has cut a narrow cañon, which is a deep, narrow trench in the middle of the older, broad valley. If such an elevation should occur along the coast line, separate streams might be caused to unite into one. For instance, if the region about Chesapeake Bay were to be raised to an elevation of 200 or 300 feet, many streams now entering this by separate mouths would be united, flowing to the sea through a single trunk stream (Fig. 146). Such elevations have occurred in the past.

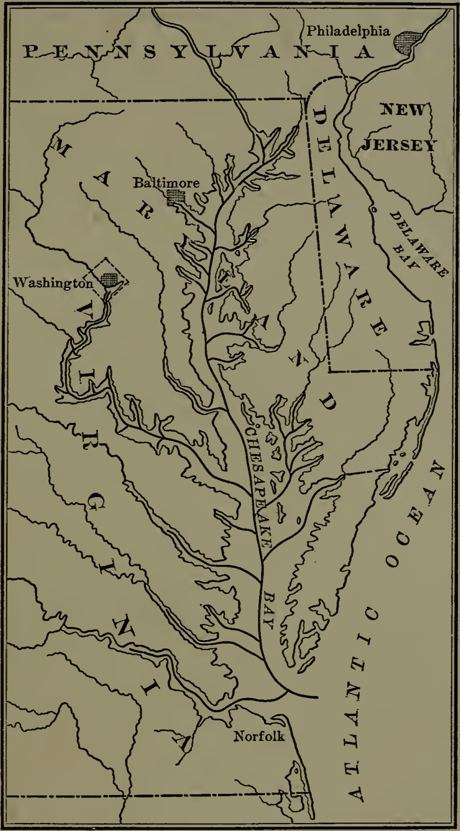

FIG. 146.

Map of Chesapeake Bay, to show (by heavy line) the way in which the various rivers would unite into a single trunk stream if the land were elevated.

If the reverse movement of depression takes place, the stream loses most of its power, because its slope is decreased; and then it may build a broad floodplain (Fig. 138), because it is no longer able to carry all its sediment, but must deposit some in its bed or to one side of the channel. If in this case the depression is near the sea, the stream valley may be *submerged* or *drowned*, and in fact this is the cause of many of the bays, harbors, and estuaries along the coast (Plate 19). In these the sea has extended up the valleys, and this has separated or *dissected* rivers which once entered the sea by a single mouth, but which now, as in the case of the Chesapeake, enter the sea by separate mouths (Fig. 146). During recent geological times northern Europe and America have been depressed, so that the sea enters many of the valleys, transforming the coast to one of extreme irregularity (Plate 19).

Another way in which the normal development of the stream valley may be interfered with by movements of the land, is when the surface changes in level along a relatively narrow line. For instance, a mountain chain may be rising across a river valley. In this case perhaps the stream will *maintain* its course, cutting into the rock as rapidly as the mountain rises. Such a stream, called an *antecedent river*, because it existed before the mountain grew, would then cross the mountains directly, forming a deep mountain defile or gorge. Though many rivers cross mountains, as in the case of the Delaware at the Water Gap (Fig. 143), the Susquehanna, and others in the Appalachians, it is very difficult to prove that the cause for this has been that just mentioned. In the main, such mountain valleys are the result of later changes, and this applies to practically all in the Appalachians; but some believe that the Green River, where it crosses the Uinta Mountains in Colorado, is an antecedent river.

Much more commonly the growing mountain *dams* the stream, forming a lake which may later be filled up by the river sediment, after which a gorge may be cut at the point of overflow; which may be the same as the original course, or may be in a different direction. No doubt during mountain formation the land often rises so rapidly that the stream is turned to one side or *diverted*, or perhaps even forced to flow in the opposite direction, having its course *reversed;* and the mountains may rise rapidly enough to *divide* a stream into two parts. In any event, the growth of a mountain seriously interferes with the development of the valley.

Climates have changed in the past. In the Far West, places now arid once had a moist climate. Some streams in this region that were formerly larger, are now *shrunken;* and in some places, where the weathering of the damp climate was rapid, there is now relatively little weathering, and the broadening of valleys is therefore a slow process, so that the typical valley of the arid land is an angular cañon (Fig. 145). In this western region the change in climate has caused some valleys to be entirely abandoned, and some streams to be *dissected.* For instance, the rivers now flowing into the Great Salt Lake valley once united to form a larger lake, which overflowed into the Columbia, and thence to the sea; but now they all run down into the Great Basin, where they disappear by evaporation. Hence many streams, at present having an entirely separate existence, and distinct mouths, were once united into a single stream.

One of the most important accidents to rivers is that caused by the great glaciers which once overspread northwestern Europe and northeastern America. By this nearly all of the rivers have had their courses interfered with. Some were turned out of their course, others were made to join different streams, many have been obliged to cut gorges, and a very large number have had their channels choked with glacial deposits, so that they have become locally transformed to lakes. The effects of the glacial accident will be better understood when we have studied glaciers (Chap. XVII).

There are other less important accidents to which rivers are subject. Sometimes a lava flow enters a valley and dams the stream back, forming a lake and changing its course, at times causing it to cut an entirely new valley, perhaps to join a new river system, thus rejuvenating the river by giving it a new task to perform. An avalanche from a mountain may produce the same effect, and the blowing of sand into the form of sand-hills sometimes dams a river, forming a lake.

By one or all of these accidents many rivers are constantly being retarded in their development; and hence the task of river-valley formation is not only naturally a slow one, but one beset by many obstacles. Indeed, various portions of a single river may suffer different accidents and become *composite* in form. Again and again a river may start its development only to be interrupted; and although there are times when the accidents help the work along, on the average they give the stream something more to do, and therefore prevent it from passing the stage of maturity into that of real old age.

The River Course. — At first a stream chooses for its course the easiest slope, whatever this may be. This *consequent* stream course differs according to the location of the river. Upon a plain it may be very irregular, but in general will follow the direction of the slope of the plain, as the rivers of Florida flow outward from the higher central part of the state, or as the streams of eastern New Jersey and Texas flow outward toward the sea.

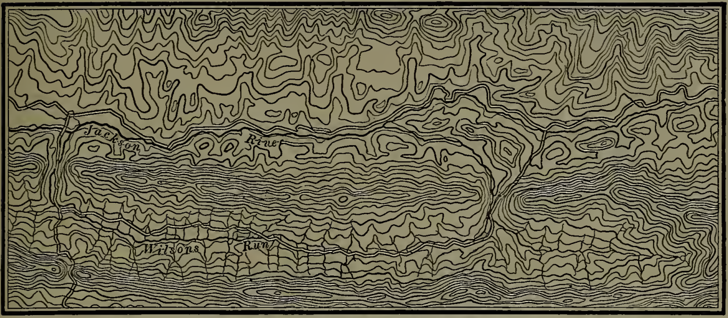

Fig. 147.

Map of a mountainous country, showing rivers parallel to ranges, and other features of drainage.

Upon a country that has been glaciated, the surface is so irregular that streams are often obliged to pursue very roundabout courses before entering the sea. Among mountains, folded as they are into ridges and valleys, the larger streams flow parallel to the ridges, with tributaries running straight down the mountain sides, and the main stream now and then turning abruptly from its valley between the ridges,

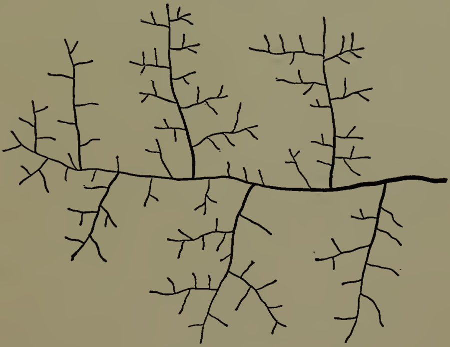

Fig. 148.

River drainage on a plain, showing rectangular tributaries.

and crossing a ridge to enter another valley, which it follows for awhile (Fig. 147). Upon a plain the tributaries, which form an arborescent, interlocking series, may at first enter the main stream at right angles, or nearly so (Fig. 148); but as the work proceeds, they enter it at a more and more acute angle (Fig. 149), for they eat against the downstream bank, because the current is turned that way by the velocity of the water in the main stream.

This consequent course may be followed for a time, but in many cases this course changes as the stream develops. If at first it was irregular, and a longer journey was undertaken than necessary, the river slowly straightens its course so as to flow *more* directly. Or if after cutting through a plane of horizontal rocks, the river finds itself cutting into tilted beds, it may find it necessary to *adjust* its course to agree with the tilted rocks. Such a river, which is called *superimposed*, after cutting through the horizontal beds, may find itself flowing across the edges of a series of tilted layers, some hard, others soft, whereas if its course were just a trifle different, it could follow a single layer of *soft* rock, and therefore have an easier task. In such a case the river gradually changes, until it becomes more in accord with the rock structure, and finally becomes adjusted to it.

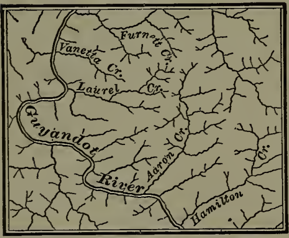

FIG. 149.

Map showing interlocking tributaries of rivers draining a plain.

Once in a soft bed, the river tends to remain there; and as the stream develops, there are many changes in course, until finally it has found the easiest path. This adjustment of river courses is not easy to comprehend without going more fully into the question than we are able to do here, and so it may be merely stated as a fact, that in regions where hard and soft rocks occur together, the harder beds stand up as hills or ridges, while the softer ones are lowlands and hence valleys, not necessarily because rivers were *first* located there, but because in the course of time soft rocks wear away more rapidly than hard.

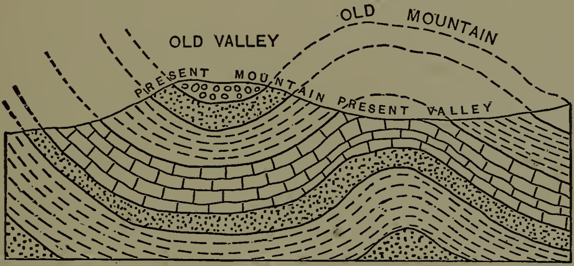

FIG. 150.

Diagram showing the condition in parts of the Appalachians where old mountain tops have been changed to valleys.

Hence a stream, perhaps originally smaller, located in a soft layer, will develop more rapidly than another in a harder layer, and gradually will gain upon its neighbor, and perhaps in the end entirely rob it of its drainage area. The stream that is more favorably situated cuts rapidly, its tributaries have more slope, and hence more power, and slowly they push the divide back into the area of the less favorably situated stream. Thus there is a constant but slow *migration of divides*, for the streams on one side are usually more powerful than those on the other. Hence the smaller stream may grow larger, and the large river dwindle, until by slow changes an *adjustment* is reached, with the larger stream located in the more favorable situation. By such changes as this, mountain valleys have been transformed to mountain tops, and mountain tops to valleys (Figs. 150

and 151). This is common in the Appalachians, where the rivers are well adjusted to the rock structure. During this slow change there is sometimes a case where the divide is forced so far back, that the headwaters of the neighboring stream are actually drawn off and carried into the robber's territory, and then one of the rivers is quickly reduced in size, while the other is enlarged by the capture.

There is a constant battle for territory between neighboring streams, and those that have the greatest slope, or the softest rock, or the heaviest rainfall, will be the most successful in the battle. Therefore we must look upon the river valley as a thing ever changing, and the river system as a thing of activity and even of life, struggling to reach a definite end of valley development. The river history is complex, and the valley probably composite; but it has a story to tell: it is not a dead thing, formed and then left to remain ever the same without change. Looking at the surface of the land, every one may read a part of the story told by the river valleys; and by a more careful study it is possible to decipher many of the stages of the previous history, which has been so briefly outlined here.

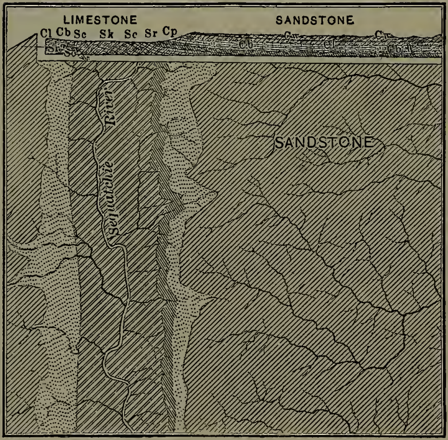

Fig. 151.

Map and section of the Sequatchie valley in the southern Appalachians, a river adjusted to the rock structure, and flowing in a bed of limestone which is a part of an old mountain.

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PLATE 18.

Delta of the Mississippi.

River Deltas. — When the water of a river enters a quiet lake, or the sea, its velocity is checked; and if it is carrying sediment, some of this must be deposited near the point of entrance. Hence near their mouths, rivers are dumping a load of rock fragments, sometimes coarse, sometimes fine. In this way deltas are built. They are flat-topped plains of alluvial material, extending beneath the sea or lake, to their end, which is a steeply sloping embankment (Fig. 152). This steep seaward face, which is entirely submerged, grows outward as more and more is added; and it remains steep for the same reason that a railway embankment does when loads of gravel are dumped upon it.

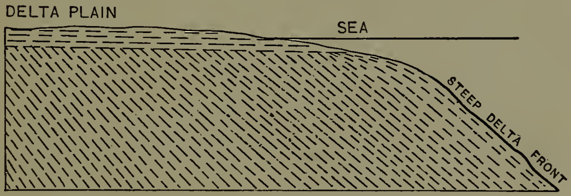

Fig. 152.

Cross section of a delta, showing its structure in a diagrammatic way.

The reason why the top of the delta is a plain, is that its surface cannot be raised much above the level of the sea. It does rise *slightly above sea level*, because as the river flows out over the plain which it has built, it flows over such a moderate slope, that the channel is not able to hold all the water in flood times. Then the plain becomes transformed to a broad, lake-like expanse of slowly moving and shallow water, in which sediment settles, gradually building the plain higher, but never to any very great elevation above the sea or lake.

Because of the very levelness of the delta plain, the water of the stream that forms it often flows through several mouths or *distributaries*, which divide from the stream near the head of the delta, spreading out fan-shaped. Hence the delta, instead of being formed by one channel, is often made by several, and its front is broad, so that the form of the delta plain, between its sea margin and the two outer distributaries, is often triangular, like the Greek letter delta (Δ), whence its name. In the larger deltas of the world, streams flow in very uncertain courses, so that a slight cause is often sufficient to make the stream abandon one of its former channels. Such rivers as the Yellow of China change their course frequently, flooding farms and villages and often destroying much life. This is because the slope is so slight that the river deposits sediment, and builds its bed higher, so that in time it abandons its old course to find a new and lower channel.

Deltas are not always, nor in fact usually, found at stream mouths. They are much more common in lakes than in the sea, mainly because lakes are shallow, so that less sediment is needed to raise the bed to the surface of the water. The fact that the *depth* is great is one of the reasons why deltas are absent from most river mouths on the seashore; but one may be certain that any stream which carries sediment would in time build a delta, unless there were some other cause which prevented; for no matter how slow the accumulation might be, year by year it would rise nearer the surface, until finally it reached sea level.

Among these interfering causes are the presence of strong *waves*, tidal *currents*, or other movements of the sea, which take the sediment as fast as it comes, and distribute it far and wide. This is one reason why, next to lakes, enclosed and nearly tideless seas, such as the Mediterranean, are the places where deltas abound. Of course a river with much sediment will ordinarily build a delta faster than one carrying little or none; but there are cases of rivers heavily laden with sediment and entering enclosed bays, yet not constructing deltas. Such cases are those in which the bed of the sea is *sinking*, or has recently sunk so rapidly that the river deposit has not been able to build up to the sea level. For delta formation the most favorable conditions are much sediment, absence of strong waves and currents, a sea not too deep, and a sea bottom either remaining in the same position or else being slowly elevated. The absence of the latter condition explains the absence of deltas on the coast of eastern North America and western Europe, where the land has recently subsided.

FIG. 153.
Alluvial fans in the arid lands of the west.

Even on the land, rivers sometimes make a deposit which somewhat resembles a delta. Where the stream comes down from a steep mountain valley upon a plain, its velocity is checked almost as effectually as if it had entered the sea; and if it is bearing much sediment, as it often is, some of this must be deposited in the form of a fan or cone-shaped accumulation, with the apex at the point where the stream emerges from the mountain. Over this *alluvial fan*, *fan delta*, or *cone delta* (Fig. 153), the stream flows by means of distributaries, constantly adding to its height and extending its area. Like a delta this deposit is somewhat triangular in outline; but it has not the flat surface nor the steep front of the delta, but has a gradual slope from apex to base.

River Floodplains. — Streams that are carrying much sediment are often obliged to deposit some of it in the channel, in places where for any reason the current is checked. This may happen when the floods subside; or during ordinary times the condition may occur in an eddy in the current, or on the down-stream side of a boulder, or of a tree that has become lodged in the channel. The *bar* may be very tiny, or it may grow to the size of an island, which divides the river and is covered only in flood stages. Some island-like bars are caused by the splitting of the stream, which for awhile follows two channels, forming an island in the middle; but in time one of these is abandoned and one chosen as the channel for all the water. In almost any stream valley of moderate slope, one may see a great variety of bars, islands, and partly closed stream channels, and by the study of them one may often find their cause. Most rivers are constantly changing their position, and as they do this, the form of their channels.

Oftentimes the river is bordered on one or both sides by a plain which in time of flood is covered by river water (Fig. 138). This "river bottom," or *floodplain*, may be narrow, or, as in such large rivers as the Mississippi, very broad. Each time that the river floods overspread the plain, a tiny layer of sediment is deposited on its surface, and gradually it is built upward. Indeed, the floodplain is really *made* by the river floods, and represents the accumulation of sediment, where the river slope is not great enough for the flood water to carry all the load. Extensive floodplains are more common in mature rivers, and particularly near their mouths where the slope is less. After a delta is built, and the river flows out over it, it is transformed to a floodplain; and when a bay is filled with a level sheet of river sediment, as Chesapeake Bay may some day be, this also becomes a floodplain.

Some of the narrow floodplains, especially those in mountain valleys, are made of coarse gravel; but the larger plains are built of very fine-grained clay, and they constitute some of the best farming land in the world. Many of the meadows on the sides of small streams are tiny, yet true, floodplains. On the larger plains the surface is nearly level excepting near the stream bank, where the elevation is slightly greater than on either side. The river channel on both sides is bordered by a low embankment or *natural levee*. This is the place where the rapid current of the channel and the current in the middle of the floodplain come in contact; and here the velocity of the water is less, so that more sediment is deposited, thus building the embankment. Upon these are built the artificial levees which men construct in order to confine the river to its channel and prevent it from flooding the neighboring plain.

Over a broad floodplain the river flows with a curving or meandering course, circling about in great, swinging curves. These are constantly but usually slowly changing in form and position. In the meander the river current has its greatest velocity on one side (Fig. 138); and hence in places it is cutting against the soft banks, thus increasing its swing as it eats its way into the land. This does not broaden the channel, but merely changes its position, for as the water cuts against one bank, it deposits sediment on the opposite one, where the current is not so rapid. Therefore the *width* of the channel remains about the same, but its *position* slowly changes, and in time the river wanders over all parts of its floodplain. On many of these level areas the river increases the *curve of meander* so that in passing down stream upon a steamer, one may often look across a narrow neck of land and see the river half a mile away, but several miles distant as the boat must go. Gradually eating against its banks, the river sometimes cuts through them, taking a shorter course and abandoning the "ox-bow" curve, which then becomes a somewhat circular lake in the floodplain, called an *ox-bow cut-off*. These are common in streams and there are many large ones on the Mississippi floodplain.

Waterfalls.— Waterfalls and rapids are formed where-ever the stream channel changes its slope rapidly. They are *convexities* in the river bed, and between falls and rapids there is no distinct difference, excepting that in the one case the bed descends with nearly vertical slope, and in the other less steeply. A fall may change to a rapid, or *vice versa.* There are various ways in which these conditions may be introduced into the stream bed. By some means the river may be turned out of its course and forced to fall over a precipice or down a steep hill-side. This was the case with Niagara, which at the close of the Glacial Period found its course leading it to the edge of the bluff at Lewiston, over which it fell, forming the first Niagara, seven miles distant from the present fall. A lava flow, or a land-slide, or the growth of a mountain across a stream bed, may introduce a similar steep slope; and sometimes rapids or falls are caused where a side stream brings coarse materials into the main river, which, not being able to bear them away, allows them to accumulate, forming a steep

Fig. 154.

A view at Ludlowville, central New York, during time of low water. A hard limestone bed with soft shales below causes a waterfall. Shales beneath cut out in the form of a cave. A miniature Niagara in all features.

slope in a part of the bed. There are rapids of this kind in the valley of the Colorado River.

But many streams *develop* rapids and falls as they proceed in the construction of their valleys. If in cutting down in their channels they encounter a hard layer with a soft one below, they can cut the latter more rapidly than the former, and hence increase their slope (Fig. 154). This very increase of slope gives them new power to dig, and so they deepen the channel more and more, perhaps in the end forming a very high fall. Many of the waterfalls of New York, and other regions, have been formed in this way, and Niagara, though first caused as above stated,

Fig. 155.

A general view of Niagara, showing Horseshoe Falls in the distance.

still continues to exist for this very reason. Therefore we may take Niagara as a type of this kind of fall.

Niagara began as a waterfall at the bluff at Lewiston and has gradually retreated up stream, until it has reached its present position, where it is a great fall about 160 feet high (Fig. 155), and 7 miles from its original position, from which it is now separated by a gorge, 200 or 300 feet in depth, which it has cut out of the rock. The fall is still moving backward at a rate which has been measured. During the last 50 years Niagara has moved up stream about 250 feet, yet it stands at about the same elevation. The reason why Niagara has thus retreated is found in the difference in rock structure. Just beneath the water, at the crest of the Falls, is a sheet of hard limestone, beneath which are beds of soft shale. Dashing over the fall, the water digs into the shale and cuts it out from beneath the

FIG. 156.

A peat bog in the Adirondacks with a pond enclosed — the last remnant of the former lake. (Copyrighted, 1888, by S. R. Stoddard, Glens Falls, N.Y.)

hard layer of limestone until some of this is undermined, when a block falls, and the waterfall moves up stream for a few feet (Fig. 154).

This process of undermining continues, and Niagara remains as a fall because it cannot cut the hard limestone as fast as the shale. The fall will remain just so long as these conditions exist in the stream bed; but it will of course disappear when the stream has reached its lowest slope, or the profile of equilibrium; for it cannot then cut one part faster than another. There are thousands of falls in this country where the cause is the same as this; and these are all in streams that are young enough to be digging into their beds, and hence able to discover differences in the hardness of the rocks. Therefore falls and gorges are closely associated.

Lakes. — A waterfall is a convexity in the stream channel; a lake, a *concavity*. When for any reason a lake exists, the basin must be filled as high as the lowest part of the rim, where it will outflow, provided the rainfall is sufficient. There are many ways in which such basins may be caused. A surface of new land, like a sea bottom just elevated, may have saucer-like depressions upon it; or these may be caused by the change of level of the land. For instance, a mountain developing across a stream channel, often causes a dam, behind which lakes gather; or a lava flow may check a stream; or deposits left by glaciers may build dams. The latter cause accounts for most of the lakes of the world, especially those of northwestern Europe and northeastern America (Chap. XVII). A lake is therefore a part of the river valley.

Lakes will exist in the course of a stream only for a short time, because rivers "are the mortal enemies of lakes." They are cutting down the outlets and filling the basins with sediment. Generally they cut very slowly, because they have no tools with which to work, having been robbed of most of their sediment in passing through the quiet lake water, which acts as a filter. The lake will last until destroyed by the combined process of filling and cutting at the barrier, and the last stage will be a *swamp*, for when the water becomes shallow enough, vegetation commences to grow, completing the filling, and transforming the water to land. The great majority of the swamps of the world are the result of the filling of lakes.[1] When the lake is filled, the streams flow over the surface of the deposits, and being no longer robbed of their sediment, begin to cut into the lake beds, and perhaps cut cañons where the lakes formerly existed. The filling of small ponds is a small task, but the destruction of such immense bodies as the Great Lakes is a much more difficult one, though still possible if time enough is allowed.

Sometimes lakes are caused to disappear by other means. For instance, a great lake once existed near Salt Lake City, the Great Salt Lake being the shrunken remnant. This which once outflowed into the Columbia, was destroyed by a change of climate from moist to dry, so that the water evaporated faster than it was supplied. Also in the valley of the Red River of the North an immense lake has recently existed, at the time when the great glacier formed a dam and prevented the river from flowing northward, causing it to outflow toward the south into the Mississippi. This lake disappeared when the glacier withdrew far enough to allow the water to take its natural northward course.

So also at a time when the glacier prevented them from outflowing as at present, the Great Lakes have been higher than now. For in-

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[1] There are other kinds of swamps, the next most important being river swamps caused by river water overflowing its floodplain.

stance, once when the ice occupied the St. Lawrence valley, the lake waters rose higher than now, and Lake Ontario outflowed through the Mohawk. Even before this, when the Mohawk was also ice-filled, the lakes flowed through other channels, once past Chicago, and once past Fort Wayne, Indiana. While these high stages existed, the lake waters built beds, cut cliffs, and deposited layers of sediment over their beds, and these now appear on the land, so that we may study them, and from them see what is now being done in lakes. This is the reason for the extensive wheat plains of Dakota and Manitoba, in the valley of the Red River, which were built in the bed of a lake; and also of the elevated beaches which pass through New York, near Lakes Ontario and Erie, and thence westward into Ohio.

Lakes generally have outlets; but sometimes, where the climate is dry, they do not fill their basins to the rim. There are many such lakes in the Great Basin, and in other dry regions of the world, and among these are many *salt lakes*. In time any lake without outlet will become salt, because all water that is flowing over the rocks bears some salt. When it evaporates, the vapor is nearly pure water, without the salt, and hence the salt is left behind. So day by day, more and more salt is supplied, and the water that brought it does not flow away with it to the sea, but passes into the air *without* it. Thus little by little the fresh-water lakes become salt, and then salter and salter, turning to *dead seas*, and perhaps becoming so saline that some must be deposited as rock salt in the lake. Even the Great Lakes would become saline if the climate should become so dry that they could not rise to their rims.

CHAPTER XVII

GLACIERS AND THE GLACIAL PERIOD

Valley Glaciers. — In some parts of the earth the snow remains on the ground throughout the year. This occurs on high mountain tops or else in high polar latitudes, where much of the precipitation is in the form of snow, and where the effect of summer melting is not sufficient to remove the supply of snow. The line above which this remains permanently on the ground is the *snow line.* Among mountains the snow line, if present, is found in the upper portions; and in temperate latitudes only the high valleys and peaks are covered with perpetual snow. Here, since each summer fails to remove the fall of the preceding winter, snow gathers year by year, filling many valleys and clothing mountain sides in a permanent coat. This is known as a *snow field*, and it is from here that valley glaciers, such as those of the Alps, have their origin.

A snow field on a high mountain is elevated into the zone of strong winds; and therefore much of the snow that falls upon it is whirled away, settling at some lower level, and very often in the valleys between the peaks. By this means there is a constant movement from the snow fields into the valleys. Besides this, the high peaks of the mountains are very steep, and much of the snow that falls cannot lodge upon the slopes, but slides down into the valleys. Much more slides down in the form of great *avalanches*, or snow slides, after the snow has become so deep upon the slope that it must slip off. By this means the snow is prevented from reaching great depths in the high parts of the mountains, and much of it therefore passes down into the valleys, as water does on the land. Indeed, we may call the snow field the *supply region* for the ice streams or glaciers which occupy the valley.

Fig. 157.

Snow field in the high Alps.

In a snow field the material is true snow, in the glacier real ice. There is a region between these two, near the head of the glacier proper, where the snow is changing to ice, and this is called the *névé*. By melting and freezing, and by pressure, the snow becomes compacted into ice, and then it slowly flows down the valleys as glaciers, passing down by a slow movement, somewhat as wax will flow if a large piece is placed upon an inclined surface and gradually warmed. In other words, the glacier ice behaves like a *viscous body*.

Hence supplied from the ice field, the valley glacier slowly passes down the mountain side, extending well beyond the snow field, just as a river flows out beyond the place from which its water comes. It will pass down as far as the supply exceeds the melting, and will then end; and the terminus of the glacier will therefore extend much further if the supply is great, than it would if this were small. Throughout its passage down the mountain valley the glacier receives much rock material. Just as in the case of a mountain river, so here, weathering supplies rock fragments. Avalanches, single

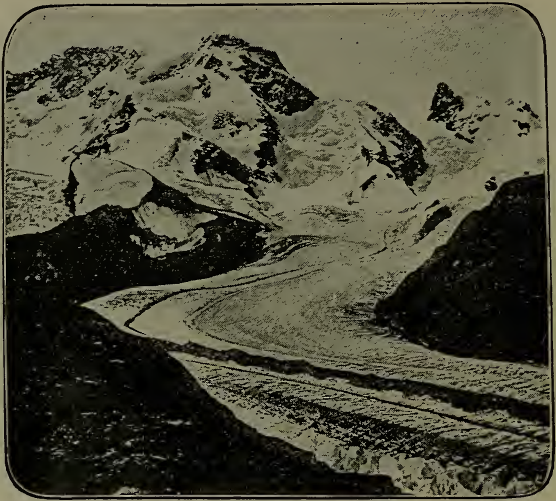


Fig. 158.
An Alpine glacier, showing snow field, ice stream, and medial moraine.

blocks, and bits whirled by the wind, are carried upon the ice, forming a *moraine.* Those piles of rock fragments, dropped mainly from the valley sides, and resting on the surface of the glacier near its margin, are called *lateral moraines.* When two glaciers unite, two of the lateral moraines may join, forming a *medial moraine* (Fig. 158). This is a dark band of rock and gravel in the middle of the ice, and on some glaciers there are several of these.

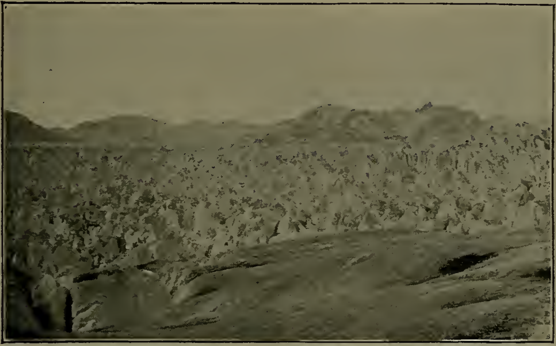


Fig. 159.

Rough crevassed surface of Muir glacier, Alaska.

Although when subjected to slow pressure the ice flows like a viscous body, if for any reason it is strained, or caused to move rapidly, it may crack, as we may break ice or wax by striking it a blow. Therefore when flowing over its bed, since this is generally an irregular rock surface, it is often cracked or *crevassed*, perhaps becoming exceedingly rough and even impassable. Where the valley bottom slopes rapidly, an *ice fall* may be caused, in which the ice is crevassed into an irregular surface, quite closely resembling a river surface tossed about in a rapid.

Through these crevasses some of the surface moraine falls to the bottom of the glacier, and it is then dragged along the bottom, where it obtains more material rasped from the bed. The rock fragments in the bottom of the ice form what is known as the *ground moraine.* This together with the lateral and medial moraines, journeys slowly forward in the glacier until the end is reached, where the ice melts and flows away in streams, while much of the ice load of rock materials remains behind, forming a moraine at the end of the glacier, the *terminal moraine.* If the ice front remains at one place for a long time, the terminal moraine may be built to a considerable height, being made of hills of gravel and boulders brought and dumped by the ice.

As it passes over the rock of its bed, the valley glacier acts like a powerful sandpaper, grooving and polishing the surface over which it passes, and grinding the fragments to a fine clay. In its *mode of work* it is unlike a river, for it presses down on its bed under the heavy weight of solid ice above, while water, buoying up the sediment which it carries, makes the pebbles and sand lighter. The glacier differs also in the material which it carries. Since the rock fragments are frozen into the ice, a large boulder is transported as easily as a bit of sand, and so they journey along side by side; but in a stream the velocity may be rapid enough to carry sand, but not to carry pebbles. Hence it is that the deposits made by the glacier are composed of bits of rock varying from fine clay to large boulders, many of which are scratched because they have been ground under the ice (Fig. 162). But the materials deposited by rivers are *assorted* according to the size which can be carried with a given velocity. If the glacier disappears from a valley by melting, — and many have done so in the past, — the moraines are left on the surface, perhaps damming the streams and forming lakes, or turning them out of their path into more irregular courses, in which perhaps they are obliged to cut new valleys.

From the front of the glacier there generally emerges a stream (or sometimes several) coming from an *ice cave*, out of which they flow with considerable velocity, bearing much sediment, which usually makes them milky white in color. This they carry down their valleys, depositing some of it in the channel, when the slope decreases, or perhaps over floodplains, or in lakes. Therefore not all of the material which the glacier carries, remains in the terminal moraine at the margin of the ice.

Valley glaciers move at a variable rate, depending upon the slope and the snow supply. Their movement is ordinarily only a few inches or a few feet a day, but some of the valley tongues of ice on the Greenland coast move as much as 75 or 100 feet a day. The glacier movement is generally so slow that it is necessary to observe very carefully in order to detect it. The movement is more rapid in the centre than on the sides, where it is retarded by friction, and for the same reason less rapid near the bottom than at the surface. They flow in valleys which previously existed, and probably glaciers have never carved their valleys as rivers have; but in some places they are widening and deepening them. Where they cut into the bed more rapidly than elsewhere, they have carved out basins in the rock, in which lakes later accumulate after the glaciers have left the valleys.

Mountain valley glaciers exist in the Caucasus Mountains, the Alps, and in the Norwegian mountains, in Europe; in New Zealand, the southern Andes, and in various parts of central Asia and western America. There are many thousands in the world, but in the United States proper there are only a few small glaciers, in the northern Rockies and in the Sierra Nevada; but as soon as the Canadian border is reached they commence to be numerous among the mountains. Glaciers exist on the line of the Canadian Pacific Railway, and from this place to northern Alaska they are very numerous. No part of the world has larger or more perfect valley glaciers than Alaska. The most noted of these is the Muir Glacier, north of Sitka; but in this region, and further north in the Mt. St. Elias region, there are many other grand valley glaciers which frequently terminate in the sea.

While glaciers are now scarce in this country, in recent geological times there have been many in the higher valleys of the Rocky Mountains and the Sierra Nevada. These existed at the time of the Glacial Period, and have left a record of their existence in the presence of moraines, ice-polished rocks, and boulders which have been taken from the mountain tops down into the valleys. Where now there are only a very few tiny glaciers, scarcely more than mere snow fields, there were formerly hundreds of well-developed valley glaciers. Because of a change in climate they have gradually disappeared from the land.

The Greenland Glacier. — In two parts of the world there are immense glaciers covering all the land and moving over both hill and valley. One of these is in the Antarctic region, surrounding the south pole, the other in Greenland, which is almost entirely ice covered. Almost nothing is known about the former, but many geologists have visited the latter. In Greenland all but the margin is buried beneath snow and ice, the total area of this great glacier being about 500,000 square miles, an area 10 times as great as the state of New York. Both in summer and winter snow falls upon the high interior region, in which there is absolutely no land, and where the country has been buried to a great depth and its surface raised to an elevation of 10,000 feet by the accumulation of snow. The snow of the interior becomes compacted to ice at a slight depth, and as it accumulates, slowly flows out in all directions from the interior toward the coast, north, south, east, and west. It moves somewhat as a pile of wax might flow if a weight were placed upon the top.

Fig. 160.

Margin of Cornell Glacier, Greenland showing terminal moraine. Black layers of ice carry quantities of rock fragments.

Near the sea there are occasional mountain peaks projecting above the glacier, forming what the Greenlanders call a *nunatak;* and there are also many islands and peninsulas over which the ice does not extend, though upon which there are many small valley glaciers. The great ice cap of Greenland, riding over all the land, and burying even high mountain peaks, moves slowly down to the sea, which it enters at the heads of bays or fjords, where it breaks off in the form of icebergs. Between these places the ice rests on the land (Fig. 160), where it melts, forming streams which course along between the land and glacier. Now and then the water is dammed into a tiny lake into which the streams carry much sand and clay, building deltas (Fig. 161).


Fig. 161.
Delta in tiny lake formed by ice dam at margin of Cornell glacier, Greenland.

Away from the coast the surface of the Greenland ice cap is pure and free from moraine; but near the sea, where peaks project above the surface, there


Fig. 162.
A scratched glacial pebble from moraine of Cornell glacier.

are lines of moraine on the glacier, though these are not numerous. Therefore nearly the entire surface of the Greenland ice sheet bears no moraine; but in the lower parts there is considerable rock material, consisting of fragments varying in size from grains of clay to huge boulders (Fig. 160). Therefore the glacier is armed with cutting tools with which it can grind the land over which it slowly glides. Indeed just beyond the edge of the ice are seen rock surfaces recently covered, and now grooved and polished by the ice-scouring which they have received. That the ice worked well is shown by the scratches and grooves of the rock, which point in the direction from which the glacier flows. These were formed by the ice, which pressed the boulders against the bed rock and dragged them along, as we might scratch two rocks by rubbing them together. The fragments brought in the ice are often quite unlike those on which the edge of the glacier rests; and hence it is certain that they have been brought from some other place.

Fig. 163.
Photograph of a piece of floating ice, showing the relative amount of ice above the water surface (AA) to that below.

Where the glacier enters the sea, the ground moraine materials float off in the icebergs; but where it ends on the land, some goes off in the streams, but much remains, building terminal-moraine ridges and hills, as in the case of valley glaciers. At some recent geological time the ice has been more extensive, having formerly covered much of the land which now rises above it, and perhaps having entirely obscured the Greenland margin. The evidence of this is the presence of moraines on the land, boulders that have been brought from some other place, and smoothed and scratched rock surfaces. In fact, these are the same as may now be seen exactly at the margin of the glacier.

Fig. 164.
Iceberg off the North Greenland coast.

Icebergs.—When a glacier ends in the sea, fragments of ice break off and float away, forming icebergs; and these vary in size from tiny pieces up to great masses, perhaps a mile in width, and 100, 200, or even 300 feet in height; but in the Arctic, icebergs rising more than 100 feet above the water are uncommon. Since ice when floating has 8.7 parts below the surface to one above, a berg 100 feet high sinks deep in the water, and is really an immense ice mass. In the Antarctic, some huge icebergs have been reported to be so large that they have been mistaken for islands.

Breaking off from the glacier front with a thundering crash, sounding like a volley of artillery, they rock backward and forward, setting the water into commotion and causing powerful waves to move out in all directions. Then they float majestically away, being driven to some extent by the wind, but mainly by the ocean currents, changing position now and then, and once in a while running upon a shoal, where they remain until by melting they can once more float away. Gradually they journey toward warmer latitudes, slowly melting until they finally disappear, perhaps thousands of miles from their place of birth. The ocean steamers which cross the Atlantic to Europe, often encounter icebergs 1000 or 2000 miles from the parent glacier. Starting very often with a load of rock fragments in their bases, they strew these over the sea bed as they slowly melt.

FIG. 165.

Map showing extension of ice in eastern United States (by shading). The heavy lines mark the position of terminal moraines.

Glacial Period: *Evidence of this.* — Over northwestern Europe and northeastern America, down to the line marked on the accompanying map (Fig. 165), the surface presents many peculiar appearances. The soil is not the residual soil of rock decay that commonly forms when rocks are exposed to the weather, but generally consists of a clay in which there are occasional, or in some cases numerous boulders. This is known as *boulder clay*, or *till* (Fig. 166). This till is not found everywhere, but here and there, especially in stream valleys, are beds of sand and gravel, not unlike those now occurring where streams flow from the end of a glacier, as in Greenland. These deposits are not strewn over the surface regularly, but in some cases are 200 or 300 feet deep, though elsewhere there may be no more than a mere veneer of boulder clay upon the rock. Indeed, in some cases the surface is bare rock.

The pebbles and boulders which occur in the till are not the same as those of the rock in the neighborhood, but many have been brought from the north, some now found in the United States having come from Canada. Moreover they are scratched, quite like some now found in the Greenland moraines, as if they had been ground against other rocks; and the bed rock of the region is scratched and polished as in Greenland (Fig. 167), and the surface is

Fig. 166.
Glacial till or boulder clay, Cape Ann, Mass.

scoured into rounded outline, giving the form known as *roches moutonnées*, or sheep-back rocks. The grooves and scratches point toward the place from which the boulders have come, as they do in Greenland.

FIG. 167.
Rock surface in Iowa, scratched by passage of glacier.

In the regions where these peculiarities occur, there are also many lakes and waterfalls, where streams have been dammed or forced out of their valleys by deposits of boulder clay and gravel. There is an area extending across our country, in a general westerly direction, in which these conditions are found, but south of which they are absent. This line of division separates a land of lakes, falls, and gorges, or in other words of young streams, from one in which these are either absent or very much less abundant. Moreover, on the one side the soil is boulder clay, on the other residual; and on the one side the boulders are foreign to the region, and both the pebbles and bed rock are scratched, while on the other they are not scratched, and there are no foreign rocks.

If we were to go to this area of separation, we would find that it was marked by a line of hummocky hills quite closely resembling a terminal moraine. This, which we may call the *terminal moraine of the Glacial Period*, extends across country, passing up hill and down; and it marks the limit to which ice extended at a recent period, bringing boulder clay and scratching and grinding the rocks over which it passed. Because the conditions so closely resemble those seen at the margin of actual glaciers, and because no other agent will do what has been done here, geologists have concluded that in a recent geological period, a great *continental glacier* covered northeastern America and northwestern Europe, as Greenland is now covered.

Fig. 168.

Terminal-moraine hills near Ithaca, N.Y.

Cause of the Glacial Period. — The *fact* that the Glacial Period really has existed cannot be doubted; and this being so, we must believe that there has been a great change in climate which allowed ice to advance over the country, and then another which caused it to withdraw. This is in harmony with the evidence concerning the shrinking of the Greenland ice, and the disappearance of glaciers from the mountain valleys of the west. Concerning the cause of this there has been much discussion; but like many scientific facts, the true explanation has not yet been found and proved. We have many theories, but it is difficult to prove one and disprove the others, for the question deals with conditions that are past, and the *effects* of which only can be studied.

FIG. 169.

A boulder-strewn moraine hill, Cape Ann, Mass.

Glacial Deposits. — When the ice front stood at any one place for a considerable length of time, it dragged ground moraine down to its edge and piled it up along the margin as a terminal moraine. There are many such moraines in the United States and Canada; for not only did the ice advance to and stand at the line described above, but as it slowly melted from the land, its front stood along lines further and further north, and each time that it halted a moraine was built. These terminal moraines are among the most characteristic land forms in this country (Figs.

168 and 169). They consist of a dump of rock fragments, varying in size from boulders to clay, and their surface outline is irregular and hummocky, as any mass of earth would be if dumped without order. There are small hills, saucer-shaped valleys, ridges, and in general an exceedingly irregular surface. They are chiefly composed of till brought by the glacier and laid down without assortment, and hence without stratification; but they also contain beds of *stratified* sand and gravel, which were deposited by water furnished by the melting ice. Therefore these moraines are complex in structure as well as outline.

When the ice advanced, it carried with it a load of rock fragments which it held as a ground moraine; and when finally it disappeared, this was left as a sheet of boulder clay strewn over the surface, sometimes as a thin layer and sometimes in very thick beds. When the ice crossed valleys, till was often dragged down into these and left there, so that some valleys have been entirely buried, while others have a filling of perhaps 100 or 200 feet of boulder clay. Some of the till is very bouldery (Fig. 169); but in other cases, where the supply of hard rock was scanty, there are few large rocks (Fig. 168), and in some of the till no boulders are found. This till has various forms, but generally it is a sheet extending uniformly over the surface of the rock on which it rests. The streams from the ice have also deposited sheets of gravel and built low hills of various kinds, and the land which has been ice covered is therefore strewn with various kinds of glacial deposits.

Effects of the Glacier. — While it existed the ice did much work. It has moved materials from one place to another; it has swept off the old soil and replaced it by a new kind; it has worn and lowered many of the hilltops, deepened some of the valleys, and partly or entirely filled others; and it has left the land surface quite different from the way in which it was found. Still with all its work, it has not been able to erase the larger preglacial hills and valleys, but merely to modify them.

The most important effect of glacial action has been upon the drainage. When the ice stood as a barrier on the land it stretched across many stream valleys whose slope was toward the north, and these were then transformed to lakes, which being prevented from flowing as the land sloped, were forced to seek some other outlet. Therefore many north-flowing streams for awhile flowed southward, and some of these, cutting down the barriers at their outlet, lowered them so greatly that when the ice disappeared, the slope of the land no longer led them northward, and they continued to flow in their reversed direction.

One of the best cases of this is found in the headwaters of the Alleghany, which before the Glacial Period belonged to the St. Lawrence drainage, but now joins the Ohio. While these lakes existed, beaches and deltas were built in them; and since the water has now disappeared from the basins, we may often see these old lake deposits clinging to the hillsides. Not only did these conditions exist near the *southern* terminal moraine, but along the margin of the ice, wherever it stood on the land. Hence as the glacier withdrew northward, as it was melting from the country, the zone of *temporary glacial lakes* extended further northward.

Before the ice came, the land was carved into hills and valleys, and streams occupied the surface; but while the glacier existed they were for a time extinguished. As soon as the ice left, the streams again occupied the land, but only to find the old valleys considerably altered. In some cases, as in Ohio and the other level states of the plains, the valleys were entirely obliterated by glacial deposits, and new ones had to be started by young streams flowing on the plains of glacial deposit. In other cases, and particularly in the moderately hilly countries, streams were sometimes caused to leave their *old valleys* and carve new ones. Or they were turned from the *old channels* by glacial deposits and caused to cut gorges in the rock, or in the till, to one side of their former course. Therefore, they were locally *rejuvenated;* and hence it is that so many streams in the glaciated country flow in gorges for a part of the distance, and that in these there are numerous waterfalls (Chapter XVI).

With equal frequency *dams* of moraine have been thrown across the stream course, forming lakes. Upon the irregular sheet of till, the terminal moraine and the gravel hills of United States and Canada, there are probably more than 100,000 lakes and ponds. Practically all the lakes of northern United States and Canada are the result of glacial deposits, either because their surface was dotted with saucer-shaped depressions, or else because they have formed dams across stream valleys. This is one of the reasons for the existence of the Great Lakes, though they were undoubtedly caused in part by the action of ice in digging valleys deeper, and in part by changes in the level of the land which have formed rock dams. Even with these causes, much of the area of the Great Lakes is due to the effect of glacial deposits which have partly choked old preglacial valleys.

CHAPTER XVIII

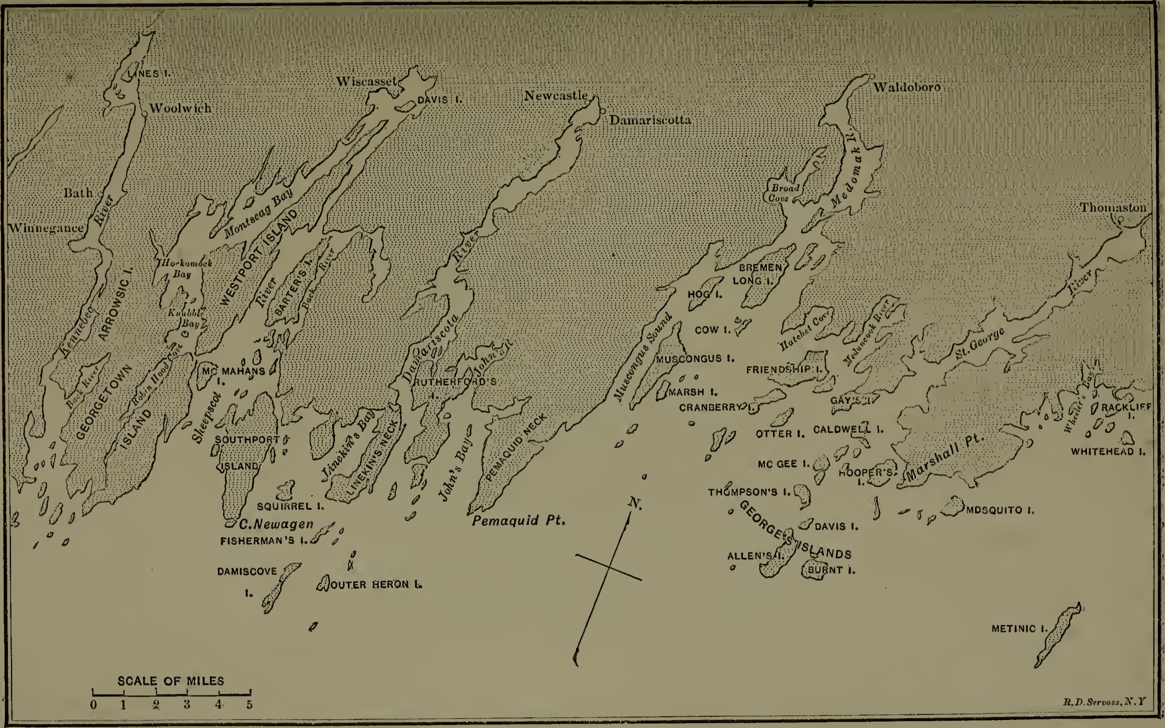
SEA AND LAKE SHORES

Difference between Lake and Sea Shores. — While there are many differences in detail, the shores of sea and lake so closely resemble one another that they may be considered together. In both we find cliffs and beaches, promontories and bays; and in each there are many differences between these from point to point. In both places there are waves constantly at work, and these differ in force from place to place; and there are also wind-formed currents in each. But in several ways they differ: no great circulation, like that of the ocean currents, is found in lakes, nor are there well-developed tides. Besides these, animal life is less abundant in lakes than in the sea, and therefore certain kinds of shores which are constructed by ocean animals are never found in lakes. On the other hand, the action of plant life is different in the two bodies, being more important in the fresh water.

Form of the Coast. — If we pass along an extensive stretch of coast line, we find many differences as we proceed. For instance, the coast of New England, north of Cape Cod, is chiefly rocky, and exceedingly irregular. There are tens of thousands of islands and peninsulas, great and small, and as many bays, harbors, and estuaries. To go on foot along the margin of such a shore for a distance of a dozen miles, as measured from headland to headland, may require one to walk not less than 100 miles, in passing around the bays (Fig. 176 and Plate 19). While rocky in general, it would be found by such a journey that the abrupt sea cliffs and headlands often enclose beaches, either of pebbles or sand, and that salt marshes and mud flats line the head of many of the bays.

Passing south of Cape Cod, it is found that the coast becomes less abrupt and rocky, and at the same time less irregular, until on the Carolina coast the shore is a series of sand bars and beaches, with no rocks and few irregularities, excepting those formed by the sand bars. Still further south, on the southern end of Florida, the coast again becomes irregular; but here the islands, or as they are called, the *keys*, are made of coral fragments. Carrying the examination to more distant lands, we see that while the coast of Europe and the northern coasts both of western and eastern America are exceedingly irregular, the west coast of South America, although rocky, is so uniformly straight that good harbors are scarce. These differences are due to perfectly natural causes, most of which can be simply explained.

Sea Cliffs. — Beating against the coast, the waves, armed with pebbles and sand, are cutting into the land. They gradually wear away the hardest rocks, and on many coasts have made important changes, even since man has inhabited them. Where waves are at work violently, whether in lake or sea, their resistless sawing at the rocks cuts them into the form of cliffs (Fig. 170), which if the rock is hard, may rise nearly vertically, or if soft, with less steep slopes; for then the sand, clay, or gravel will slide down until it can come to rest. With the action



Facing page 314.

PLATE 19.—Map of a part of the coast of Maine. A drowned coast.

of the waves and their allies, the wave and wind currents, not only is the rock cut away, but it is removed, leaving the cliff open to fresh attacks. Just so long as this is done the cliff will maintain its steepness; for the waves saw along a narrow zone near sea level, and thus, undercutting the cliff (Fig. 171), perhaps forming *sea caves*, undermine the rock above, causing it to fall because its support is removed. So, gradually by this undermining action, fragments of the cliff face are caused to fall, and slowly it moves backward, the falling fragments being carried away by the waves. If the time comes when the materials cannot be taken away, the waves cease to cut into the cliff, and under the influence of weathering it gradually loses its steepness.

FIG. 170.
A sea cliff on south shore of Bermuda.

Sea cliffs of great size, rising hundreds of feet out of the water, are found in the open ocean where the full force of powerful waves can be exerted against the shore; but similar though smaller cliffs occur in lakes (Fig. 172), and also in the enclosed bays of the seashore, where smaller waves are generated. Their form varies greatly with the *kind of rock* out of which the coast is made; some shores crumble so rapidly under weathering that they are never vertical, and this is particularly true where the material is soft sand or gravel. In other cases the rocks are so hard that they can be cut into the form of a cliff, which maintains the form of a precipice for a long time. Sometimes these vertical cliffs are several hundred feet in height, rising directly from the water; but in other cases the shore consists of rounded and somewhat irregular outlines. The sea cliff is the natural result of wave work where they are free to cut as they will. One may therefore expect that this would be not only the grandest but also the commonest of seashore features; but the latter is certainly not true.

FIG. 171.

Wave-cut islands, Bermuda, showing undercutting action of waves.

The Beach. — When the waves are cutting against a cliff and wearing it back, they are obtaining materials which must be disposed of if they would continue their work of cutting. As has been explained, the materials wrested by the waves are removed by the undertow, the wind-formed currents, and the swash of the surf, which rushes upon the land at a slight angle to the direction in which the coast extends. By the first of these some of the material is carried *off shore*, and by the others *along shore;* but to that burden which the waves themselves take, is added one *imposed upon them.* Weathering, wind action, and rivers, are furnishing other materials to the waves, and these supplies sometimes become so great that the waves are *overburdened*, and cannot perform the great task of removal thrust upon them.

For instance, along the entire coast of the United States south of New York, excepting at the southern end of Florida, the waves have more material than they can carry off. Hence it is that the great ocean waves that beat against the Carolina coast are *not* cutting cliffs in the soft rock, but are breaking upon sand beaches, often at distances of several miles from the *real shore*, from which the outer beach bars are separated by lagoons and marshes. These bars, such as those forming Cape Hatteras, have been built up by the waves out of materials which were furnished them, but which they could not carry away. Being forced to lay down their burdens, they have built hundreds of miles of bars; and then the winds, taking the sand from the beaches, have piled it up in the form of sand dunes or sand hills. Therefore the bars are partly wave-formed and partly wind-formed; but the supply has been furnished chiefly by the rivers.

Along an irregular rocky coast, like that of Maine, the waves have an easier task. They have harder rocks against which to work, and hence get less of a load to carry, and the rivers entering the sea there do not transport so much sediment. The coast is more irregular, and because of this the waves beat against the relatively few headlands, wear fragments off, carry some out to sea, and drive others along shore until an indentation of the coast is reached, where the load is dropped, because upon entering a bay or harbor, the power of the waves decreases. Hence upon this coast there are many little *pocket beaches* of sand, pebbles or boulders that have been wrested from the neighboring cliffs and driven into the depressions. In the larger indentations there are extensive beaches of sand and pebbles (Fig. 110). Further up, near the head of bays, where the waves are always tiny, mud flats exist, because here even clay cannot be carried away, and that which the waves wear off, as well as that furnished by weathering and streams, is accumulated there.

FIG. 172.
Wave-cut cliff with beach in small bay, Lake Superior.

By this means the bays and other indentations of the coast are gradually filling up. They become a dumping ground for the wave-derived materials, as well as those coming from the land itself. Because of this fact some harbors have been rendered useless, while upon others it is necessary to spend large sums of money every year, in order to keep them deep enough for large ships to enter. Therefore the double action of cutting the cliffs and filling the bays results in production of *more regular coasts*.

Fig. 173.
Bar built across bay, Cape Breton Island, Nova Scotia.

One of the first steps in harbor filling is the forming of a bar across the mouth of the indentation (Figs. 173 and 174). Driven along shore, the materials are dropped, causing the water near the mouth of the bay or harbor to become shallower. Later as more is added, the bar reaches the surface, and finally stretches from side to side, perhaps completely enclosing it, and transforming it to a pond, though more commonly a small opening is maintained through which the tide ebbs and flows. Along the United States coast there are thousands of such bar beaches, some of them miles in length.

Wave-carved Shores. — Besides constructing these *wave-built* forms, and cutting the sea cliffs, the waves have done much work of *carving* rocky shores into irregular outline. Wherever there is a softer layer between harder walls, the waves will find this and eat into it more rapidly (Fig. 175). Hence a rocky coast on which the materials vary in kind, is liable to be very irregular, consisting of alternating headlands and minor indentations. But these do not become very great, because as they increase in depth, the waves that enter have less power, and they become then a place of deposit, and have beaches built at their heads, which protect the rocks from the further attack of the waves.

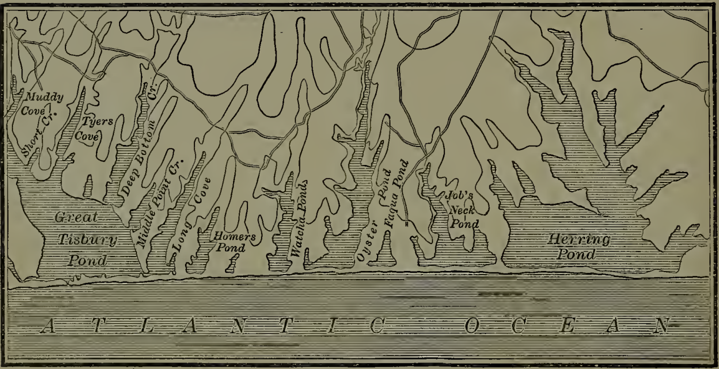


FIG. 174.

Map of a part of Martha's Vineyard, showing arms of the sea cut off by bars.

It has sometimes been stated that such great bays as the Chesapeake, and the straits, bays, and harbors of the coast of New England, have been cut out by waves and tides;

but this is certainly not true, for waves cease to be able to cut when they enter bays, and tides have not the power to do the cutting. Indeed careful study shows that such bays are being *filled*, not deepened and enlarged by tides and waves; and so it is necessary to look for another cause to explain these greater irregularities.

A Sinking Coast. — The elevation of the land is subject to frequent change, and some places are rising, others sinking, while some have recently changed in one or the other of these directions. If the land should sink near the coast, one of the effects would be to cause the sea to enter the valleys, transforming them to bays, if they were broad, or to fjords if narrow. Should the submergence continue, in time the water would rise over low divides and transform them to straits, and make some hills into islands, others into promontories and capes. The coast would then become very irregular (Figs. 176 and 180, and Plate 19).

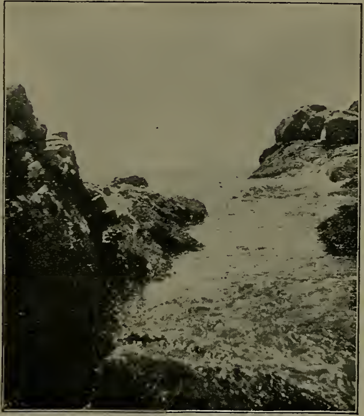


FIG. 175.

A wave-carved indentation on shore of Cape Ann, Mass. Small bay formed where a soft trap rock crosses the harder granite.

This description of what *would* happen may be applied to the eastern coast of North America and the western shores of northern Europe. Here there are islands which resemble hilltops, straits between capes and islands, and bays, harbors, and fjords which end in river valleys on the land. In fact the resemblance is so close to what actually would happen if the land should be partly drowned, that it is one of the strong proofs that such sinking actually has occurred. For instance, the strait separating Great Britain from Europe appears to represent a low divide sunk beneath sea level. The Hudson River, into which the tide rises above Albany, appears to be a river valley carved on the land. The Bay of St. Lawrence and its tributaries, and the Chesapeake and its branches, appear to be nothing more than land valleys now partly beneath the sea (Fig. 146).

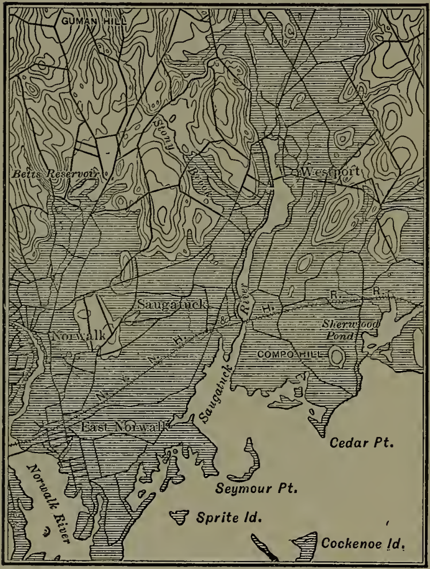


FIG. 176.

Map of part of Connecticut, showing present outline of coast with bays, peninsulas, and islands, and (by shading) the similar outline which would result if the land should sink a hundred feet more.

A sinking coast brings the sea water in contact with the hard rock of the land, and therefore reduces the amount of material which waves can cut. It makes the shore line more irregular, and therefore furnishes depressions into which the waves can drop their load. It causes the water to rise higher and higher, submerging the beaches which the waves commence to build. Therefore, for these various reasons, a sinking coast is liable to be not only an irregular one, but also one of numerous cliffs and few beaches. Thus on the coast of Greenland, which is now sinking, there are very few beaches; but high cliffs rise directly out of quite deep water. In lakes the rising of the water for any reason produces the same results, as may be seen on the south shore of the Great Lakes.

A Rising Coast. — A rising coast is less irregular because the sea bottom is much smoother than the land. It is covered with soft mud and sand, and hence the waves obtain a great load, and generally more than they can carry off, so that bars are often built, as in the case of the coast of Texas, which has been recently elevated. The western coast of South America is also rising, and this is the reason why there are so few harbors and such a wonderfully straight coast. In lakes whose level is being lowered, similar though much less pronounced effects are produced.

Marshes. — On many shores, such as those of eastern United States, there are extensive marshy plains in the protected bays and estuaries. These are seen on the New England coast as well as behind the sand bars of the more southern states. *Salt marshes* are formed by a partial, and in some cases a complete, filling up of these enclosed areas, which are out of reach of the ocean waves. Here rain and rivers wash materials into the arms of the sea, and to this deposit is added sediment driven in by the waves and borne by the tidal currents. Settling, the accumulation slowly raises the sea floor until the depth is shallow enough for certain plants to take root, and then these raise it still higher, partly by entangling sediment and causing it to settle, and partly by their death.

The salt marsh grass can grow only in places where it is at some time exposed to the air, though it must also at some time receive a bath of salt water. Gradually the surface rises to the level of the high tide, becoming then a remarkably level plain, through which extend numerous channels occupied by the rising tide, which fills them and then overflows the plain with a sheet of salt water. In time the marshes rise even above this level and then become dry land. Before this stage, in many countries, men have built dykes to keep out the salt water, and have established farms and even towns upon a plain which is really below the level of the high tide. Both in England and America there has been much land reclaimed in this way, and large areas of Holland were once salt marsh.

The mangrove (Fig. 77), a tree which can grow with its roots in salt water, is building similar marshes, though in this case tree-covered. In this country these are found in the bays of Florida, and they exist on other subtropical as well as tropical coasts. In lakes, similar treeless and tree-covered marshes are built by the aid of plant growth; and many small ponds are bordered by such swamps, while some have been entirely replaced by them. Both in sea and lake these marsh lands can develop only where the waves are not active enough to remove the clay or sand in which the vegetation takes root.

Coral Reefs. — Where conditions are favorable, animal life in the sea exists in great luxuriance; and particularly is this true in the shallow water in and near the tropical regions, where the reef-building corals abound. These animals can thrive only where the water is warm and the temperature never lower than 68° or 70°, the depth not more than 150 feet, and where they are not exposed to the air between tides. In addition to this, the animals must have a good supply of food, and hence they are generally found where ocean currents exist. If the water is muddy, or if fresh water enters the sea, they cannot abound. Hence reef-building corals need a combination of unusually favorable conditions, and their distribution in abundant colonies is not great. Where these favorable conditions are combined, the abundance of coral and other lime-secreting animals is marvellous (Fig. 79).

Corals may abound in the shallow waters near the land, along which they build *fringing reefs* rising nearly to sea level. Or they may build a reef just off shore, which is then known as a *barrier reef*. They grow so luxuriantly that they build the bottom up so near the surface that the waves, coming upon the shore, break over the reef, forming a great line of surf, in which the animals thrive because the water is kept in commotion, thus causing a constant passage of food, which must *come* to the corals, since they are firmly anchored in place. Upon passing over the reefs, the waves break off fragments of coral, or tear away entire masses, and drive them ashore upon the beach, where they are ground up (Fig. 177).

FIG. 177.

Beach on coast of Florida. Position of coral reef shown by line of breakers.

This coral sand, taken by the wind, may be blown into the form of hills; and hence land will be actually constructed out of coral fragments. The southern end of Florida and the Bahama Islands are made of coral substance; and the entire area of the Bermudas, above sea level, is made of shell sand derived from reefs and built into the form of hills by the action of the wind. Along the shores of northern Australia there is a reef, called the Great Barrier Reef, which is over 1000 miles in length; and from this is being supplied a vast amount of material out of which rock is being built.

In the southern Pacific there are many coral islands far away from any land, and having the form of a more or less perfect ring. These are known as *atolls*, and the coral ring rises a number of feet above the water surface, partly because the waves have thrown fragments above sea level, but chiefly because the wind has blown the coral sand from the beach into the form of low hills.[1]

Islands. — Islands are either *new land* built up in the sea or else remnants of *old land* partly destroyed. The former may be called islands of *construction*, the latter islands of *destruction*. By far the greater number of islands exist near the sea coast, but not a few are found in mid-ocean. In size they vary from tiny bits of land, covered at high tide, to immense islands, like that of Greenland.

By Construction.—Islands may be *built* by various means. *Near deltas* they are often formed because the waves cannot remove all the sediment out to sea. Along such coasts as that of eastern United States, particularly along the shore line of the southern states, where the waves have more

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[1] For the theories to account for these interesting atolls a book on geology may be consulted.

sediment than they can dispose of, the combined action of *winds and waves* builds a great many sand bars, which are true islands, generally very long and narrow. Along our coasts there are many thousands of these, mostly small, but sometimes a score or two of miles in length. Such bars can be made only *near land*, where the water is shallow. *Animals* are also building islands; the coral reefs and the atolls just described are of this class. Along the coast of Bermuda there are many tiny islands that have been built by *serpula* (a worm that makes a calcareous shell) into the true ring form of the atoll (Fig. 178).

Fig. 178.
Serpula atolls, Bermuda.

Islands may be constructed by the *elevation* of an irregular sea bottom; for then higher parts of the bed may be raised above the sea, forming islands. Or the *folding* of the sea bed through the formation of mountains may also raise parts above the sea level. This is the origin of many of the larger islands of the world. The East and West Indies are parts of mountains not now raised high enough to form a portion of the continents near which they lie.

The Hawaiian Islands are an instance of this; for between the several islands of this group there extends a ridge of upfolded sea bottom, evidently a true mountain range beneath the sea. The peaks which rise from the crest of this ridge are illustrations of another type of constructed islands, *the volcanic*. By outpouring of molten rock these peaks have been raised as islands, and in this case also there are many similar elevations not yet raised above the surface. All the isolated islands of the open ocean, excepting those made of coral, are volcanic peaks; and it is probable that most, if not all of the isolated coral atolls of the mid-ocean have been built by animals upon platforms constructed by volcanic causes.

FIG. 179.

Islands on shore of Bermuda, cut from the land (on right) by wave action.

By Destruction. — By far the greatest number of islands are caused by the *destruction* of land. For instance, the *waves* beating against the shore and wearing it back, may leave some parts standing for awhile, thus forming islands (Fig. 179). Such islands can never be large, being really tiny fragments of the coast line not yet destroyed.

The *sinking of the land* accounts for the greatest number of instances of islands of destructive origin. The partial drowning of an irregular coast transforms the shore into an exceedingly irregular area of promontories and islands, the latter being produced when the hilltops are surrounded by water. The subsidence of the Bermudas has caused the large number of islands seen there (Fig. 180). Those extending along the coast of Maine are due to this cause also (Plate 19), and the vast number along the shores of northeastern America, some of which are of large size, represent merely high peaks of the old land now partly drowned in the sea.

Fig. 180.
Islands in the Bermudas, due to sinking of the land.

Some islands are being *increased* in size by the causes which constructed them; but as soon as these causes cease, they, like other islands, are attacked by the waves. Since they are surrounded on all sides by water they can be attacked in all directions, and this attack will be active on all sides, especially if they stand well out in the open ocean. Gradually then they disappear, and hence if new supplies be not added, any island will in time be destroyed. The volcanic peaks rising in the sea grow in size as long as the volcano erupts; coral keys grow as long as the animals thrive; and a sand bar, built by the waves, increases just as long as the waves bring more than they can carry away; but when these conditions cease, as they may in time, the island is doomed to destruction.

Fig. 181.

Island joined to mainland by two bars, Cape Breton, Nova Scotia.

Promontories. — What has been said about islands applies to promontories and to capes, which are merely small promontories. Some are *built* by the waves, others may be caused by the joining of coral reefs to the land, or by the elevation of the sea bottom, or by volcanic eruption, or mountain growth. The Malay peninsula, standing side by side with the island of Sumatra, is a mountain uplift just as is Sumatra itself. The Japanese islands, and the Philippines to the south of these, have been lifted out of the sea by mountain folding; and in time, if the uplift continues, they may be joined to the Kamtchatka peninsula.

Tiny capes may also be formed by wave erosion; and small capes, as well as great peninsulas, like that of Nova Scotia, or of Labrador, may be caused by the sinking of an irregular land. These represent the high places in the ancient country, and the sinking has not been great enough to transform them to islands, though by a very small additional submergence Nova Scotia would be cut off from the mainland, just as Newfoundland now is.

Islands may be transformed to peninsulas by means of bars built from them to the land by wave action (Fig. 181). On the coast of the United States there are many illustrations of this; and sometimes the connection is only made at low tide, while in other cases, the bar is so high that a road may be built upon it.

Changes in Coast Lines. — In England the coast has changed very considerably in the past thousand years; and in America, during the short period of fifty years since good maps of the coast have been made, many changes have been noticed. These consist in a cutting back of the headlands in one place, the formation of bars in others, and the filling of bays in still other places. The seacoast is the seat of very active changes, otherwise this could not have been seen by man.

Not only is there this action of the waves, but the outline of coasts is slowly changing, either through rising or sinking (pages 321 and 323). There was a time when the New England land extended many miles further than now, and when present islands and capes were hilltops, and straits and bays were dry-land valleys between hills, quite like those now found in New England.

CHAPTER XIX

PLAINS, PLATEAUS, AND MOUNTAINS

Plains. — The term *plain* refers to a rather level stretch of country of not very great elevation. It is generally somewhat irregular, being crossed by streams which have carved valleys, and its surface often consists of a series of wave-like undulations. A large plain presents the most monotonous scenery to be found in any part of the land, for as far as one may look there is nothing but level country. Where plains exist at a considerable elevation above the sea, they may be more deeply dissected by valleys; but these higher plains are more properly called plateaus.

Fig. 182.
A view on the plain of the Everglades in southern Florida.

There are many different kinds of plains. Bordering the coast of Texas, and in fact most of the states south of New Jersey, there is a narrow strip of level land which is really a part of the old ocean bottom, now raised into the air, just as plains would be produced if the continental shelf were elevated. The levelness of Florida is of the same origin; but the delta and floodplain of the Mississippi have been *built* by the deposit of sediment carried by the river. Salt-marsh plains have also been built up, and there are many level stretches where lakes have once existed. In North America many small plains and swamps are really old lakes; and the great plain of the Red River valley of the North represents an old lake bottom.

In addition to this, level country may be caused by denudation, for a land may actually be worn down until it is nearly level. The plains of the central states, probably never very high land, have been gradually levelled by past denudation; and then much drift, left by the glaciers, has been deposited upon their surface, so that many parts have been filled, making the surface even more level than it was before the Glacial Period. Therefore the prairies of the Mississippi valley have a double cause for their levelness.

Even without much denudation, plains may result if the rocks lie in nearly horizontal sheets, as they do in the greater part of this country. With the same climatic conditions over a large area, streams will cut through the rocks, forming valleys; but between these there will be level areas, because the rocks lie in sheets which wear down with the same rapidity in all points, excepting where stream channels lie.

Starting upon a plain, the rivers carve valleys, at first narrow and steep-sided, but in time becoming broader. If the elevation is not great, this does not decidedly roughen the surface; but if the region is elevated, the valleys may become deep and the country hilly, until finally it loses the characteristics of a plain, as in the case of western West Virginia, Tennessee, Kentucky, etc. If time were allowed, the surface would gradually become smooth again, and the roughened plain would again become a true plain, which would be an *old land;* but for the same reason that old river valleys do not exist, old plains are not found.

Plateaus. — A plateau is an elevated plain (Fig. 145); but it also has other features. Being more elevated than a plain, the streams have more power to cut, and it is generally dissected by deep valleys, and even by cañons. Therefore, although in places the plateau is level, one rarely has to go far to find it greatly roughened, as in the plateau through which the Colorado River of the west cuts its cañon (Fig. 145).

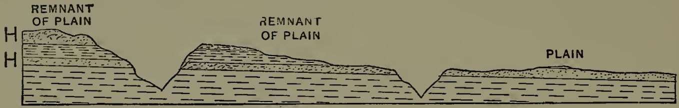

Fig. 183.

Diagram to illustrate dissection of plain where hard strata (H) resist denudation, leaving rather flat hilltops between the river valleys.

Plateaus are generally formed by the uplift of horizontal beds of rock which make the country level-topped, because denudation, in carving them, finds hard layers, which being horizontal, resist denudation everywhere excepting where the streams cut through them (Fig. 183). As denudation proceeds, the plateau may become exceedingly irregular and rough, as in the case of the Catskill Mountains, and the highlands of southern central and western New York, which are true, though much dissected plateaus. In the course of this denudation flat-topped areas may be left between the streams, and in the west the Spaniards have called these *mesas*, or tables. If still smaller in area, and rising steeply as a hill, these remnants of formerly extensive level stretches are called *buttes* in the west (Fig. 129).

Treeless Plains. — In this country most of the plains and plateaus are treeless, by far the greater number of these being so because of the dryness of the climate. This is true of the entire western plateau and most of the great plains west of the Mississippi; but the cause of the *prairies* of the Mississippi valley must be different, because in this region the rainfall is quite heavy enough for tree growth. The explanation of this peculiar absence of trees is not entirely certain. Some have argued that the soil is too dense, but others believe that the Indians have caused the open prairie, — that they set fires in connection with their hunt for the buffalo, and have thus kept the land clear of trees. The latter seems to be the most acceptable explanation, for it is known that trees can grow in the prairie soil; and moreover it has been proved that Indians did build fires, and that they have actually extended the area of the prairies since white men came into the region. Both on the plains and prairies, trees grow in the river bottoms near the streams.

There are treeless plains in other regions: the salt marsh is an instance; and the low, level land along the Texas coast is without trees because it is too swampy for them to grow. The steppes of Russia and the pampas and llanos of South America, are great treeless plains.

MOUNTAINS

Nature of Mountains. — There is very much difference in the use of the term *mountain*, but to most it means any considerable elevation above the surrounding country. Therefore in a level region a small hill is called a mountain, and in mountainous countries high peaks are called hills. As used in this book, the term refers to parts of the earth's crust which have been uplifted as the result of folding or breaking of the rocks of the crust. That is, the strata have been folded into waves, as we might fold the leaves of this book. In plateaus the rock layers remain nearly horizontal, as they were deposited; but when raised into mountains they have been inclined, This folding of the rocks has occurred in various parts of the earth, the most notable cases in this country being the Appalachians in the east, and the several mountain ranges occupying the western part of the United States. In these places the rocks have been tilted, either by folding or faulting, so that they rise above the general level, sometimes to heights of 5000 or 10,000 feet. A series of such folds forms a *system*, such as the Appalachians, which extend from Alabama to New York, or the Rockies, reaching from Mexico into Canada. Two or more systems closely associated, such as the Rockies, Basin Ranges, Sierra Nevada, and Coast Ranges, constitute a *cordillera.*

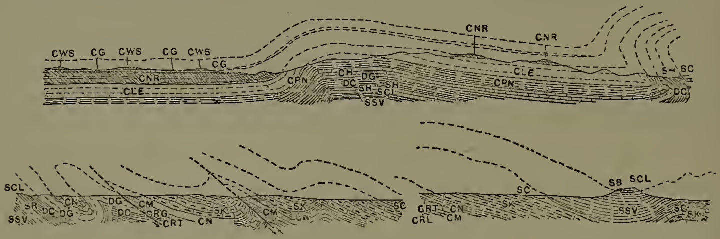

FIG. 184.

Sections through portions of the Appalachians, showing folded rocks and faults. Former extension of strata indicated by dotted lines. Letters identify layers.

In each system there are parts known as *ranges*, which consist of uplifted portions side by side and separated by valleys; and in each range there may be single *ridges* (Plate 20). The characteristic feature of each of these is that the rocks are tilted, so that the length of the elevation is greater than the width. But the most striking feature among high mountains is the *peak* (Fig. 185), a lofty elevation whose length and width do not greatly differ,

Facing page 336.

Plate 20. — A mountain ridge in the northwest.

but which rises above the surrounding region, sometimes to a great height. It is the mountain peak which people have in mind when they name a hill, a mountain. Really these peaks are true hills of great size and height among mountains; and it is not necessary that the rocks of which they are made shall be folded.

Fig. 185.

Grandfather Mountain; a peak in the Blue Ridge of North Carolina.

Development of a Mountain System. — In order to understand the origin of the features of mountains, perhaps the best way to proceed is to imagine that we can trace the growth of a mountain system. Let us suppose that it starts in the sea, where for some reason the bed is being raised and the layers of the bottom are being folded. Gradually the bed rises, with little other change than the folding (or perhaps faulting) and uplifting, though probably volcanoes pour forth lava at various points along the crests of the rising ridges. Such a mountain range exists in the sea along the line where the Hawaiian Islands rise above the surface, and this range extends not less than 1500 miles.

As soon as the range rises into the air, a new chapter begins. Formerly, as the folds gradually rose, there was nothing to check the increasing elevation; but as soon as they reach the air, the agents of denudation commence their work of sculpturing and destruction, rains fall, winds blow, rocks decay in the weather, rivers gather on the land, and perchance the ocean waves beat against the margin. So the folds no longer rise uninterruptedly, but their elevation is ineffectually opposed, and they continue to rise with battered and scarred surfaces, never reaching the height to which they would have risen had denudation been debarred. They begin to be sculptured, and the hard rocks stand up because the softer ones are worn away more rapidly.

Such a stage has been reached by the Japanese Islands, which are even now rising mountains. They represent a mountain system with several ranges,[1] but denudation has cut into the ranges, and finding hard layers of rock in the form of inclined sheets, has carved out ridges where the hard layers exist. Because the rocks were folded as sheets, the ridges are nearly parallel;[2] and wherever denudation finds such hard layers, ridges may be formed, as has happened in the Appalachians (Fig. 143), which are old mountains that have been exposed to the air for a long time. But if there exists a more massive rock, like granite, not standing in a layer, it also will resist denudation and stand

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[1] As we may fold paper into two or three folds, each representing a range, and the whole a system.

[2] As our paper mountain would be if we should take a pair of shears and clip off the tops of the folds.

up, thus forming not a ridge, but a peak (Fig. 185). A very large number of well-known peaks in the world[1] rise above the surrounding folds, because some such hard rock as granite has resisted denudation better than the softer ones that surround it. Had the durable rock existed as a *layer*, a ridge would have been produced, though perhaps one which has been carved into many peaks along the line of the ridge, as seen in the Teton Mountains of Wyoming, and others in the west.

Fig. 186.
Mt. Moran, in Teton Mountains.

Carrying the development of the mountain system still further, it may rise and become a part of the continent, as the Japanese Islands will if they continue to be elevated, and as the Coast ranges of California already have. Between them and the mainland, there is at first a partly enclosed

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[1] Such as the peaks of the White Mountains of New Hampshire, the Adirondacks, Pike's Peak, Mt. Everest in the Himalayas, the Matterhorn, and other Swiss peaks, as well as hundreds of others.

sea, then as the outlet rises above sea level, great enclosed lakes outflowing to the sea, and then perhaps a great valley.[1] Finally, as the elevation continues, the valley may become a plateau, or perhaps an enclosed basin, like the Great Basin between the Sierra Nevada and the Rockies, into which rivers flow without passing into the sea, because their water is evaporated by the dry air, which has been robbed of its moisture.

By the growth of the mountains not only may *great basins* be enclosed between the systems, but other valleys of smaller size may form between the ranges, while rivers carve still others *on* the mountain sides, *across* the ranges (Fig. 143), and *between* the ridges. The valleys which the rivers carve are deep cañons with steep and rocky sides, because the water courses down them with great velocity, and therefore can dig rapidly (Fig. 134).

The Destruction of Mountains. — Although mountains rise slowly, so long as they grow their elevation is usually more rapid than the downcutting by denudation; but the streams have such a slope that their valleys are deeply cut, and differences of rock texture are brought into very sharp relief. It is not merely because of the *slope* of the streams, but also because the peaks rise into the higher regions of the atmosphere, where winds are fierce and frost action powerful, so that weathering is rapid (Fig. 127). Moreover, the high mountain tops rise above the timber line (Figs. 85 and 187), and are therefore not protected from the weather. Hence it is that a young, and particularly a growing mountain is carved into very rugged forms. Just as cañons are characteristic of young streams,

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[1] Like the Sacramento valley of California, which lies between the Coast Ranges and Sierra Nevada.

so rugged mountains, like the Rockies, Andes, Alps, and Himalayas, are also young.

But in the course of time there comes a period when the mountain-building forces *cease* to cause the ridge to rise, and then denudation has full sway, and the ranges slowly melt down. The Appalachians, consisting of low ridges strikingly different from the Alpine ranges, have for a long time been subjected to destructive agents, until they have lost their ancient elevation and irregularity. In fact denudation may go further than this, and lofty ranges be reduced to low hills. Nova Scotia, all of New England, and the very sites of the cities of New York, Philadelphia, Baltimore, Washington, and Richmond, are all reduced mountains which once rose to heights rivalling those of the Rockies and the Alps. We know this because the rock layers are folded in such a way that if they were continued, as they once must have been, they would rise thousands of feet into the air (Fig. 184). Therefore, such is the length of

Fig. 187.

Near the timber line, Gallatin Range, Montana.

time since the earth was young, and so powerful are the agents of denudation, that if they have plenty of time in which to work, even mountain ranges may be reduced to low hills.

Other Kinds of Mountains. — While only elevations due to folding or faulting, or true mountain ranges, have been considered here, it must be said that there are true mountainous elevations which may be formed without rock folding. The *real* mountain peaks are caused by the sculpturing of rocks among ranges; but *wherever* unusually high areas have been formed by the unequal carving of the strata, mountain peaks may result, even though not situated in regions of folded rock. Many of the buttes of the west are high hills or low peaks, and therefore properly called mountain peaks.

Indeed, *ranges* of considerable extent may be formed where unusually durable rocks have resisted destruction better than the neighboring land; and this is the case in the *Catskills*, where the strata are *not folded*, but where hard sandstone occurs, which is much more durable than the surrounding layers. They therefore stand higher, and have been carved into very irregular form, so that, though they are really a very much sculptured plateau, they closely resemble a true mountain range.

The Cause of Mountains. — The origin of mountains leads us to a question about which very little is known. Since it is not possible to state even the most important suggested explanations, nor to discuss them fully, it will be well to state but one, the *contraction theory*, which has found most favor, though it must be said that it has not been proved. We *know* that the heat of the earth increases with the depth, and it is *believed* that the interior is highly heated. If this is so, the earth is cooling; for the heat is escaping into space just as certainly as it is from a stove into a room. A hot body is larger than it would be if cool, and therefore, as it cools, it becomes smaller.

So the theory is, that the earth, a hot body within, surrounded by a cold, solid outer crust, is cooling, and hence slowly shrinking. The interior is therefore constantly becoming smaller; but the solid crust, already cool, is *not* losing size, and therefore it must either be separated from the interior or else sink down upon it, as the core becomes smaller. If this is done, the only way in which it can fit the shrinking central part is by crumpling, as the skin of an apple does when this dries, losing water from the inner pulp and therefore becoming smaller. This supposed loss of bulk, or contraction of the earth's interior, is a very slow process, and therefore the uplifting of mountains will also be slow. The elevation of the crust will occur along lines which for some reason are weaker than other places.

Really, contraction causes the earth's surface to slowly settle, and this sinking is evidently occurring over most of the sea bottom; but locally, along mountain ranges, and in the continents, portions are rising, for the crust has a greater diameter than the shrinking interior, which is ever becoming smaller; and hence, while the greater part sinks, some must rise.[1] To the contraction theory there are some objections, though none that seem fatal to it as an explanation; and it now stands as the best attempt so far made to explain the *fact*, which all know so well, but whose *cause* is somewhere in the earth beyond the reach of human vision. Not being able to see and hence thoroughly understand what is going on below the surface, we can only reason upon the basis of the facts which we already possess.

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[1] This can be proved experimentally by taking a ball and attempting to make a flannel cover, a little larger than the ball, fit upon its surface. In doing this there will be some ridges of cloth.

CHAPTER XX

VOLCANOES, EARTHQUAKES, AND GEYSERS

VOLCANOES

Birth of a Volcano. — In the year 1831, in the Mediterranean south of Sicily, quite without warning, there rose out of the sea a great volume of steam, bearing in it red-hot cinders, which falling back, built a shoal in the sea, which shortly rose as an island. A volcano was born, and its birth was announced by a roar and commotion of the water. In a short time quiet again reigned, and in a few years Graham's Island had disappeared before the attack of the waves, and now no land exists to mark its site.

The new island was low (being about 200 feet high, and 3 miles in circumference), and was built entirely of loose fragments of volcanic ash, light in weight because pierced by innumerable tiny cavities, quite like pumice. It had risen through the crust as liquid molten rock, driven upward by the steam, which expanding in the lava, had blown it full of holes.[1] The steam, escaping as it does from an engine, carried the ash high into the air, until spreading out above, it was brought down by gravity, falling at one side of the vent through which it had escaped. This vent the steam kept clear, so that

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[1] As steam rises through oatmeal, or as gas makes porous the bread that is becoming solid in baking.

when the eruption ceased there was a cavity or *crater* there. Most of the ash, and especially the heavier pieces that settle more quickly, fell near the outlet on all sides of it, forming a *cone*, which was nearly as steep as the angle at which loose fragments of rock will rest in the air.[1]

This newly born volcano, which died after a single gasp, illustrates perfectly a typical volcano, though it rose only about 200 feet, while the elevation of most cones is measured in thousands of feet. Had there been another eruption, the size of the cone would have been increased, and in time a large volcano would have been built; but during its history, perhaps with a life of tens of thousands of years, there would have been many changes, for volcanic action is very capricious. During long periods it might have been quiet, then perhaps a violent eruption might have partly destroyed the cone, sending it into the air; and first ash might have been erupted from the vent, and later lava. Also throughout its history, denudation, the enemy of the land, would have attacked it, removing some of the materials out of which it was built. To understand what *might* have happened during its history, let us look at what *has* happened to some of the volcanoes of the earth.

Vesuvius. — When the Italian peninsula was first visited from the east, a lofty conical mountain rose above the Bay of Naples. As time passed, towns were built at its base

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[1] An experiment illustrating this can be shown by having a U-shaped tube, containing sand, with one end rising through a piece of cardboard partly resting on a table. Upon blowing through the tube the sand rises in the air and builds a cone with a crater. Care must be taken not to put too much sand in the tube; and in order to build a high cone, sand must be put into the tube several different times.

and upon its sides. It had the form of a volcano with a crater in the centre, but it did not erupt. Apparently, therefore, it was a dead or *extinct* cone open only to destruction from denudation. For centuries this condition lasted; but the volcano was not extinct, it was only sleeping or *dormant*. About the year 79 A.D. the Bay of Naples was visited by earthquake shocks. Monte Somma, the ancestor of Vesuvius, was preparing for a terrific eruption, and during the year 79 an outbreak occurred, so violent, that when it ceased, the cone was changed in form. Part of the old rim of Monte Somma had disappeared, being blown into the air, while a new and smaller cone had been built amid the ruins.

Monte Somma slept no more, and after a rest of many centuries the active Vesuvius was born. Ash rose thousands of feet in the air, and spreading out, formed a cloud so dense that the day became as dark as night. The ash fell upon the flanks of the mountains and upon the neighboring lowland. People fled before the shower of hot rock. Homes and towns were abandoned, and when the eruption had ceased, the sites of cities, villages, and farms were covered by a great barren stretch of pumice and ash. For centuries these were buried, and even now, no doubt, scores of towns are entombed beneath the products of this eruption. Two of them, Pompeii and Herculaneum, have been discovered and extensively excavated, showing the dwellings of the people who were driven from them more than eighteen centuries ago (Fig. 188).

Since that terrible eruption of 79, Vesuvius has had periods of quiet; but every now and then an outbreak has occurred, and the mountain is still, at the present day, an active volcano. There have been rests of many years, at other times frequent eruptions. Sometimes the outbreaks have been violent, again relatively quiet; but at no time has there been such a destructive explosion as that which gave modern Vesuvius its birth. Often the material erupted has been ash; but at other times liquid rock has welled out, and flowing down the mountain side, has cooled to form solid lava. Therefore this volcano has sent out both ash and lava, so that it differs from Graham's Island, which had but one eruption, and that of ash.

FIG. 188.

A portion of Pompeii excavated from beneath the ash. Vesuvius in the background. A part of the old rim of Monte Somma on the right.

Krakatoa.— In the late summer of 1883, the sailors in the Straits of Sunda saw a great cloud rising above a small island, and this, upon spreading out, obscured the sun, while ash fell from the air. Upon the neighboring land the same was seen, and the ground was shaken, while upon the low coasts a great water wave rushed, destroying thousands of lives. Krakatoa, which had not been in eruption during this century, had again broken forth, with the most terrific explosion that man has recorded. Ash rose miles in the air, and spreading out, fell on the surrounding land and water, and for awhile it was so thick upon the surface of the sea, in the Straits of Sunda,[1] that the progress of vessels was impeded. So high did it rise that the lighter ash, floating about by the upper winds, staid suspended in the air for months, some of it falling in America and Europe. A great water wave, generated by the explosion, crossed the Pacific to the California coast, and it was observed on the shores of Africa and Australia.

FIG. 189.
The volcano of Mauna Loa, Hawaiian Islands.

Where?

When the eruption had ceased it was found that Krakatoa had been split into two parts, one of which had disappeared into the air, leaving ocean water where there had

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[1] For volcanic ash and pumice will float in water.

been dry land. The part of the island that remained was covered with a deep coating of ash, and not a living thing was left, neither plant nor animal. Since then there have been no more eruptions; and now Krakatoa is either dormant or extinct, but which, cannot be told for centuries. This eruption may have been the death struggle of the once mighty cone, or it may have been but a temporary awakening, after a long rest.

FIG. 190.
The lava floor in the crater of Kilauea.

The Hawaiian Volcanoes. — A series of eight islands lie in a chain in the mid-Pacific, and all of them have been built by volcanic eruptions. Most are now extinct and are rapidly disappearing before the attacks of wind, weather, rivers, and waves; but upon the largest, Hawaii, there are several craters, one Kilauea, another Mauna Loa (Fig. 189), and a third Mauna Kea. The latter rises 13,805 feet above the sea, Mauna Loa 13,675 feet, and

Kilauea about 9000 feet. The two latter are now active and have been well studied.

One may ascend to the top of the immense crater of one of these and look down upon a lake of liquid rock, through which jets of steam rise, occasionally throwing bits of lava into the air. There is no danger in this journey, which is constantly being made by tourists, while a house is built for their accommodation on the margin of the Kilauea crater. Once in a while, however, on an average of once in about seven years, an eruption occurs; but it is not at all like those just described. There is no ash, but a flow of lava, not from the crater, but out of the side of the cone, through which the molten rock escapes by a fissure which had broken open the side of the mountain. From this the lava flows down the mountain side, sometimes reaching the sea, and perhaps passing 30 or 40 miles before coming to an end. At first it flows rapidly, a glowing stream of liquid rock; but soon, becoming cooled in the air, a crust

Fig. 191.

An eruption of a tiny volcano in the Mediterranean.

forms on the top, under which the molten lava is enclosed. Then it flows less rapidly and finally barely creeps, slowly advancing for weeks, until at last, when the force from behind is exhausted, it stops, perhaps at the very outskirts of some town which it has threatened to destroy. Nearly all the eruptions of these volcanoes have been of this nature, — flows of black lava, known as basalt.

Other Volcanoes. — From the hundreds of cones in the world we might select other instances; but these that have been given, furnish illustrations of the chief differences. Some, like Fusiyama in Japan, and many in the Andes, always erupt ash; others, like the Hawaiian cones, practically always emit lava; but most, like Vesuvius, Ætna, and the volcanoes of Iceland, now erupt ash and now lava. Some, like the tiny volcanoes of the Lipari Islands in the Mediterranean, have toy eruptions, so moderate that they may be witnessed from a ship, near by, without danger; and from these there is every gradation, to those terrible eruptions of Vesuvius and Krakatoa just described, and the frightfully destructive outbursts of the Icelandic volcanoes. While in some cases the outbreaks are frequent, in others they come at irregular intervals, perhaps centuries apart. Even the tiniest eruption is an impressive scene; but a violent one is the most awe-inspiring phenomenon which nature presents upon the earth's surface.

Materials Erupted. — In volume and importance, steam is the greatest of volcanic products. Often in the quiet eruptions of Kilauea, great banks of *steam* rise from the lava; and in great eruptions so much rises, that reaching thousands of feet into the air, it condenses into drops, and falling back to the ground, produces deluging rains, so heavy that torrents rush down the sides of the cone, adding to the destruction caused by the other products. Perchance falling upon loose ash, it washes this down with it in such quantities that a destructive torrent of mud passes on, overwhelming everything in its path. Herculaneum on the flanks of Vesuvius was buried beneath such a *mud flow*.

Other gases than steam arise, but they are of much less importance. Sometimes the *lava* wells out quietly as a flow, and there is always lava in the tube of a volcano. However, when for any reason the steam has the power, the lava is blown into shreds and bits, and upon cooling, forms *ash* and *pumice*. These vary in size from mere bits of dust to huge blocks of rock. In nearly every case the ash is merely lava which the steam has blown out, though sometimes, when a mountain side like that of Krakatoa is blown into the air, it is apparently made up of the broken fragments of the mountain, like the bits of iron which are thrown out during a violent boiler explosion.

Form of the Cone. — A typical volcano is a cone with a crater in the centre. Sometimes the perfection of this has been destroyed by a violent explosion, like that which split Krakatoa, and that of 79 A.D., which partly destroyed Monte Somma. Some cones are very low, if the eruptions have been few, while others are of great size. There is also a difference in the shape of the peak. For instance, Mauna Loa, though rising above the sea to the height of 13,675 feet, does not rise steeply (Fig. 189). Its diameter at the base is great, and hence it is a moderately sloping, but very high cone. This is because the material of which it is built is lava, which flowing away from the place of exit, extends over a score or two of miles, first as a liquid, then as a more viscous body. Fusiyama in Japan, and many of the South American volcanoes, are narrow at the base but very steep. These are made of volcanic ash which has settled near the crater, taking an angle as steep as loose fragments can maintain in the air, just as a heap of dirt will when dumped from a wagon. Those that are made partly of ash and partly of lava will be less steep, and these are the most common of volcanoes, and are therefore more typical than either the steep Fusiyama or the great mound of Mauna Loa.

There is another point, too: when a volcano erupts ash some is lost, for the winds carry it away; but in the lava eruption all remains within a score or two of miles of the cone. Hence a much larger peak will be made by the same number of lava eruptions than of ash, provided the quantity sent out is the same. Therefore the *bulk* of rock in such a cone as Mauna Loa is many times as great as that of some of the ash eruptors.

Extinct Volcanoes. — Not only do volcanoes erupt, become dormant, and then active again, but sometime in its history every volcano will die, as certainly as every animal and plant will. Of *extinct* volcanoes we have thousands of instances in the world, but in no part of the earth are they more numerous than among the Cordilleras of the western part of this country and Mexico. Some have ceased erupting for so short a period that it cannot be certainly stated that they are more than dormant (Fig. 192). It need surprise no one to hear that a volcano in

Fig. 192.

Popocatapetl, Mexico. A dormant or else extinct volcano rising above the plateau.

the west has again burst forth into activity. Near some there are lava flows that have certainly not been exposed to the air for a full century.

Cones forming under the sea[1] rise without being attacked by the forces of destruction; but all through their history volcanoes that rise in the air are subject to the attack of the agents of denudation. The work of these is not so rapid as the supply of lava or ash, and so the cones rise; but when these supplies are cut off, they slowly melt away.

Fig. 193.

Volcanic necks or plugs, remnants of volcanoes, on the plateau of New Mexico.

Among the Hawaiian Islands, and elsewhere in the Pacific, there are cones in all stages of destruction, and the same is true among the plateaus and mountains of the west. First the crater is breached and gullied (Fig. 192), then the cone form disappears, and finally only the hard core of solid lava in the tube or neck stands up. All of

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[1] It seems certain that there are active craters in places in the sea, particularly on the Asiatic coast.

the cone, the ash and the lava flows, have now disappeared. There are hundreds of these remnants in the west (Fig. 193).

In past ages volcanic cones existed in New England, especially in the Connecticut valley, and from there along the Atlantic coast at least as far as North Carolina. Some of the ancient lava flows still remain buried beneath other rocks, but the cones have long since disappeared; and in the east there have been no volcanoes in times sufficiently recent to have left even a part of a cone.

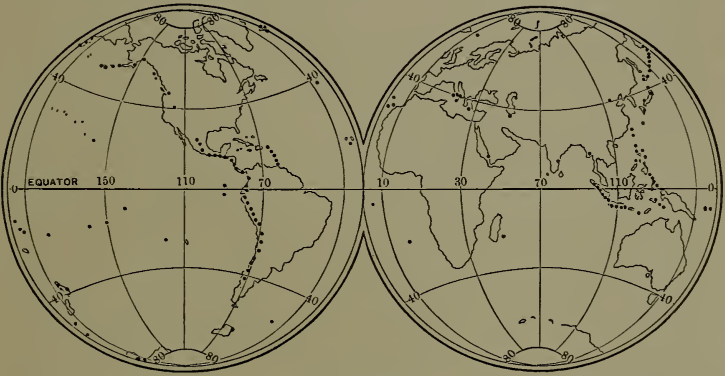

Fig. 194.

Diagrammatic sketch to show (by dots) distribution of volcanoes.

Distribution of Volcanoes. — At present volcanic cones are most abundant along the borders of the Pacific Ocean, though there are some elsewhere. In all cases they are either in or near the sea; and generally, if not always, they are associated with mountains that are growing. Those that are extinct, like the partly destroyed cones of the west, are found among mountains that have ceased rising; and it seems certain that as soon as mountains cease their growth, the volcanoes that exist among them die out. Very often, as in the Hawaiian and Japanese islands, the cones extend in chains along lines.

Cause of Volcanoes. — Some action or condition in the earth melts the rocks in places. Some believe that the roots of volcanoes reach through the crust into the zone where the heat is high enough to melt strata, and certainly there is such a zone, if the temperature of the earth increases at the same rate as it does in the part so far explored. Others think that the *movement* of rocks in mountain folding causes melting by the heat of friction of the particles moving over one another, as we may warm two pieces of rock by rubbing them together. Since this mountain folding is probably due to the heat within the earth, in either case the *first* cause for volcanoes is this heated condition; though in the second explanation, it is thought that the melting is a secondary result of this.

Whichever of these is correct, the expelling force of the lava is *steam*, so that this is the *immediate* cause for the eruption, as it is in the explosion of a boiler. The reason for the association of growing mountains with volcanoes, may be the *melting* of rocks, or it may be the *squeezing* of the melted rocks up to places where they can escape. Whichever is the true explanation, the folding of the strata causes breaks, or fissures and faults, *through* which the lava may escape. This accounts for their arrangement along lines.

Explanation of the Differences in Volcanoes. — When the lava contains little steam, or is in such a condition as to allow it to readily escape, as it does from the lava lake of Kilauea, it cannot gain violence enough to blow the liquid rock into the form of volcanic ash; but if for any reason its escape is retarded, it gathers force until escape is finally made possible.[1] Sometimes a crust forms over the crater,

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[1] It is very much like a boiler against the sides of which steam is constantly pressing; but the boiler is strong enough to stand the pressure up to a certain limit, though after this is reached an explosion takes place. An engineer does not usually allow the pressure to become great enough for an explosion, but every now and then permits a little steam to escape, thus relieving the pressure.

or in the upper part of the neck, and this may grow so thick that the steam cannot blow it out, and then the volcano either becomes extinct or remains dormant, slowly gathering force enough for an outbreak. At times the plug becomes so strong, that when the pressure is high enough, it is easier to break a new opening than to force the plug out, as it is easier for some guns to explode than to drive the wadding out. Then a cone may be built at the side of, or near, the old one. Mt. Shasta is a double volcano of this origin.

EARTHQUAKES

Before and during a volcanic eruption, the movement of the steam and the lava sends jars through the rocks, and the earth trembles, and sometimes is so violently shaken that buildings are thrown down. There may be hundreds of such earthquake shocks during a violent outburst, and the destruction of life is very great. Any jar to the rocks will produce an earthquake, if upon the land, or will cause a great water wave, if in the sea.[1] Next to volcanic causes, the most important source of earthquakes is the breaking of rocks. As they move along the fault plane, jars pass out, and these reaching the surface, cause earthquakes. In many cases, as in Japan in 1891, the breaking of the rocks which caused the shock reached to the surface, and in this case the ground was cracked, roads rendered impassable, and streams interfered with. Since both volcanoes and faults are associated with mountains, earthquake shocks are frequent only in those places. Hence the

---

[1] A miniature shock is caused when gunpowder is exploded, and the jars that pass over a frozen pond on a winter night are similar shocks.

greater part of the earth is free from them, though near Vesuvius, on the western side of South America, in Japan, etc., earthquakes are exceedingly frequent. While *slight* jars are not uncommon in central and eastern United States, there have been only three *violent* earthquakes in these regions since they were settled; one during the last century, near Boston, another in 1812, near the boundary of Louisiana and Arkansas, and one near Charleston, South Carolina, in 1888. During the same period there have been hundreds in Japan, or near Vesuvius.

FIG. 195.

Effect of the Japanese earthquake of 1891 upon a railway bridge. The earth was shaken from beneath the track.

The earthquake, being a jar starting from some centre, extends outward from this in all directions, as a series of waves of rock movement, very much as the jar caused by a blow upon a piece of iron passes outward to both ends of the bar. If the shock started from a *point*, the waves would be spherical, and if the rock were of one kind, they would advance as spheres of movement, reaching points at equal distances from the place of origin, or *focus*, at exactly the same time. In reality the focus is *not* a point, and rocks *differ* in character, so that the waves are much less simple. The place directly above the focus, called the *epicentrum*, is the place where the shock is most violent, and its force decreases on all sides from this. At a certain distance from the epicentrum, in all directions, the shock reaches the surface at exactly the same time. If the waves were really spherical, these places would be at equal distances from the epicentrum, but really they are not. The somewhat circular, though quite irregular, lines drawn around the epicentrum, and passing through places at which the shock was felt at the same time, are called *isoseismal* lines.

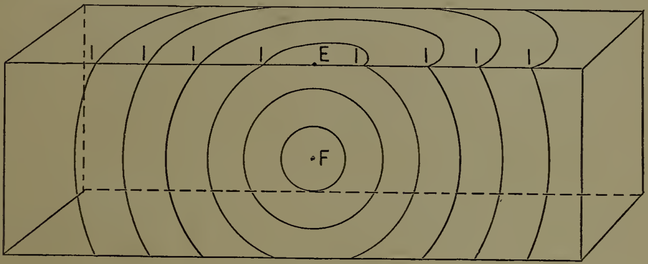

FIG. 196.

Diagram to illustrate passage of earthquake wave from a point, the focus (F); E, epicentrum; I, isoseismals.

To understand the effects of the earthquake a brief description of the shock which devastated Lisbon, Portugal, in 1755, may be introduced. The epicentrum was out to sea, not far from Lisbon. Without other warning than a sound like thunder proceeding from the ground, there came, almost at the same moment, a violent shaking of the earth which destroyed most of the houses in the city, so that in six minutes 60,000 people were killed; and fires, starting immediately after this, added to the destruction. The surface of the ocean fell, then rose, and a wave rushed upon the shore to the height of 50 feet above the ordinary level. Many people who had escaped, gathered upon a quay or stone pier, which extended out into the water, where they would be free from the falling buildings; but this sank into the water, carrying the people with it, and hence Lisbon was nearly destroyed, while a large part of her inhabitants were exterminated. This was one of the greatest of earthquakes since man has kept definite records. The shock was felt in the Alps and in Germany, Sweden, and Great Britain, and the water wave reached across the Atlantic as far as the West Indies.

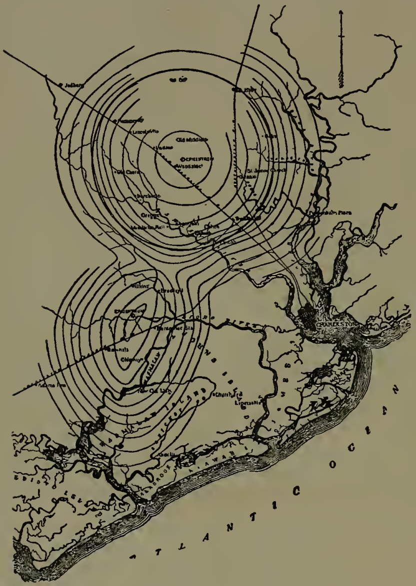

Fig. 197.

Map near Charleston, S.C., showing the two epicentra and the isoseismal lines during the shock of 1888.

When occurring in the open country, even a violent earthquake is not destructive; but if the epicentrum is near a city, the falling buildings, and the fires that are caused, add greatly to the destruction. In countries like

Japan, which are visited by frequent shocks, the inhabitants build low houses, so constructed that they are not easily thrown down; yet even in Japan single shocks have destroyed thousands of lives.

Fig. 198.

Giant geyser in eruption, Yellowstone Park.

Geysers. — Hot springs emit hot water, which flows out as it does from any spring, with the exception that the water is heated, perhaps even to the boiling point. In some cases the cause for this heat is no doubt intruded lava which has not reached the surface; but at other times its cause may be friction along the sides of fault planes, where the grinding of the particles produced heat for the same reason that a knife becomes hot when held against a dry grindstone. Perhaps the water sometimes comes from such a great depth that it brings out some of the heat that exists deep in the crust.

In several places in the world, but especially in the Yellowstone Park, New Zealand, and Iceland, the hot water comes forth not regularly, but intermittently, forming *geysers.* There are periods of quiet, and then, perhaps after intervals of a few minutes, hours, days, or even months, there comes an eruption, and a fountain of hot water and steam rises into the air and quickly subsides. Some geysers erupt at regular intervals, but others irregularly. The cause for the eruption is the presence of a supply of heat, which warms the water down in the tube until it reaches the boiling point, expands to steam, and expels the water above it into the air. Then being relieved, it remains quiet until the heat again raises the temperature of the water to the boiling point, when another eruption occurs. The time between these outbursts will therefore depend upon the length of time needed to heat the water in the tube.[1]

---

[1] A geyser may be artificially made by warming water in a long, narrow glass tube, applying heat to one part of it. If the teacher wishes a more detailed explanation of the cause of geysers he will find it either in Le Conte's *Elements of Geology*, or in my *Elementary Geology*, p. 362.

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Morgan School, Clinton	Conn.
High School, Collinsville	"
Wesleyan Univ., Middletown	"
Normal School, New Britain	"
Hillhouse High School, New Haven	"
Williams Mem. Inst., New London	"
High School, South Manchester	"
East Greenwich Academy	R. I.
Mr. Diman's School, Newport	"
Miss Wheeler's School, Providence	"
Normal School, Johnson	Vt.
High School, Barre	"
" " Brandon	"
" " Portsmouth	N. H.
" " Wolfboro	"
Seminary, Kent's Hill	Maine
Teachers' College	New York
Columbia Grammar School	"
Quincy School, Poughkeepsie	"
Colgate Academy, Hamilton	"
Manual Training School, Brooklyn	"
Union School, Warsaw	"
Academy, Middletown	"
Stevens School, Hoboken	N. J.
Collegiate Institute, York	Pa.
Columbia Academy, Washington	D. C.
Public Schools, Xenia	Ohio
" " Akron	"
High School, Newark	"
Prep. Dept. Univ., Wooster	"
Webb School, Bell Buckle	Tenn.
Citronelle College	Ala.
State Normal School	Ind.
High School, Westfield	"
" " Marion	"
" " Peru	"
" " Pendleton	"
High School, Attica	Ind
" " South Bend	"
" " Hanover	"
" " Connersville	"
" " Jackson	Mich.
State Normal School, Ypsilanti	"
The Fourteen High Schools, Chicago including those at	Ill.
Hyde Park	"
So. Chicago	"
Englewood	"
Morgan Park	"
Oak Park	"
Aurora	"
Lewis Institute, Chicago	"
Armour Institute, Chicago	"
Acad. of N. W. Univ., Evanston	"
High School, Carthage	"
" " Princeton	"
" " Pittsfield	"
" " Waukegan	"
Lake Forest Academy	"
Morgan Park Academy, Morgan Park	"
Monmouth College, Monmouth	"
High School, Kansas City	Mo.
" " Hannibal	"
" " Burlington	Ia.
" " Cedar Falls	"
" " Davenport	"
" " Marshalltown	"
" " Iowa City	"
" " Grand Rapids	Wis.
" " Randolph	"
" " Marshall	Minn.
Shattuck School, Faribault	"
State Normal School, Winona	"
High School, Lincoln	Neb.
Agricultural College	N. D.
Normal School, Los Angeles	Cal.
" " San Jose	"
" " Chico	"
High School, Riverside	"
" " Sacramento	"
" " Stockton	"
" " St. Helena	"
" " Redlands	"
" " Petaluma	"
" " Visalia	"
" " Selma	"
" " Tulare	"
Univ. of Pacific, College Park	"
Cartner Seminary, Irvington	"
Los Angeles Academy	"
Throop Polytechnic Inst., Pasadena	"
Trinity School, San Francisco	"

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