PHYSIOGRAPHY

AREY — BRYANT
CLENDENIN — MORLEY
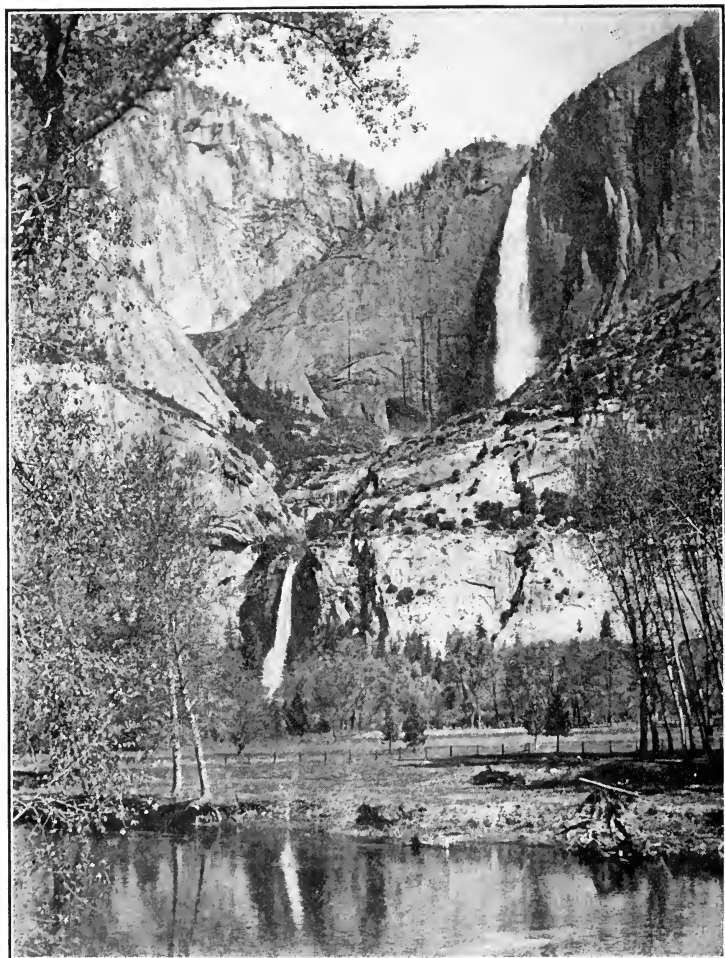
YOSEMITE FALLS FROM SENTINEL HOTEL.
A flood plain in the foreground.
By permission of Oliver Lippincott.
Frontispiece.

PHYSIOGRAPHY

FOR HIGH SCHOOLS

BY

ALBERT L. AREY, C.E.
GIRLS' HIGH SCHOOL

FRANK L. BRYANT, B.S.
ERASMUS HALL HIGH SCHOOL

WILLIAM W. CLENDENIN, M.S., M.A.
WADLEIGH HIGH SCHOOL

AND

WILLIAM T. MORREY, A.M.
BUSHWICK HIGH SCHOOL

NEW YORK CITY

———oo°o°oo———

PREFACE

For a number of years the authors have felt the need of a text that presents physiography from the high school point of view, both in content and in treatment. Since more than nine tenths of the pupils who enter secondary schools complete their formal education in such schools, the needs of this great class cannot be neglected; and subjects must be planned with the fact in mind that secondary pupils should know the scientific explanation of the common phenomena of nature.

A course in physiography in a college is naturally limited by the existence of parallel courses in astronomy, geology, and meteorology; and the fear of overlapping has led college men to omit many valuable topics from their courses and from the texts which they have prepared. No such limitation is found in the high school, and teachers are at liberty to select such topics as will contribute most to the culture of the pupil.

High school pupils should know of the earth as a whole, its relation to the other heavenly bodies, and the influence of its size, shape, and motions upon our daily life. They should know of the sun and the moon and their influence, and lack of influence, upon us. We have, therefore, included in our course, such astronomical topics as are necessary to this end. The pupils should also know of the natural resources of our country and their importance, and should understand the influence of climate and physical environment upon a given region as well as upon the history and the development of our nation and of the civilizations of the world. We have, therefore, included topics usually treated only in geology, meteorology, and history.

The abstract discussion of processes, as processes, belongs to the college rather than to the high school; we have, therefore, discussed such topics as diastrophism, erosion, and the like in connection with concrete instances of their work.

We are not in accord with those who would make physiography in the high school a regional subject. The secondary student easily masters a scientific treatment of a general topic such as mountains when the mountains of various regions are studied and contrasted; but he fails to do so if mountains are discussed in a fragmentary manner in connection with descriptions of various regions.

The treatment of the subject here presented has been in successful use in our class rooms many years, and we believe that it will be found equally satisfactory to others.

This text contains more matter than can be mastered by first-year pupils, and we have indicated by smaller type the paragraphs that it is our custom to omit with first-year classes; it is expected, however, that each teacher will make his own selection of the topics to be omitted. Where the subject is taught in the fourth year, no omissions will be necessary.

The italicized words in the text are intended as a guide to the teacher and the pupil. Technical terms are italicized when first introduced, and are to be defined by the pupil. Sentences in italics are to be memorized. In descriptions of functions and properties, the important words are italicized for emphasis. This use of italics makes printed questions on the text unnecessary.

The questions found at the end of each chapter cannot be answered by quoting the text. Each requires the pupil to draw an inference from some fact or facts stated in the text, or to exercise his judgment in contrasting facts. Some of them call upon him to exercise his imagination, and here suggestions from the teacher may be in order. We have found them particularly valuable as a stimulant to independent thought on the part of the pupil.

CONTENTS

PART I

THE EARTH AS A PLANET

PART II

THE AIR

PART III

THE SEA

PART IV

THE LAND

PART I

THE EARTH AS A PLANET

PHYSIOGRAPHY

CHAPTER I

THE EARTH IN SPACE

The earth is a ball nearly 25,000 miles around. It is composed of rock, with about three-fourths of its surface covered with oceanic waters having an average depth of only 2½ miles. The whole is surrounded by an envelope of air probably more than 200 miles thick.

On its surface we are unconscious of any motion because of the steadiness and freedom from jar, still we know that the familiar phenomena of the rising and the setting of the sun are due to the turning of the earth on its axis. At night the star dome appears to revolve about the earth, and gives us further evidence that we live on a ball that is turning in space uniformly and regularly.

We also learn that while the earth is whirling, it is rushing through space with inconceivable velocity. While the seconds' pendulum of a clock makes one swing, the earth moves 18½ miles, which is a thousand times the speed of the fastest express trains.

In going this distance each second, the earth curves about one-ninth of an inch from a straight line. This slight rate curvature continued for a year, brings the earth around to the place of starting.

The absolute uniformity of turning of the earth on its axis, and the regularity of movement as a whole about the sun, are of great service to mankind. The former affords a convenient means of measuring the length of the day, and the latter marks off the year.

The earth is only one member of a family of rotating balls. This family, together with other bodies, is controlled by the sun and constitutes a system.

A conception of the earth in space, as a member of the *solar system*, and some knowledge of conditions on other worlds, may give us clearer views of our real insignificance in space, time, and matter.

Condition of the Interior of the Earth.—The interior of the earth is believed to be solid throughout, although the temperature is undoubtedly above the melting point of materials on the earth's surface. The melting point increases with the pressure, but it is believed that the pressure raises the melting point faster than temperature rises as the center is approached, so that the fusion point is never reached. Because the earth as a whole has a greater density than the material near the surface, the central portion is thought to be more dense than the so-called crust.

Careful studies made of the variation in the position of the earth's axis, the effects of tide-producing forces acting upon the earth, and the velocity of earthquake waves through the earth, have led to the conclusion that the earth is more rigid than steel.

Form, Size, and Weight.—Water and mud fly off from the fast rotating wheels of wagons and automobiles, when running on wet, muddy roads. This is due to the tendency of bodies to move in a straight line. When a body moves in a curved path it appears to be pulling away from the axis of rotation. This pull is called *centrifugal force.* The centrifugal force is greater, the greater the distance from the axis.

Because of the rotation of the earth, the excess of centrifugal force developed in equatorial regions causes it to bulge out there and to flatten in the polar regions. The resulting form is that of an *oblate spheroid.*

This does not necessarily indicate a one-time molten condition of the earth. The sea bulges at the equator and flattens at the poles, and the land wears down to sea level.

The axis of rotation of the earth, or the polar diameter, is 7,899.76 miles, and the equatorial diameter is 7,926.60 miles, the latter being nearly 27 miles more than the former. The ends of

the earth's axis are called poles. The average of the different diameters of the earth is nearly 8,000 miles, and the circumference is about 25,000 miles.

The surface area of the earth is nearly 197,000,000 square miles, of which 54,000,000 square miles are land. The earth is 5.6 times as heavy as a sphere of water the same size.

Problem of Eratosthenes.—The first successful attempt to measure the size of the earth was made about 200 B.C. by Eratosthenes, an astronomer and geographer of Alexandria, Egypt. He learned that at Syene, the
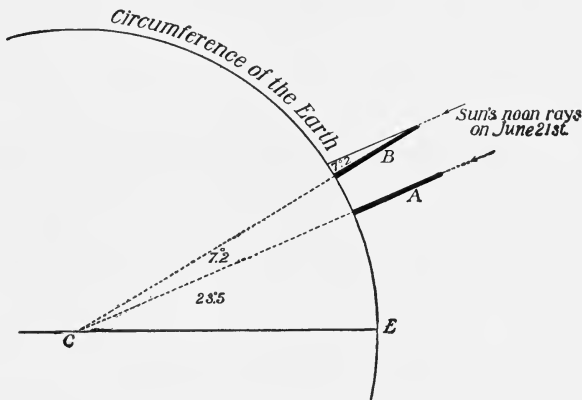

FIG. 1.—METHOD OF ERATOSTHENES

A, a vertical pillar at Syene, is 23½° north of the equator at *E*, a point on the Tropic of Cancer. *B*, a vertical pillar at Alexandria is 7.2° or 5,000 stadia further north. *C* is the center of the earth and *CA* and *CB* radii.

most southern city of Ancient Egypt, the gnomon or vertical pillar cast no shadow at noon on June 21st. At Alexandria, 5,000 stadia directly north of Syene, the sun's noon ray on the same day made an angle of 7.2 degrees with a vertical pillar. Assuming the earth to be a sphere, this angle of 7.2 degrees is equal to the angle formed at the center of the earth between radii to Alexandria and Syene. It follows that as these two places are on the same meridian, an arc of 7.2 degrees equals in length 5,000 stadia, so that 360 degrees, or the distance around the earth, equals 250,000 stadia. As the distance between Syene and Alexandria is about 500 miles, the circumference of the earth would be 25,000 miles, which is not far from the truth.

EVIDENCES THAT THE SURFACE OF THE EARTH IS CURVED

1. During every eclipse of the moon, that portion of the shadow of the earth cast on the moon always has a curved edge.

2. The circumnavigation of the earth proves that it is not flat. It does not prove that the earth has the form of a sphere. It might, for instance, have the oval form of a football.

3. As ships sail away their hulls disappear first, and as they come into port their masts appear first. This shows that the water surface is actually rounded up between us and the distant ship.

4. At sea, the circle known as the horizon seems both to sink and to increase in size with an increase in elevation above the surface of the water. If the water surface were an extended plane, our area of visibility would not increase with an increase of elevation.

5. That the weight of a body is about the same everywhere on the earth's surface shows that the earth is globular in form. The slight increase in weight noticed as one approaches the poles is in part due to a flattening of the earth's surface in those regions.

6. That the apparent shifting of the sky position of the stars is directly proportioned to the distance traveled north or south, shows that the earth's surface is curved along north-south lines like a sphere.

7. Places not on the same meridian have different times of day as a result of the curved shape of the earth's surface along east-west lines. If the earth were flat all places would have the same time.

8. On the shores of a calm lake, away from the tides and swells, the
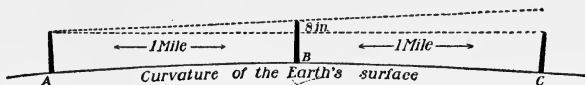
FIG. 2.—POST METHOD FOR MEASURING THE CURVATURE OF THE EARTH

curvature of the earth may be measured by erecting in a straight line three posts, A, B, C, at the same height above the surface of the water.

When looking with a telescope from the top of post A to the top of post C, the top of post B will be above the line of sight. If the distance from A to B is a mile, top of post B will be 8 inches above the line of sight, or the curvature of the water surface is 8 inches to the mile. In two miles the curvature is 8 inches × 2 squared, or 32 inches; in three

miles, 8 inches $\times$ 3 squared, or 72 inches—that is, the curvature for any distance is equal to 8 inches multiplied by the square of the number of miles.

THE MOVEMENTS OF THE EARTH

Rotation and Revolution.—The earth has two principal motions, a uniform spinning motion called *rotation*, and a forward movement in its path about the sun called *revolution*.

The angular rate of motion due to rotation is 15° an hour; and the absolute rate of motion of a particle on the earth's surface is greatest at the equator. Here it is 25,000 miles a day, or more than a thousand miles an hour, and decreases toward the poles, where it is nothing. The rate of motion of the earth as a whole, due to revolution, is about a degree a day. This amounts to 1,600.000 miles a day.

ROTATION AND ITS EFFECTS

1. The side of the earth that at any moment is turned toward the sun is in sunshine, and the side turned away from the sun is in darkness. The rotation of the earth from west to east produces a movement of illumination and shadow around the earth from east to west.

2. The eastern horizon is really sinking and the western horizon rising, which has the effect in the lower latitudes of making the sun, moon and stars appear to rise along the eastern and set along the western horizon.

3. The period of rotation, in respect to the sun, is 24 hours, and determines the length of day.

4. The slight bulging of the earth in the equatorial regions is due to rotation.

5. Winds and ocean currents, because of the earth's rotation, are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This may be illustrated by pouring water upon a rotating globe.

6. Every particle of matter on the earth's surface describes each day a circle. These circles are largest at the equator, and particles there consequently have the greatest velocity. This motion has the effect

of lessening the weight of bodies, due to the tendency of bodies to fly away from the center of rotation. Bodies therefore, for this reason, weigh less at the equator than in higher latitudes.

FIG. 3.—STAR TRAILS, DUE TO THE EARTH'S ROTATION, MADE ON A PHOTOGRAPHIC PLATE.

7. Bodies falling from a considerable height fall to the east of a vertical line suspended from the point of starting.

Foucault Pendulum Experiment.—In 1851 Foucault, a French physicist, devised a remarkable proof of the earth's rotation by means of a pendulum. From the dome of the Pantheon in Paris he hung a heavy iron ball about a foot in diameter by a steel wire more than 200 feet long. The pendulum was set in motion and the plane of vibration seemed to rotate slowly toward the right. It can be easily shown by a simple

experiment that the plane of vibration of a pendulum remains fixed. The true interpretation must then be that the floor of the Pantheon was actually turning under the plane in which the pendulum was swinging.

If the pendulum were suspended at the pole, the earth would turn around under it in twenty-four hours. The time required for the earth to shift entirely around under the plane of the vibrating pendulum increases as the latitude decreases. At the equator there would be no tendency for the earth to shift.

REVOLUTION AND ITS EFFECTS

Stars Shift Westward.—The movement of the earth, in its path about the sun, causes the sun to appear to move eastward among the stars. This has the effect of

FIG. 4.—FOUCAULT'S EXPERIMENT

making the stars appear to shift westward about a degree a day. The real path the earth travels each year is called its *orbit*.

The path which the sun appears to follow around the heaven once a year, as a result of the annual movement of the earth in its orbit about the sun, is called the *ecliptic*. It is so called because all the eclipses of the sun and moon occur when the moon is in the plane of this path.

The *zodiac* is the belt of the heavens, 16 degrees wide, 8 degrees on each side of the ecliptic. It is so called because the constellation or groups of stars in it are thought to resemble or outline the forms of animals. The 360 degrees of the zodiac are divided into twelve equal parts, each called a sign.

The Latin names, with the symbols used to represent them, are as follows :

	The Spring Signs		*The Autumn Signs*
♈	Aries, the Ram.	♎	Libra, the Balance.
♉	Taurus, the Bull.	♏	Scorpio, the Scorpion.
♊	Gemini, the Twins.	♐	Sagittarius, the Archer.
	The Summer Signs		*The Winter Signs*
♋	Cancer, the Crab.	♑	Capricornus, the Goat.
♌	Leo, the Lion.	♒	Aquarius, the Waterman.
♍	Virgo, the Virgin.	♓	Pisces, the Fishes.

Change of Seasons.—As the earth moves forward around the sun, its axis is always tipped 23½ degrees from a perpendicular to the plane of its orbit.   The earth's axis is always inclined in the same direction, so that during a revolution the axis remains parallel to itself in all positions.   It is because of the (1) *inclination of the earth's axis* and its maintenance of (2) *parallelism* during a complete (3) *revolution,* that the change of seasons occurs.

Cause of Unequal Days and Nights.—The same causes produce a shifting of the daily sky path of the sun during the year, and the consequent variations in length of daylight and darkness.

Ellipse, Perihelion, and Aphelion.—The orbit of the earth has the form of an ellipse, with the sun at the north focus.   The earth is at perihelion, or nearest to the sun, on January 2, when it is 91,500,000 miles away, and at aphelion, or farthest from the sun, on July 3, when it is 94,500,000 miles away.

In the sketch (Fig. 5) the earth is shown in four positions as it makes its annual journey about the sun.

On December 21 the north pole is tipped away from the sun and in the middle of the long period of darkness.   The noon tangent rays just reach the Arctic Circle, thus causing the whole area within that circle to be in darkness.   At this time the sun's noon ray is vertical over the Tropic of Capricorn.   It is winter in the northern hemisphere and summer in the southern.   The area within the Antarctic Circle is lighted and the south pole is in the middle of the long period of sunlight.   The days are shorter than the nights in the northern hemisphere.

On March 21 the noon ray is vertical over the equator and the rays are tangent at the poles.   Day and night are equal all over the earth.

On June 21 the north pole is tipped toward the sun.   The tangent noon rays just reach the Antarctic Circle, thus causing the area within that circle to be in darkness.   At this time the sun's noon ray is vertical over the Tropic of Cancer.   It is summer in the northern hemisphere and winter in the southern.   The area within the Arctic Circle is lighted and the north pole is in the mid-
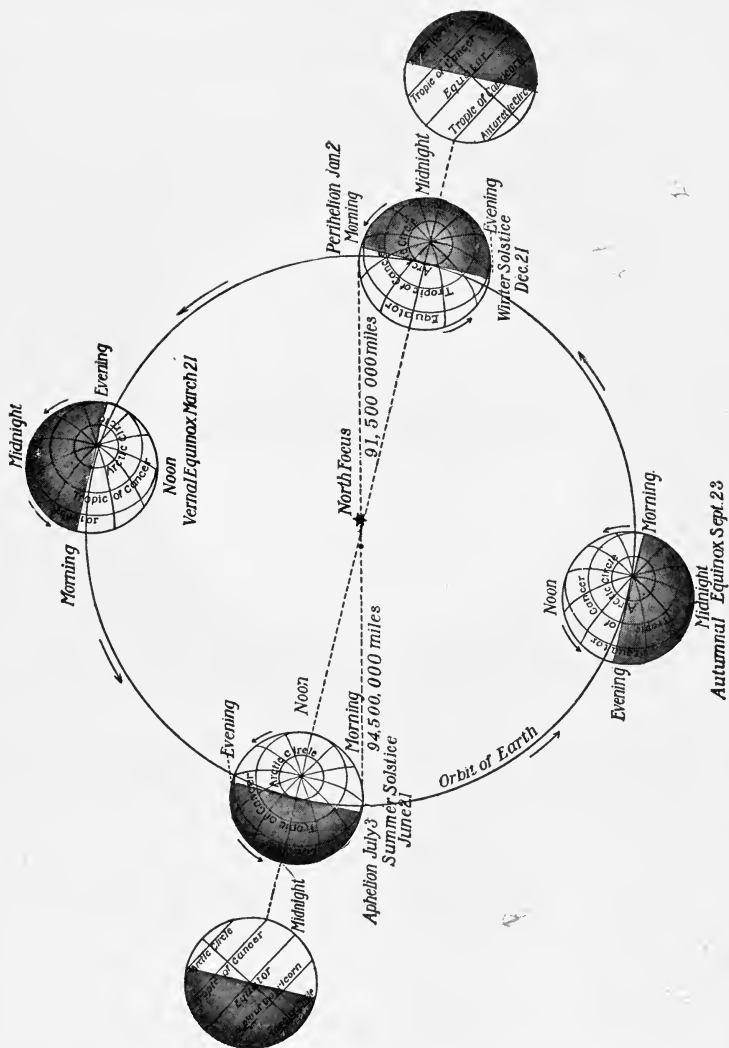
FIG. 5.—FOUR POSITIONS OF THE EARTH CORRESPONDING TO THE FOUR SEASONS

In the winter and summer positions two different views are shown, one looking along a line
perpendicular to the earth's orbit and the other looking parallel to the earth's orbit.

dle of its long period of sunlight. The days are longer than the nights in the northern hemisphere.*

Direction of Sunrise and Sunset.—The sun rises directly in the east and sets in the west only twice a year, on March 21 and
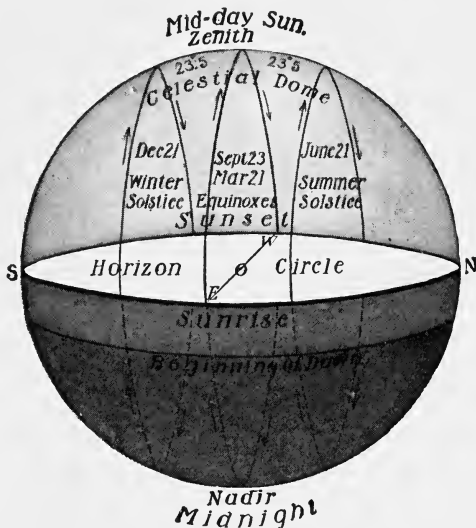

FIG. 6.—SHOWING POSITION OF SUN'S APPARENT DAILY SKY PATHS AT THE EQUATOR
Paths are vertical to the horizon and days and nights always equal.

September 23. At these two dates, called the *Equinoxes*, the sun's noon ray is vertical at the equator, or as more commonly expressed, "the sun is crossing the line," and days and nights are everywhere equal.

From the March, or Vernal Equinox, to the September, or Autumnal Equinox, in the northern hemisphere the sun rises north of east and sets north of west, and the days are longer than the nights.

From the September to the March Equinox, in the northern hemisphere the sun rises south of east and sets south of west,

*See Chap. **VIII** for more exact length of days in higher latitudes at different times of **year.**

and the nights are longer than the days.   (Make corresponding
statements for the southern hemisphere.)

The northern journey of the sun culminates on June 21,
called the Summer Solstice. The southern journey culminates on
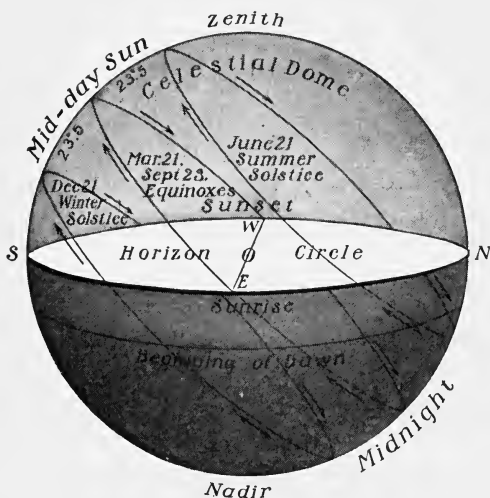December 21, called the Winter Solstice.

FIG. 7.—SHOWING POSITION OF SUN'S APPARENT DAILY SKY PATHS AT LATITUDE 41° N.
The paths are tipped toward the south, showing our long days in summer and our short days
    in winter.   The direction of sunrise and sunset at different times of year may be read from
    the figure.

The Sun's Daily Sky Path.—Because of the inclined position of
the earth's axis, the sun's daily sky path (not only the sun's vertical
ray and the sunrise and sunset position, but also each corresponding
position for every moment of the day), migrates northward for
one half of the year and then southward for the other half of the
year. The effect of this is to bring about the regular changes in
the inequality of the lengths of day and night. From a study of
the above sketches, the shifting position of the sun's daily sky path
for the year may be seen in places of different latitudes. The
middle position is the sun's daily path for the March and Sep-
tember equinoxes, and the position farthest north is the sun's

path for the June solstice, and the position farthest south is the sun's daily path for the December solstice.
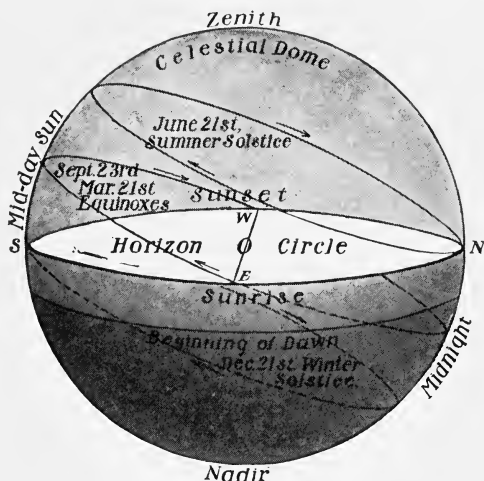
The planes of all the sun paths are always inclined from a

FIG. 8.—SHOWING POSITION OF SUN'S APPARENT DAILY SKY PATHS AT THE ARCTIC CIRCLE, LATITUDE 66½° N.

On June 21 the sun remains above the horizon and on Dec. 21 below the horizon for the entire 24 hours.

vertical an amount equal to the latitude of the observer, for the planes are parallel to each other. See Figs. 6, 7, 8, and 9.

QUESTIONS

1. How do we know that the earth is whirling uniformly in space?

2. Make a sketch of an oblate spheroid and draw in the axis and the equatorial diameters. Properly letter the sketch and locate the poles. Where is the centrifugal force due to rotation the greatest? The least?

3. What is the area of the water surface of the earth? What substances are as much as 5.6 times as heavy as water?

4. Why are not the so-called evidences proofs that the surface of the earth is curved? Which evidences are strongest? Which weakest?

5. What are the relative positions of daylight and darkness upon the earth? In what direction do they travel?

6. Try to picture in your mind, by using a globe, the actual path which a particle at the equator describes due to the combined motion

of rotation and revolution. Make a free-hand sketch to show the motion and describe it.

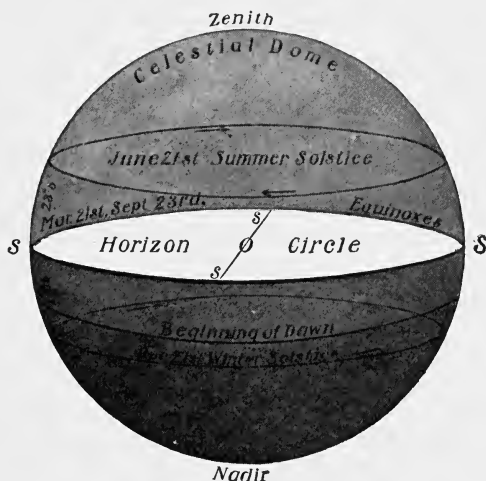7. A degree of longitude in latitude 40° equals about 53 miles. How

FIG 9.—SHOWING POSITION OF SUN'S APPARENT SKY PATHS AT THE NORTH POLE
Paths are nearly horizontal. The year is divided into two periods of sunlight and darkness.

many miles an hour does a point in that latitude move? How does this result compare with the distance the earth as a whole moves in an hour, due to revolution?

8. When riding on a railroad train, in what direction does the outside view from the window *appear* to move? What does this illustrate in respect to the apparent motion of the sun, moon and stars?

9. What effect has centrifugal force, due to rotation, upon the weight of bodies at the surface of the earth? Where is this effect greatest? Where the least?

10. The stars that rise and set, rise about four minutes earlier each night. Why? In a month these stars appear to shift westward. How far? What effect has this in twelve months? What is the real cause of the apparent shifting of the star dome?

11. If the earth's axis were perpendicular to the plane of its orbit, would revolution cause a change of season? Suppose the inclination of the earth's axis varied during a single revolution, what effect would that have upon the change of seasons? Is revolution necessary for a change of seasons? Explain.

12. In what direction does the sun's daily path through the sky shift from December 21 to June 21? During this period of six months, which is growing in length, our period of illumination or the period of darkness? Why? How is it from June 21 to December 21?

13. Why is not the sun always the same distance from the earth?

14. In about what latitude is the noon ray of the sun vertical on January 1st? March 1st? July 1st? September 1st? At these different dates, which is the longer here, the daytime or the night? In what latitude approximately are the northern and the southern limits of illumination at these dates?

15. State whether at these different dates the sun rises north or south of east and sets north or south of west.

16. Why are the Tropics placed where they are?

17. What is meant by the expression "sun crossing the line"? How often does this occur? In what direction is the sun migrating at each time?

18. Make an estimate of the time of the exposure of the photographic plate used in making the cut for Fig. 3 on page 8.

CHAPTER II

LATITUDE, LONGITUDE, AND TIME

LATITUDE

The equator is the circle extending around the earth midway between the poles. Circles parallel to the equator are called *parallels*. The planes of all parallels, as well as the plane of the equator, are at right angles to the earth's axis. *The distance expressed in degrees, north or south of the equator, is called the latitude of a place.*

The axis of the earth extended northward marks the position of the north pole of the heavens. The elevation of the celestial or sky pole above the horizon equals the latitude of the observer. The angle between a vertical line and the plane of the earth's equator also equals the latitude of the observer.

Because the equatorial bulge makes the curvature of the surface of the earth grow gradually less from the equator toward the poles, degrees of latitude increase slightly in length toward the poles. Less curvature of the earth's surface in the higher latitudes means that the surface has the form of an arc of a larger circle. A degree, or 1-360 of the length of the circumference of a larger circle, is evidently longer than a degree of a smaller circle. A degree of latitude at any place is therefore 1-360 *of the circle whose curvature is that of the meridian at that place.*

The circle *N E S E'* represents a meridian section of the earth, *N S* being the axis and *E E'* the equator. *H O H'* is the plane of the horizon with the observer at *O*.

O N' extends north and is parallel to the axis *N S*. The point *Z* is the zenith directly over the observer.

The angle $O\,C\,E'$ is the latitude of the observer and equal to $N'\,O\,H$, the altitude of the north pole of the sky.

Proof.—Angle $Z\,O\,N'$, the zenith distance of the north pole of the sky plus the angle $H\,O\,N'$ equals a right angle, or 90 degrees, since $Z\,O$ is the perpendicular to $H\,H'$.

Angle $N\,C\,O$ plus angle $E'\,C\,O$ equal a right angle, or 90 degrees, since the axis of the earth is perpendicular to the plane of the equator.
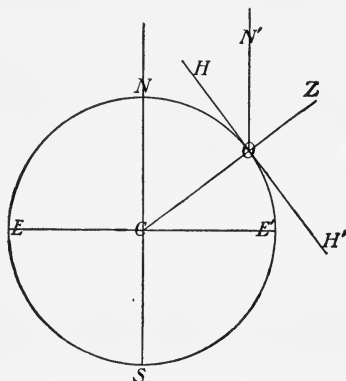

Fig. 10.—The Altitude of the North Sky Pole, Angle $N'\,O\,H$, Equals the Latitude of Observer O, Angle $O\,C\,E'$

Angles $N\,C\,O$ and $N'\,O\,Z$ are equal, being corresponding angles made by a line crossing two parallel lines.

Therefore the complementary angle $E'\,C\,O$, the latitude of the observer, equals $H\,O\,N$, the altitude of the north pole of the heavens.

How to Find a North and South Line.—By the following methods, a north and south line may be located:

(*a*) On any clear night the direction of Polaris, when it is directly above or below the sky pole (see Fig. 11), is due north. This occurs twice in every twenty-four hours, when Polaris and Mizar, the star in the bend of the handle of the Big Dipper, are in a vertical line.

(*b*) The direction of a magnetic needle, when corrected for variation, will enable one to locate a north and south line.

(*c*) The direction of the shortest shadow cast on a horizontal plane by a vertical post is north and south. When the sun is at

its highest point in the sky, shadows are shortest. This occurs at solar noon, which is approximately noon, local time.

Latitude Determined by Night.—The latitude of an observer may be found on any clear night by means of the Pole Star (Polaris).
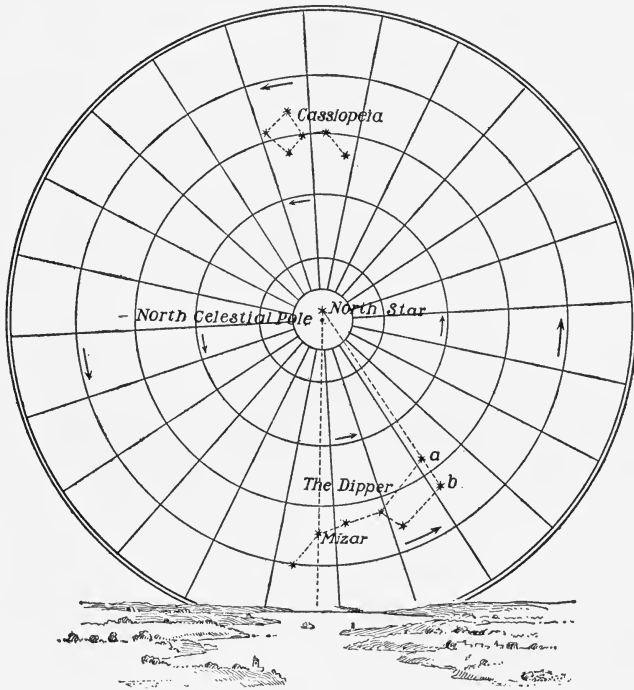
FIG. 11.—SHOWING THE ROTATION OF THE HEAVENS ABOUT THE NORTH STAR

The number of degrees of a heavenly body above the horizon is called its *altitude*. At the equator the North Star appears on the horizon, and its altitude is consequently zero. At 40 degrees north of the equator, for instance, the North Star is 40 degrees above the horizon (altitude 40°); and at the north pole of the earth it is in the zenith (altitude 90°). The altitude of the North Star in the northern hemisphere equals, therefore, the latitude of the place

where the observation is made. This is not always absolutely correct, since Polaris describes daily a circle, $1\frac{1}{4}°$ from the north pole of the sky.

Latitude Determined by Day.—Another method of finding the latitude of a place is to measure the distance of the noon sun from the observer's zenith. At the time of the equinoxes the sun is on the sky equator, and the distance of the noon sun from the zenith equals the latitude of the place where the observation is made.

To find the latitude of a place at other times of the year by means of the zenith distance of the noon sun, certain corrections should be made. The Nautical Almanac gives the position of the noon sun in reference to the sky equator. This is called the sun's declination. In the northern hemisphere, if the sun is north of the sky equator, the zenith distance of the noon sun will be that number of degrees less than the latitude. If the sun is south of the sky equator, the zenith distance of the noon sun will be just that number of degrees more than the latitude of the place.

The zenith distance of the sun should be found just as it crosses the observer's meridian, that is, when it is on a north and south line.

LONGITUDE

The lines that pass from pole to pole on the earth's surface are called *meridians*. Meridians are farthest apart at the equator and converge toward each pole.

The meridian that passes through Greenwich, England, is the *Prime Meridian*, and the meridian from which longitude from 0° degrees to 180° east and 180° west is reckoned.

Definition, Prime Meridian, Use.—Longitude is the distance expressed in degrees east or west from the prime meridian. A degree of longitude at any place is 1-360 of the parallel of that place.

The location of a place anywhere on the earth's surface may be found by determining its latitude and longitude. A place in latitude 40 degrees north and longitude 75 degrees west is on the parallel 40 degrees north of the equator, at a point where the meridian 75 degrees west of Greenwich crosses it.

How Longitude is Determined.—Longitude is determined by finding the amount by which the noon at Greenwich is earlier or later than the observer's noon. Since the earth turns eastward through 360 degrees in 24 hours, it turns 15 degrees an hour, or 1 degree in four minutes. An hour slower than Greenwich means that the place is 15 degrees west longitude, and an hour faster means that the place is 15 degrees east longitude.

Various methods for the determination of longitude are used:

(a) *By the Chronometer*, which is an accurate clock that keeps Greenwich time. Chronometer time is compared with local time found by taking an observation of the noon sun. At sea observation is made with a sextant. Before noon the sun's altitude is increasing. When it ceases to increase the sun is on the meridian and the time is apparent noon.

(b) By making a *direct telegraphic comparison* between the clock set to local time of the observer and that of some station of known longitude. The difference in time will give the difference in longitude between the two places.

TIME

How Time is Determined.—The rotation of the earth furnishes us with a measure of time. The day is a universal unit of time. It is the interval between two successive passages across a given meridian of a given heavenly body. If the sun is the heavenly body taken for reference, the day is called a *solar day*, if the moon a *lunar day*, and if a star a *sidereal day*.

The three kinds of days may be better understood from a study of Fig. 12. *E* represents the earth in its orbit about the sun *S*, and *E′* is the position of the earth a day later. *M* represents the moon in its orbit about the earth, and *M′* its position a day later. Far to the left of the diagram is a certain star so far away that lines drawn to it from any point on the earth's orbit are practically parallel. The moon *M*, the sun *S*, and a star *S′* are on the meridian with the observer at *O*.

The earth rotates as it moves forward in its orbit. The direction of the motion of revolution of both earth and moon, and the direction of the motion of the rotation of the earth, when seen from above the north pole, are counter-clockwise, as indicated by arrows in figure.

The real movement of the earth of approximately a degree a day in its path or orbit about the sun causes the sun to appear to move among the stars eastward about a degree a day. This has the effect of making the stars rise four minutes earlier and set four minutes earlier on successive nights. In a year's time the stars come back to the same position in the sky at the same time of day, for four minutes each day of the 365 days of the year make about one whole day.
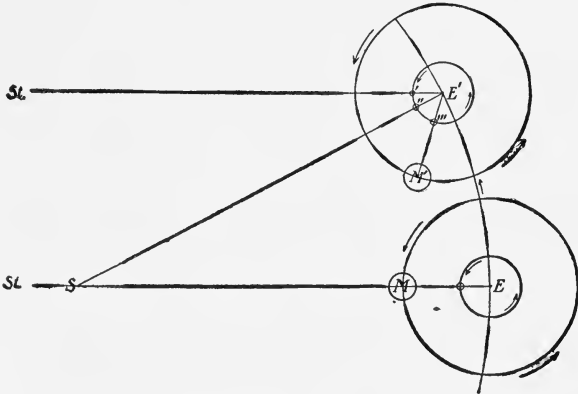

FIG. 12.—DIAGRAM SHOWING EFFECT OF REVOLUTION OF THE EARTH UPON THE LENGTHS OF DIFFERENT KINDS OF DAYS

Sidereal Day.—During one complete rotation of 360 degrees, the earth moves from its position at E, Fig. 12, to a new position at E', and the observer at O is brought to O'. The same star has again come to the observer's meridian and one *sidereal day* has ended.

A sidereal day may then be defined as the interval of time between the passage of a star across a meridian and its next passage across the same meridian. It is divided into 24 sidereal hours. Astronomical clocks keep sidereal time and mark the hours from 0 to 24. The sidereal day, being about four minutes shorter than the solar day, sidereal noon comes four minutes earlier each day, so that during a year it occurs at all hours of the day and night.

Solar Day.—Since the forward motion of the earth in its orbit is about a degree a day, the earth must rotate eastward one degree more than 360 degrees to bring the sun again to the observer's meridian, that is, the earth turns through 361 degrees from O, Fig. 12, to O'' to complete one *solar day*.

Lunar Day.—The daily motion eastward of the moon in its orbit is about 13 degrees. The earth must rotate 13 degrees more than 360

degrees to bring the moon again to the observer's meridian, that is, the earth turns through 373 degrees from O to O''', Fig. 12, to complete one *lunar day.*

Mean Solar Time.—The apparent motion of the sun being faster when nearer the earth and slower when farther away, makes the sun a poor timekeeper.

By taking the average length of all apparent solar days in a year, a definite length of our day is obtained. Our clocks and watches are regulated to keep this mean solar time. The apparent solar time read on

the *sun dial,* and the mean solar time read from our clocks, agree only four times a year. This average day is called the *mean solar day,* and may be considered as *being regulated by an imaginary sun that has a uniform motion and consequently crosses the meridian at regular intervals.*
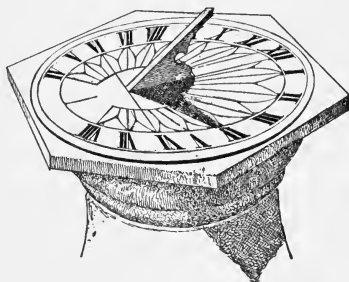
The attempt to construct clocks with compensating devices that would keep *real* solar time was made during the eighteenth cen-

Fig. 13.—Sun Dial

tury. The variation in the sun's apparent motion was so complex, that *apparent time* clocks were abandoned early in the nineteenth century.

The *sun dial* consists of two essential parts, a style or gnomon and a dial. The style is placed parallel to the earth's axis and casts a shadow on the dial. The different hours of the day are marked on the dial, and the shadow of the style cast by the sun passing over it, as the sun moves through the sky, indicates the time of day.

The style is usually a rod or edge of a thin plate of metal, and being parallel to the earth's axis makes an angle with the horizontal dial-plate equal to the latitude of the place where the sun dial is located.

Equation of Time.—When the sun does not cross the meridian until after mean noon time the sun is said to be slow, and when it crosses the meridian before mean noon the sun is said to be fast. The amount that the real sun is ahead or behind the imaginary average sun is called the *equation of time.*

The Civil Day.—Our ordinary day, called the civil day, begins at midnight and ends on the following midnight. Business is generally suspended at that time, and the change of date can be made

then with the least confusion. The first 12 hours are called a.m. (ante-meridian), and the second period of 12 hours p.m. (post-meridian); 12 m. means noon or sun on the meridian. To find the exact time at which the sun is actually on the meridian the table for the equation of time must be consulted or an observation must be made.

For a person who travels around the earth, the number of times the sun crosses his meridian would be one less if going westward and one more if going eastward, than it would be if he stayed at home. It is evident, then, that if the traveler does not add a day when going westward and drop a day when going eastward, upon his return his reckoning will differ one day from that at home. It has been agreed among mariners to make the change of date at the 180th meridian from Greenwich.

To avoid confusion of dates on islands crossed by the meridian, an off-set eastward a few degrees is made about New Zealand and an off-set westward is made about the Fiji Islands. Another off-set eastward is made to avoid passing across the extreme eastern part of Siberia. After passing through Bering Strait the date line returns to the 180th meridian.

International Date Line.—The 180th meridian, together with the off-sets mentioned, constitute the *international date line*. The date on the western side of this line being a day later than on the eastern side, ships, in crossing it, omit a day in their reckoning when going westward, and repeat a day when going eastward.

The Conventional Day.—The day which by international consent it has been decided that any country has at any moment, is called the *conventional day*. The conventional day begins at the international date line, and moves westward 15 degrees an hour with the sun. Parts of two different days are on the earth at the same time. The midnight line, which is just opposite the noon sun, marks the forward or westward boundary of each advancing day.

Local Time.—The mean solar time of any place is called its *local time*. Places of different longitude differ in local time four minutes for each degree. In going around the earth at the equa-

tor, a distance of about 25,000 miles, the local time changes at the rate of one hour for a distance of about 1,038 miles. In latitude 40 degrees, a distance of about 801 miles, makes a difference of one hour in local time, and in latitude 60 degrees, 519 miles.

Standard Time Belts in the United States.—Because of the confusion that resulted from each place keeping its own local time, especially along railroads extending east and west, most railroad towns readily gave up their own and adopted the time in use by the railroad. The number of railroads increased until at certain centers there were many railroads entering the same city, each with a different local time in use. Much confusion arose from having different local times used in the same place. A definite system of keeping time in the United States was decided upon, and in 1883 the different railroad lines put it into operation. This system is called *Standard Time*, and may be defined as the *time based upon a certain meridian that is adopted as the time meridian for a definite belt of country.* Its advantage is that neighboring places keep the same time, instead of differing a few minutes or seconds according to their longitude. This is of especial importance in the operation of railroads and telegraphs, and with the transaction of any business concerned with contracts involving definite time limits. The standard time meridians of the United States, as adopted, are 75 degrees, 90 degrees, 105 degrees, and 120 degrees west from Greenwich.

This system has been extended to the remote possessions of the United States, and has spread over the greater portion of the world.

Eastern Standard Time.—The mean solar time of the 75th meridian is used for places on both sides of that meridian and in a belt approximately 15 degrees wide, and is called *Eastern Standard Time.* This meridian runs through Philadelphia, and there local and standard time are the same. The time within this belt is five hours slower than Greenwich time. The so-called time belts have very irregular eastern and western boundaries, depending upon the location of cities upon the railroads. Study carefully Fig. 14 and trace the time belt boundary lines.
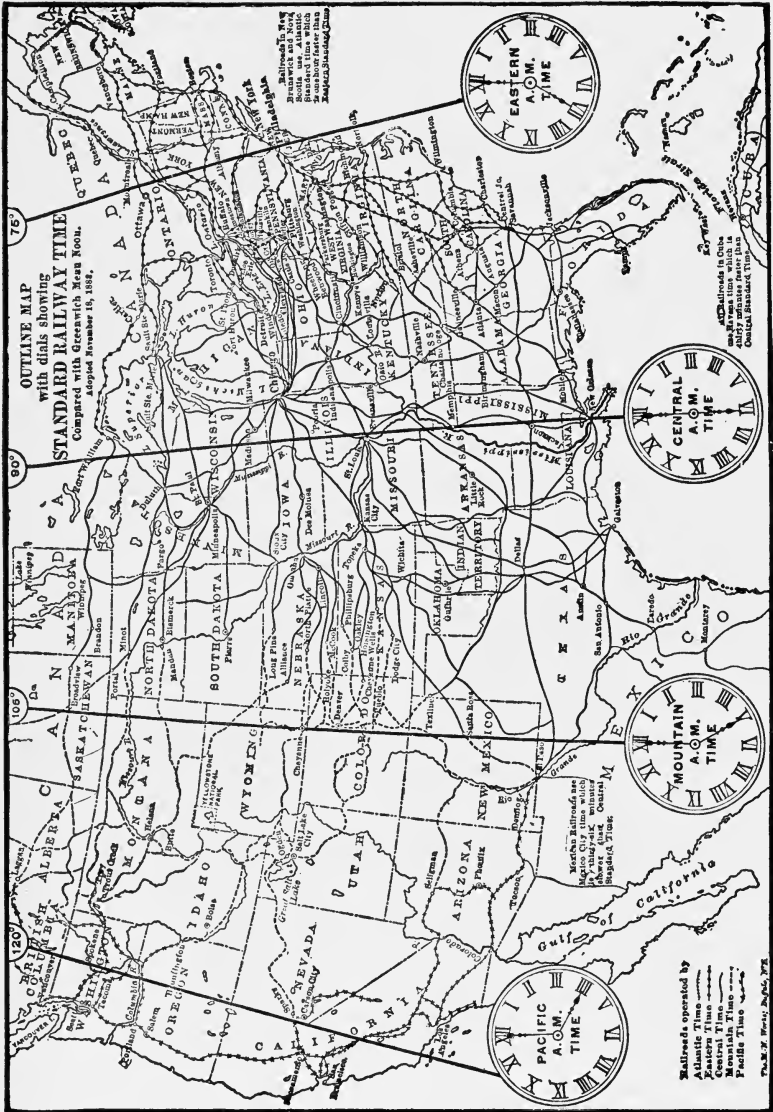
FIG. 14.—STANDARD TIME BELTS
Note the irregular boundary lines.

Central Standard Time.—The time of the next belt westward is the mean solar time of the 90th meridian, called *Central Standard Time*, and is one hour slower than Eastern time. When it is noon, Eastern time, at Washington, Baltimore, Philadelphia, New York, and Boston, it is 11 a.m., Central time, at Chicago, Minneapolis, St. Louis, and New Orleans.

Mountain Standard Time.—The next time belt westward uses the mean solar time of the 105th meridian, called *Mountain Standard Time*. Denver, Colorado, is on this meridian, so that clocks in that city indicate both mountain and mean solar time.

Pacific Standard Time.—The time belt on the extreme west of the United States covers the States on or near the Pacific coast, and has the mean solar time of the 120th meridian, called *Pacific Standard Time*. Time in this belt is three hours slower than in the eastern belt, and eight hours slower than Greenwich time. In Alaska, standard time is nine hours slower than Greenwich time.

El Paso, Texas, has the peculiar condition of having four different systems of time in use. The mountain standard time belt tapers southward to a point at El Paso. This allows the Central, Mountain and Pacific time belts to meet. The standard time for Mexico, on the south, is 24 minutes later than Mountain time. The railroads that enter El Paso from the east, south and west bring their own time. Mountain time is used by the city officials of El Paso.

Time Signals.—The time service of the United States is under control of the Government. By coöperation of the telegraph companies, time signals are sent out daily at noon, Eastern time, from the Naval Observatory at Washington, D. C., to nearly every telegraph station in the country. These regulate automatically more than 30,000 clocks, and drop time balls in scores of different ports of the Atlantic, Pacific, Gulf of Mexico, and Great Lakes coasts. Time signals for the extreme western part of the United States are distributed from Mare Island Navy Yard, in California.

THE CALENDAR

The very early calendar, worked out by the Romans, was based largely on the motions of the moon. As the yearly number of revolutions of the moon varies, the seasons and festivals did not keep in place, and the Roman calendar fell into a state of great confusion. The year consisted of ten months, March being the first and December the tenth and last. January and February were added later. There were about 29½ days in a lunar month, so the months were given 29 and 30 days alternately, beginning with January. The number of days in a week was probably based upon the number of planets then known, including the sun and moon. In the year 46 B.C., the Roman calendar was reformed by Julius Caesar, under the advice of Egyptian astronomers.

The Julian Calendar.—The Julian calendar was planned without reference to the moon. It made three consecutive years of 365 days each, and the fourth of 366 days. The extra day was added to February, that month then having only 29 days, and the other months having alternately 30 and 31 days. The length of the Julian year was 365.25 days, and since the true year has 365.24 days, the Julian year was .01 of a day, or 11.2 minutes too long.

This difference of 11.2 minutes between the length of the Julian year and the year now in use amounts to a little more than three days in 400 years. As a consequence, the date of the vernal equinox came continually earlier in the Julian year. In 1582 the vernal equinox occurred on the 11th of March.

The Gregorian Calendar.—In that year Pope Gregory XIII directed that ten days be stricken from the calendar, so that March equinox might occur on March 21. A further reform was introduced at this time in order to prevent a similar occurrence. The Pope decreed that the centurial year should not be counted as a leap year except when divisible by 400. Thus 1800, 2100, and so forth, are not leap years, but 1600, 2000, and 2400 are leap years.

The Gregorian calendar is now used in all civilized countries except Greece and Russia, where the Julian calendar is still in force in spite of repeated efforts to abolish it. The 14th of every month here is the first of the month there.

In England it was adopted in 1752. Dates of events occurring before the Gregorian calendar was adopted are termed Old Style (O. S.), and those after the adoption New Style (N. S.).

In order to gratify the vanity of Augustus Caesar, the month now bearing his name, formerly called Sextilis, was given 31 days so as to have as many as July, formerly called Quintilis, which was named for

Julius Caesar. A day was accordingly taken from February, leaving only 28 days for that month, and given to August. Because of the superstition of having three months of 31 days each, together, September and November were reduced to 30 days, and October and December were given 31.

QUESTIONS

1. How may ships be located at sea? If city streets extend east and west and at right angles to avenues, how may places be located thereby? Compare the plan of locating a place in the city with that of locating the ship at sea.

2. How may the following be determined in the southern hemisphere:—(*a*) Latitude by night? (*b*) Latitude by day? (*c*) A north and south line?

3. At what time of day is longitude usually determined? Why?

4. What is the circumference of the earth at the 60th parallel, as compared with the circumference at the equator?   ·

5. Why is a solar day about four minutes longer than a sidereal day? Do solar days differ in length? Why?

6. In laying out a north and south line by means of the noon sun, what besides a watch would be necessary?

7. What are some of the practical advantages of having the civil day change at midnight? State any difference you may see between the civil day and the conventional day.

8. How long has every day been on the earth before it reaches you? At what time by the clock at your place does a new day start on the earth? If Sunday is just east of the international line, what day is just west of the line? Explain.

9. By how much does the local time of your place differ from standard time? Why are the boundaries of the standard time belts so irregular?

10. At what hour do the noon time signals from Washington reach Chicago? Denver? Explain.

11. What advantages has the sun over the moon for calendar purposes? State the reason for the present rule for leap year.

CHAPTER III

THE MOON

Distance, Area, and Size.—The moon's average distance from the earth is about 240,000 miles. The actual distance during a single month varies about 30,000 miles, causing a corresponding variation in its apparent size.

The diameter of the moon is 2,163 miles, being about 27 per cent of the diameter of the earth.

The surfaces of the moon and earth are to each other as the squares of their diameters, or as one to fourteen. Their volumes are to each other as the cubes of their diameters, or as one to fifty.

Real and Apparent Motion of the Moon.—The *apparent* motion of the moon and stars by night and of the sun by day, is due to the earth's rotation from west to east. There is a *real* eastward motion of the moon, as may be seen by noting the position of the moon among the stars from night to night.

Since the moon makes one complete revolution about the earth in about 27⅓ days, the eastward motion is about 13 degrees a day; and as the sun also appears to move eastward among the stars about 1 degree a day, the eastward daily gain of the moon is about 12 degrees. This causes the moon to rise about 50 minutes later each day.

Moon has no Atmosphere or Water.—The moon has no appreciable atmosphere. Its absence is shown by the fact that when the moon hides a star, the star disappears suddenly and not gradually, as it would if its light passed through an atmosphere. There seem to be no effects of erosion on the moon, which also goes to show that there is no atmosphere there. If the moon ever had an atmosphere at any stage of its development it has lost it. If water existed on the moon it would evaporate during the long day there and form an atmosphere.
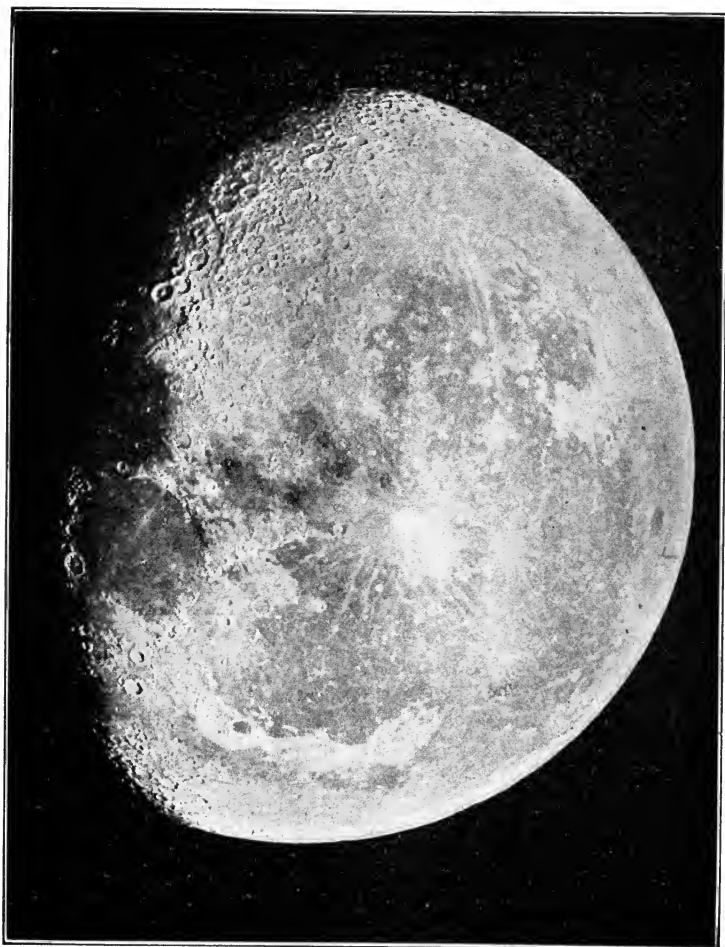
FIG. 15.—LUNAR TOPOGRAPHY (Stellar Evolution)

Moonlight Surface Markings.—Moonlight is but reflected sunlight. The surface markings on the moon are known to be due to a very uneven surface. The visible surface of the moon has an area about equal to that of South America, and nearly one-half of the area is covered with dark gray patches which were once supposed to be seas. The rest of the surface consists of mountains, so called volcanoes and craters, and ringed valleys. Some mountain chains have peaks nearly 4 miles high.

Same Face is Always Toward the Earth.—Since the same side of the moon is always turned toward the earth, it follows that the period of rotation of the moon on its axis and its period of revolution about the earth are the same, about $27\frac{1}{3}$ days. Consequently we know nothing except by inference about the other side of the moon. The side of the moon that is toward the sun is always brightly illuminated, and the side turned away from the sun is in darkness. As the moon makes her way eastward around the earth, varying portions of the illuminated half are seen. This causes the moon's phases.

PHASES OF THE MOON

New Moon.—When the moon and the sun are on the same side of the earth, the dark side of the moon is turned toward the earth and we have *new moon.* New moon, strictly speaking, occurs when none of the bright surface is visible. Popularly the moon is said to be new when seen as a very thin crescent. A day or two later, when the moon has moved a little eastward of the sun, we may see in the early evening in the western sky a small portion of the illuminated half in the form of a *crescent,* convex westward, or toward the sun, with the horns turned eastward, or away from the sun.

First Quarter.—A week after new moon, half of the illuminated hemisphere may be seen. The moon has now reached *first quarter*, and its shape is that of a half-circle. A line connecting it with the earth is at right angles to a line connecting the sun and the earth. As the moon passes beyond the first quarter the boundary line between the light and the dark area begins to be convex eastward, and the lighted portion continues to grow larger.

Full Moon.—When the moon and the sun are on opposite sides of the earth, the whole lighted half of the moon is turned toward the earth, and we have *full moon,* about a week after the first quarter. The line dividing the light and dark areas after full moon changes from the left side to the right side of the moon's disk.

Third Quarter.—The moon reaches the last or *third quarter* about a week after full moon. In this phase the half-circle is convex toward

the left instead of convex toward the right, as seen in the first quarter. After third quarter, the moon being west of the sun, the crescent curves to the left or toward the sun, and horns point to the right away from the sun.

Waxing and Waning.—In its revolution from new to full moon, the visible illuminated area increases and the moon is said *to wax*. From full to new the illuminated area decreases and the moon is said *to wane*.
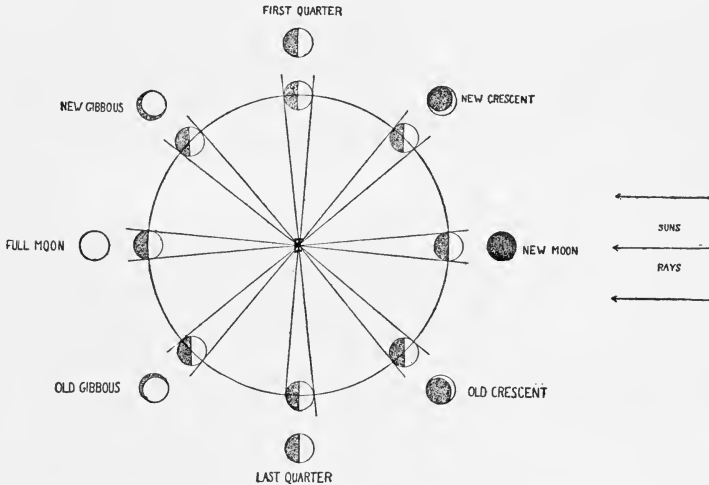

FIG. 16.—MOON'S PHASES

The real illumination of the moon is shown in the inner eight positions in orbit about the earth at *E*. The sun is at the right. The apparent illumination is shown in the corresponding outer position.

Earth-Shine.—The dark portion of the moon is sometimes lighted by sunlight reflected from the earth, called *Earth-Shine*. This occurs at the young and old crescent phases, and makes the entire disk of the moon visible.

ECLIPSES

Shadows.—All of the planets and their satellites are opaque bodies and cast long, cone-shaped shadows away from the sun. The length depends upon the size of the sphere and its distance from the sun. The average length of the earth's shadow is about 866,000 miles, and that of the moon 232,000 miles.

Cause of Eclipses.—The word eclipse as here used means a darkening of a heavenly body. This darkening may be real or apparent. The moon is eclipsed when it passes into the earth's shadow; the sun is eclipsed when the moon passes between it and the earth. During a lunar eclipse the moon is really darkened, light from the sun being cut off by the earth. During a solar eclipse the sun is only apparently darkened; the moon cuts off
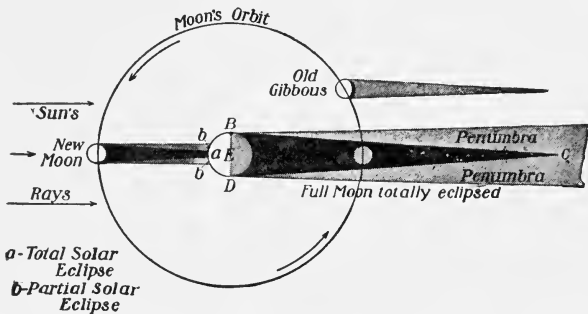

FIG. 17.—SOLAR AND LUNAR ECLIPSES

light that would otherwise reach the earth. In reality it is the earth rather than the sun that is eclipsed.

Total Lunar.—In the figure, the moon is passing through the earth's shadow, B C D, and is totally eclipsed. The moon's disk at this time is usually visible, however, because of sunlight bent into the earth's shadow by our atmosphere. This gives the moon during a total eclipse, a dull, copper colored appearance.

Partial Lunar.—When the moon passes slightly north or south of the center of the earth's shadow, and only a part of the moon's disk enters the shadow, a partial lunar eclipse occurs. The moon in its monthly revolution about the earth usually escapes the earth's shadow entirely.

Total Solar.—When the moon passes between the earth and the sun, and its shadow, called the umbra, reaches the earth, a total eclipse occurs in that portion of the earth covered by the shadow.

Partial Solar.—Just outside the umbra of the moon's shadow, an observer in the penumbra or partial shadow would see only a part of the sun's disk, and would experience a partial solar eclipse.

When the moon's shadow is not long enough to reach to the earth,

and the moon passes centrally across the sun's disk, leaving a ring of the sun's disk exposed, the *eclipse is said to be annular*. The moon appears as a black spot covering the central portion of the sun's disk, surrounded by a ring of light.

Number of Solar and Lunar Eclipses in a Year.—There are always at least two eclipses of the sun in a year, and there may be as many as four. The largest number of lunar eclipses in a year is three. As every eclipse of the moon is visible at one time from all points on one-half of the earth, and eclipses of the sun from a narrow area only, many more lunar than solar eclipses are visible at a given place.

QUESTIONS

1. Compare the moon with the earth in respect to size and physical conditions. Where and when do we see the young crescent? The old crescent? How long is each usually visible? Why?

2. During what phase of the moon do lunar eclipses occur? Solar eclipses?

3. How many solar eclipses would occur each year if the orbits of the earth and moon were in the same plane?

4. The time from full moon to full moon, called a lunar month, is $29\frac{1}{2}$ days, while the actual time of a revolution of the moon about the earth is $27\frac{1}{3}$ days. To what is this difference due?

CHAPTER IV

THE SOLAR SYSTEM

Solar System Defined.—The sun, together with the bodies revolving about it, is called the Solar System. The members of the system are the sun, the planets and their satellites, the planetoids, some comets, and meteors. They may be briefly described as follows:

1. The sun is near the center of the system, a very large, hot, self-luminous body giving heat and light to the other members. Its gravitative attraction controls their motions.

2. The planets, eight in number, upon one of which we live, revolve about the sun in elliptical orbits, in different periods of time, and at different distances from the sun. Planets are distinguished from stars by their changing position among the stars, and by their visible disk when seen through a telescope. Stars keep their relative position in the sky, and through a telescope appear as points of light.

Consult the following table:

PLANETS	Diameter in Miles.	Average Distance from Sun in Millions of Miles	Period of Revolution in Years.	Number of Satellites or Moons
Mercury	2,700	36	0.24	0
Venus	7,800	67	0.62	0
Earth	7,913	93	1.00	1
Mars	4,300	141	1.88	2
Jupiter	87,000	483	12.00	8
Saturn	72,000	886	29.00	10
Uranus	35,000	1,782	84.00	4
Neptune	32,000	2,792	165.00	1

3. All except two of the planets have satellites revolving about them. The satellites are very unevenly distributed among six of

the planets, as seen in the table above. Our moon is an example of a satellite.

4. The planetoids (planet-like bodies), about seven hundred and fifty in number, are small bodies, as compared with any of the planets, and revolve about the sun between the orbits of the planets Mars and Jupiter.

5. Comets are bodies that are temporarily visible, of large dimensions and small mass, unstable in form, usually with long tails and with uncertain orbits. Some comets revolve about the sun in closed orbits, have fairly definite periods of revolution, and are consequently members of the Solar System. Other comets with open orbits enter and then pass out of the Solar System without becoming members of it.

6. Meteors are comparatively small masses of stone or metal that enter the earth's atmosphere from outside space. The light

FIG. 18.—DIAGRAM OF ORBITS OF THE PLANETS DRAWN TO SCALE.

given out by them is due to their being heated by the friction and compression of the air. Meteors are popularly called " shooting stars."

Size of the Solar System.—It will give us a better conception of the size of the orbits of the different planets if we draw to scale a map of the solar system. The orbits of the first four planets are so small compared with the orbits of the last four, that it is difficult to find a suitable scale to use, to represent the whole upon a single page of this book. The scale, one millimeter, equivalent to 20,000,000 miles, is used.

Although the orbits of the planets are elliptical, they differ so little from circles that for this purpose the circle may be said to represent the planet's orbit.

Space Outside the Solar System.—The known bodies occupying space outside of the orbit of Neptune are comets, meteoric swarms, large gaseous masses called nebulæ, and stars.

In literature the stars are often referred to as "numberless" and "countless." As a matter of fact, only about 3,000 stars can be seen without a telescope at any one time, and in the whole heavens there are fewer than 6,000 stars that may be seen with the naked eye. With the telescope fainter stars are seen. The moderate sized photographic telescope, with the modern sensitive plate, will show stars that are too faint to be seen with the largest telescopes. It has been estimated that the photographic plate has made record of about one hundred million stars. Each of these stars shines by its own light and is consequently a sun. Many are more brilliant and larger than our own sun, and may be centers of other systems.

THE SUN

Diameter, Density, and Temperature of the Sun.—The sun is a huge sphere of incandescent gases and metallic vapors, with a diameter of 866,000 miles, and is 1.4 times as heavy as a sphere of water of the same size. Although but a small fraction of the total light and heat given out by the sun reaches the earth, yet nearly all life activities and most movements of air and water are due to this amount.

The difference between conditions on the sun and those now on the earth is due largely to a difference in temperature

THE CONSTITUTION OF THE SUN

The Photosphere.—The visible surface of the sun is called the *photosphere* (light-sphere). It is cloud-like in appearance and gives forth most of the light and heat which the sun radiates.

Sun-Spots.—Dark spots of irregular outline, called *sun-spots*, often many thousands of miles in diameter, mar at times the brightness of the photosphere. The sun-spots are probably connected with the hidden circulation in the great body of the sun below the photosphere, and are dark only in comparison with it. Observers of sun-spots soon found that the sun turns on its axis from west to east. The earth's magnetism is disturbed during a period of unusual activity in the sun. A large number of sun-spots appear and a greater development of solar prominences occurs most frequently at these times. The period of maximum disturbance occurs on an average about every eleven years.

FIG. 19. THE REAL COLORING OF THE SUN SEEN DURING A TOTAL SOLAR ECLIPSE.
Composite drawing from photograph of the corona, colored from observations made with color chart, August 30, 1905.

As the sun rotates on its axis in about 26 days, no spot would remain continuously visible for more than 13 days, being one-half of the period of the sun's rotation.   Some spots last, however, only a few days, while others persist for months.

Elements in the Sun.—By means of an instrument called the spectroscope it is possible to tell some of the substances of which the sun is
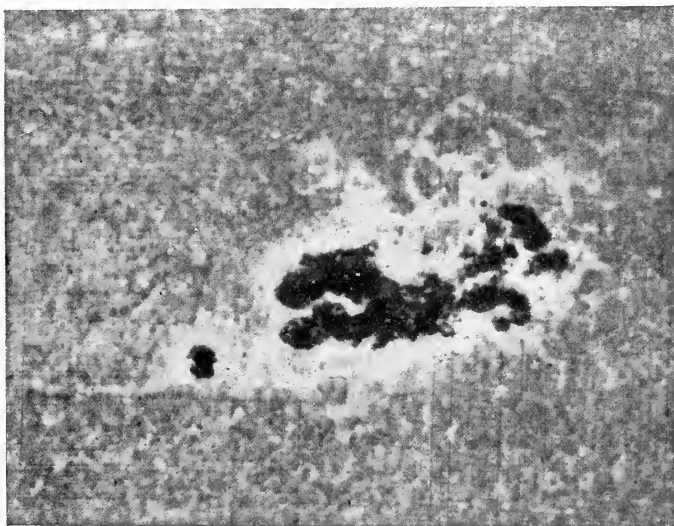
FIG. 20.—GREAT SUN-SPOT OF OCTOBER, 1903 (Stellar Evolution)

composed.   About 40 elements, such as iron, carbon, hydrogen, nickel, silver, etc., familiar to us on the earth, are now recognized in a layer of gas overlying the photosphere.

Chromosphere.—Outside this metallic layer is a deep envelope of gas, mostly hydrogen, called the *chromosphere* (color-sphere).

When the moon comes between the earth and the sun, the light from the photosphere is cut off and the sun is said to be eclipsed. During the solar eclipse the chromosphere can be seen as a brilliant scarlet ring. From its surface tongues of flame called prominences shoot out to altitudes of many thousands of miles.

The Corona.—The outermost portion of the sun is the *corona* (crown), a halo of pearly light extending out many thousands of miles, with streamers reaching out millions of miles. It is believed that the

light of the corona is due to the reflection of light from dust particles, liquid globules, and small masses of gas.

How the Sun's Heat is Maintained.—The theory that the sun's heat is largely maintained by the gradual shrinkage of its volume is generally accepted. The fall of matter toward the center would continuously generate heat, as the blow of a hammer on a nail would heat both nail and hammer. Other sources of heat may add to the total amount that the sun sends out into space, such as that resulting from combustion, the falling of meteors, and radioactivity.

THE PLANETS COMPARED

The characteristics common to all of the planets may be briefly enumerated as follows:

1. The planets move in the same direction about the sun from west to east. The sun rotates in this direction. The direction of movement as seen from above the north pole of the earth is opposite to the hands of a clock.

2. The paths or orbits of all the planets are ellipses, with the sun at one of the foci.

3. The other planets are non-luminous, like the earth; consequently the light that comes from them to us is reflected sunlight.

4. Most of the planets are known to rotate in the same direction as the earth rotates, from west to east.

THE PLANETS AS INDIVIDUAL BODIES

Mercury.—So far as is known at present, Mercury is the smallest planet, the nearest to the sun, and the swiftest in its movements about the sun. It can be seen only in the direction of the sun during early twilight or late dawn. Mercury has a thin atmosphere, if any at all, has surface markings of permanent streaks, and a known rotation period equal in length to its year of 88 days. Since the periods of rotation and revolution are the same length, Mercury always turns the same side to the sun. This side is always heated and has perpetual daylight, while the side turned away from the sun is always cold and in darkness.

Venus.—Venus shines in the sky with peculiar brightness. It has a diameter considerably more than double that of Mercury and only a little less than that of the earth. The period of rotation is now known to be 255 days, and equal to its period of revolution. Venus and Mer-

cury are the only planets that have equal periods of rotation and revolution. They pass between the earth and the sun, and consequently are the only planets that present all phases similar to those of our moon. The passages are called transits, and occur at irregular and relatively long intervals of time. During these passages Venus and Mercury look like small, round, black spots passing across the sun.

The Earth.—Although we know that the earth is a planet moving about the sun like the other planets, the earth seems to us to be a center about which the other heavenly bodies move. The earth has the general form of the other planets, that of a spheroid. It is the third in distance from the sun, and the largest of the four smaller planets whose orbits lie within those of the planetoids. The earth makes 366 rotations during one revolution.

Mars.—Mars, though having only a little more than one-half the diameter of the earth, resembles it in more respects than any of the other planets. Its period of rotation is 24 hours, 37 minutes, or a little more than our day. The inclination of its axis is about 24 degrees. Therefore, except for its greater distance from the sun, the days and change of seasons resemble those of the earth.

Surface markings on Mars indicate to some astronomers snow fields and canals. There seems to be little doubt about the white polar caps that appear and disappear according to the season. It is not certain, however, that they are fields of snow.

Although we have as yet no foundation from which to make any positive statement concerning the inhabitants of Mars, it may be claimed that if any planet other than the earth is inhabited, it is probably Mars. Mars appears in our sky shining with a steady, pale red light.

Jupiter.—Jupiter is the largest of all the planets, and, with the exception of Venus, often the brightest in the sky. Surface markings on Jupiter are described as parallel belts and spots. Because of the lack of the permanency of the markings, they are thought to be due to a deep atmosphere surrounding the planet. From observations of the spots, it has been found that Jupiter has a rotation period of about ten hours, which is the shortest known of any of the planets.

The circumference of Jupiter is about 11 times the circumference of the earth, and with a rotation period less than half of that of the earth; the rate of rotation at the equator of Jupiter is about 30,000 miles an hour, nearly 30 times the rate of rotation at the equator of the earth.

The outer four planets comprising the major group—Jupiter, Saturn, Uranus, and Neptune—are supposed to be of a higher temper-

ature, of less density, and in not so advanced a stage of development as the four planets Mercury, Venus, Earth, and Mars, comprising the minor group.

Saturn.—Saturn is distinguished from all the other planets by three thin, flat meteoric rings, easily visible through a small telescope, which surround it in the plane of its equator. The rings are together about 40,000 miles wide, and the inner edge less than 6,000 miles from the planet. At distances ranging from a hundred thousand miles to nearly eight million miles from Saturn, are ten satellites, more than have yet been discovered belonging to any other planet in the Solar System.

The surface markings on Saturn are not seen nearly so well as those on Jupiter, because Saturn is nearly twice as far from us. There are bright and dark belts, and at times faint spots. Saturn rotates on its axis in about 10½ hours. Because Saturn has a density of about three-quarters that of water, it is believed to be largely in a vaporous condition. It may be seen shining in the sky with a steady yellowish light, with about the same degree of brightness as the brightest star.

Uranus and Neptune.—Uranus was discovered in 1831, and Neptune in 1846. All the other planets were known to the Ancients. Uranus is a very faint object in the sky, and Neptune is invisible to the naked eye. Neptune is the most remote of the planets now known, and has the longest period of revolution, one year there being 165 earth years. It may be inferred that the physical condition of Uranus and Neptune is probably much the same as that of Jupiter and Saturn. The rotation period of Uranus, as indicated by surface markings, is between ten and twelve hours. These planets, being so far from the sun, receive a small amount of heat per unit area compared with that received by the earth.

The Satellites of the Solar System Compared.—Previous to 1610 the only satellite known was our moon. In that year Galileo first pointed his telescope to the sky and saw four large moons of Jupiter. Our moon is more than 2,100 miles in diameter, but not as large as any of three of the eight moons of Jupiter, and one of the ten moons of Saturn. The largest satellite of Jupiter is 3,558 miles in diameter, and considerably larger than the planet Mercury. The smallest satellites known are the two belonging to the planet Mars, both of which are probably less than ten miles in diameter. One of the two is only 5,800 miles distant from Mars, and makes a revolution in less than eight hours, one-third of the time it takes Mars to rotate.

The earth's satellite is about 240,000 miles distant from the earth, and makes a complete revolution in about 27⅓ days. The most distant satellite of Saturn takes considerably more than an earth year to

make a revolution. The mass of our moon as compared with the mass of the earth is probably greater than the mass of any other single satellite, compared with the mass of its planet. Mercury and Venus have no satellites, Uranus has four, and Neptune one.

The Planetoids.—The planetoids, sometimes called asteroids, move about the sun just as the planets do. They are so small that they are invisible to the naked eye. Not until the beginning of the nine-

FIG. 21.—HALLEY'S COMET (Evening Sky Map)

teenth century were any of these bodies discovered. There was an early belief that an undiscovered planet revolved between the orbits of Mars and Jupiter. This, no doubt, led to the discovery of the first and largest planetoid, Ceres, 485 miles in diameter. There are several whose diameters are more than a hundred miles, but the majority are much smaller, ranging down to about ten miles in diameter. New ones are now being found every year by the method of photography.

Comets.—Comets are in strong contrast with planets in appearance and physical condition. Most of them enter the Solar System with orbits in the form of open curves, make one turn about the sun, and pass away, probably forever.

Of the few comets that belong permanently to the Solar System, all have definite periods of revolution about the sun, varying from 3.3 years (Encke's Comet) to about 76 years (Halley's Comet). Halley's Comet last appeared during May, 1910.

The typical comet is largely self-luminous, and is composed of a head and a tail. In the center of the head is a bright, star-like nucleus surrounded by faintly luminous matter, called the *coma*. The
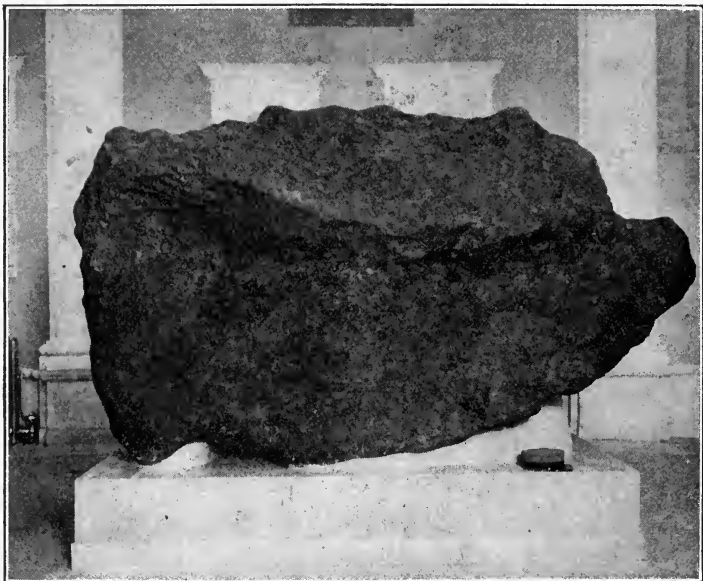

FIG. 22.—PEARY METEORITE
In American Museum of Natural History, New York

tail acts like your shadow when you walk around a lamp. It always points away from the light. Some astronomers maintain that it is the pressure of sunlight that drives the gaseous molecules from the nucleus and thus forms the comet's tail.

The head may have a diameter greater than that of the sun, with a nucleus as large as the earth, and the tail equal in length to the distance of the earth from the sun. The amount of matter in a comet is very small, in most cases less than one millionth of that of the earth.

The orbits of the planets are slightly elliptical and all are approximately in one plane; those of the comets are greatly elongated and

lie in every possible position. With the unaided eye it is a rare sight to see a comet.

Halley's Comet has been pursuing its fixed orbit about the sun since the dawn of history, and undoubtedly long before. The accounts of many of its earlier appearances seem to indicate that it has been a conspicuous object. The last appearance, during May, 1910, was disappointing. This tends to show that the great comet has for ages been slowly disintegrating.

Under the most favorable conditions the nucleus of Halley's Comet was brighter than stars of the first magnitude, the coma was a faint light, and the tail was a band of light about 8 degrees wide at its widest place and 120 degrees long. Stars were plainly visible through the comet's tail. It is believed that the earth passed through the tail on May 18, 1910. At that time there were no unusual manifestations seen, such as the falling of an unusual number of meteors, a glow of the sky, or the appearance of deadly gases, all of which had been predicted.

Meteors.—The earth in its path about the sun encounters daily many millions of small bodies which enter its atmosphere from outside space. On a clear, moonless night, one may see several an hour. They often appear at altitudes of a hundred miles, move many miles a second, give out light and heat, and are usually consumed before they reach the surface of the Earth. These bodies are called *Meteors*.

The appearance of an unusual number of meteors, usually in August and November, is known as a *Meteoric Shower*. Sometimes bodies weighing from a few pounds up to several tons fall to the earth's surface unconsumed. Such bodies are known as *Meteorites*. Some are composed of nearly pure iron, with a little nickel. Most meteorites are composed of stone, often with traces of iron in them. About thirty of the different elements found in the earth have been found in meteorites.

THEORIES CONCERNING THE ORIGIN AND DEVELOPMENT OF THE EARTH

The Nebular Hypothesis of Laplace.—Many hypotheses have been proposed, but the one that has exercised the greatest influence upon thinking people is the Nebular Hypothesis, as formulated by Laplace. This hypothesis maintains:

1. That the matter of the Solar System was once a highly heated mass of gas called a nebula.

2. That the form was a vast spheroid extending beyond the orbit of the farthest planet.

3. That the nebula was in process of cooling, and the cooling caused shrinkage. An effect of shrinkage was to increase the rate of rotation, and this increased the equatorial bulge.

4. That when the rotation increased to a certain speed, the centrifugal force at the equator of the spheroid equaled the attraction of the gravitation. Upon further cooling and contraction, the equatorial portion separated from the great rotating mass, forming a ring resembling the rings of Saturn.

5. That as the cooling and contraction of the spheroid continued, additional rings were separated. The first ring gave rise to the outermost planet, and the later ones to the other planets in turn.

6. That the central body was the sun.

7. That each ring parted at its weakest point, and the matter was collected into a planet, which was hot and gaseous.

8. That the cooling of the planet caused a contraction, which in turn increased the rate of rotation, and consequently the amount of bulging. Some of the planets followed the example of the parent nebula, and formed rings which became satellites.

9. That as the cooling and shrinkage went on, the gases changed to a liquid and then to a solid state. In the case of the earth, the volume changed from a rotating mass extending to the orbit of the moon to its present size.

10. That the more volatile material of the earth remained in a gaseous state, and formed our atmosphere, originally much deeper and of a higher temperature than now. As the atmosphere cooled, the water vapor condensed and formed clouds. As cooling continued, rain fell and the ocean formed.

THE PLANETESIMAL HYPOTHESIS

During the last few years the planetesimal hypothesis has been formulated, and may be stated as follows:

1. The hypothesis starts with a cold nebula, spiral in form, which is the most common type now seen.

2. The spiral nebula consists of a central portion or nucleus,

which became our sun, with two arms starting from opposite sides and curved spirally about the nucleus or center.

3. A significant feature of the spiral nebulæ is the presence of numerous nebulous knots in the arms. These knots are the

Fig. 23.—Spiral Nebulæ
From Stellar Evolution

denser portions of the nebula, and the nuclei of future planets and satellites.

4. The knots or nuclei are surrounded by a nebulous haze, which is composed not only of gaseous particles but also of innumerable solid or liquid particles. These particles revolve about the center of the nebula like little planets, and are called

planetesimals. The nuclei grow and become planets and satellites by the in-fall of planetesimals. The earth and moon were two companion nuclei of unequal size.

5. The earth developed from a knot in an arm of a spiral nebula by the capture of outside planetesimals. The increasing gravitational compression of the interior produced the internal heat of the earth.

6. Gases were held in the solid planetesimals as they are held in meteorites that now fall to the earth. As the growing earth became heated by internal compression, the gases were given forth gradually, thus forming an atmosphere about the earth. Until the earth had attained a mass greater than that of the moon ($\frac{1}{81}$ of the earth), its gravity was probably insufficient to enable it to hold the gases of an atmosphere such as we now know. The gases now issuing from volcanoes were occluded in the original planetesimals which formed the earth.

7. When the earth had reached such size that water vapor was held in the atmosphere in sufficient quantity to reach the saturation point, the water vapor began to condense, and then the ocean began to form.

THE TWO HYPOTHESES CONTRASTED

Nebular Hypothesis	*Planetesimal Hypothesis*
1. Nebula, hot and large, formed rings around central mass or sun.	1. Nebula, cold, formed two arms around central mass or sun.
2. Rings became planets.	2. Nuclei or knots became planets and satellites.
2. Smaller rings separated from planets and became satellites.	3. Smaller knots were captured by larger knots and became satellites.
4. Planets and satellites originally hot and large, gradually cooling and growing smaller.	4. Planets and satellites originally cold and small, gradually heating and growing larger.
5. Outermost planet, Neptune, formed first and others at later periods.	5. Planets and satellites forming at same time.
6. Earth always had an atmosphere.	6. Earth when small without an atmosphere.

QUESTIONS

1. Name points by which each class of bodies comprising the solar system differs from all the other classes.

2. Compare the diameter of the sun with the diameter of the orbit of the moon about the earth. Compare the periods of rotation of the sun and moon.

3. As far as is known, which planet has the shortest period of revolution? How do you account for this?

4. Briefly compare physical conditions on each planet with those on the earth. What planets have you seen? What are the difficulties in finding favorable opportunities for seeing the planets?

5. What purposes do the satellites seem to serve? What are some of the superstitions connected with our moon? What was the first discovery made by the telescope?

6. Why are the stars generally invisible by day? How can we distinguish stars from planets?

7. Why are planetoids never seen with the naked eye? What distinguishes meteorites?

8. What are some of the peculiarities of comets? Describe a comet you have seen.

9. According to the Nebular Hypothesis, what planet was formed first? Why are the outer planets larger than the inner planets?

10. According to the Planetesimal Hypothesis, why are some planets so much larger than others? Which theory would require the longer time for the development of the earth? Why?

11. What are two real motions of the sun? Describe two apparent motions of the sun and point out cause of each.

12. Which of the heavenly bodies are self-luminous?

13. Are any of the planets repeating a portion of the earth's history? What ones? Have any of the planets reached a more advanced stage in their development than the earth? Which ones? Explain.

CHAPTER V

MAP PROJECTION

Map making is one of the most important arts, and every great nation has a body of men engaged in surveying and map making. In the United States the General Land Office has mapped most of the country in order to allot and sell the public domain. The United States Geological Survey is making an accurate large scale map to show geological and relief features, our navigable rivers, our lakes, and our coasts. On maps, then, we depend for the sale of our public lands, and the navigation of our rivers, lakes, and seas.

A *map* is the representation of a portion of the surface of the earth on a plane. The portion represented is indicated by its latitude and longitude. The *scale* of a map is the ratio between the length of a line on the map and the actual distance the line represents. The scale one mile to the inch is also a scale of $\frac{1}{63360}$ because 1 mile equals 63,360 inches. On the U. S. Topographic Maps the scale most frequently used is $\frac{1}{62500}$, about 1 mile to the inch. The mapping of large areas with their curved surfaces and poleward converging meridians presents difficulties that are met by certain devices called projections.

Projection, in map making, is a *method* of representing the curved surface of the earth on a plane. One method is illustrated by projecting (throwing) upon a screen the shadow of the frame of a half globe, with wires for meridians and parallels. The point from which the rays of light proceed, where the eye may be placed to view the globe to get the same effect, is called the *point of projection;* the screen is the *plane of projection*, and the rays of light *the lines of projection*.

Orthographic Projection.—When the point of projection is distant and the lines of projection parallel and at *right angles* to the

plane of projection, the *orthographic* projection is formed. If the plane of projection is parallel to the axis of the globe the orthographic *equatorial* projection is formed with the equator as a diameter, the parallels as straight lines nearer together toward the poles, the central meridian straight, but the other meridians curv-
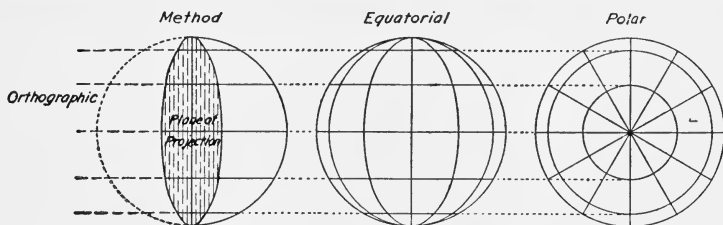

FIG. 24.—ORTHOGRAPHIC PROJECTION

ing and nearer together toward the margin. If the plane of projection is at right angles to the axis, bringing a pole to the center, the orthographic *polar* projection is formed. In it the parallels are concentric circles nearer together toward the equator, which becomes the outer circle. The meridians are straight lines radiating from the center. This projection, accurate at the center only, becomes increasingly inaccurate toward the margins, where distances are much *shortened*. It shows the actual appearance of the globe.

Stereographic Projection.—When the point of projection is at one end of a diameter of the globe and the plane of projection is at right
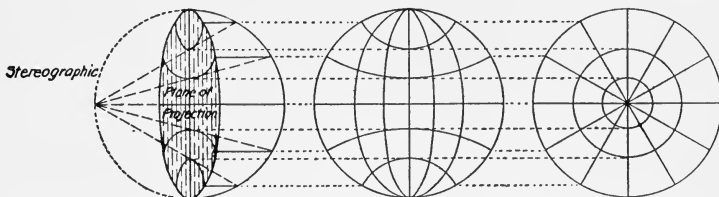
FIG. 25.—STEREOGRAPHIC PROJECTION

angles to that diameter, the *stereographic projection* is formed. **An** equatorial diameter gives an equatorial stereographic and a polar diameter, a polar stereographic. This projection, if accurate at the margin,

becomes increasingly inaccurate toward the center. Areas are represented more accurately than in the orthographic projection and less accurately than in the equidistant.

Globular or Equidistant Projection.—When the point of projection is taken about 1.7 radii from the center of the globe instead of at the surface of the globe as in the stereographic, the *globular* projection
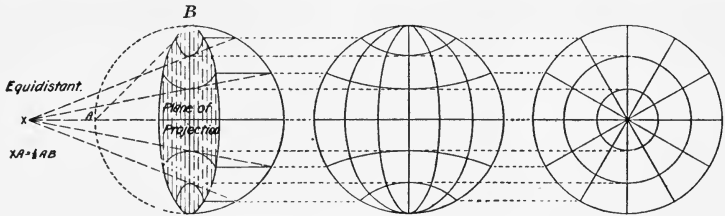
FIG. 26.—GLOBULAR OR EQUIDISTANT PROJECTION

is formed. It is also called the *equidistant* because the meridians are equidistant along a given parallel and the parallels are equidistant along a given meridian. It has a polar as well as an equatorial form. It is more accurate than the stereographic projection and much more accurate than the orthographic.
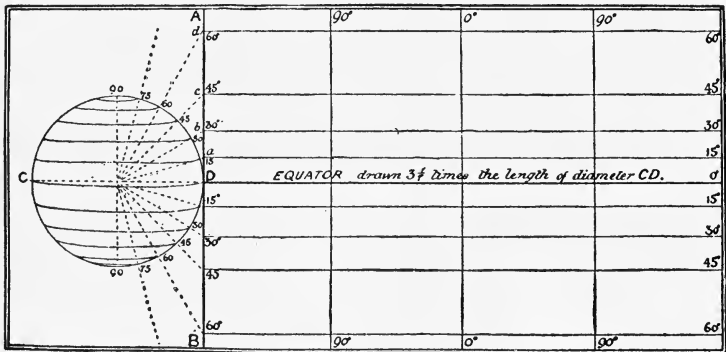
FIG. 27.—CYLINDRICAL PROJECTION

Cylindrical Projection.—The *cylindrical* projection is made upon a cylinder touching the globe at the equator only. The center of the globe is the point of projection. When the paper is slit along a meridian and unrolled the meridians and parallels appear as straight lines at right angles to each other, but at their true dis-

tances apart at the equator only. The advantage of this projection is that nearly the whole earth is shown. The disadvantage is that there is excessive exaggeration of distances toward the poles and no uniform scale. This projection is often confused with the Mercator projection which has supplanted it.

Mercator's Projection.—This is the cylindrical projection so modified that at every place the degree of latitude and the degree of longitude have the *same ratio to each other* as on the globe itself. This projection is used to show the whole surface of the earth. Mariners have adopted it because it shows directions correctly. Its disadvantages are that distances near the poles are greatly exaggerated and the scale is not uniform. (See Fig 32, page 60.)
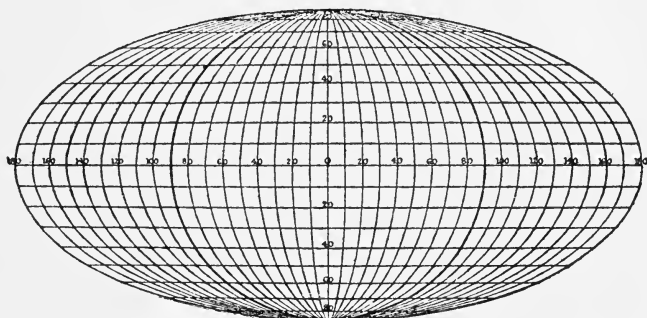
FIG. 28.—MOLLWEIDE PROJECTION

Mollweide Projection.—In this projection the equator and a meridian are laid off their true relative lengths at right angles to each other at their midpoints. The true relative distances between parallels are laid off along the meridian and the true relative distances between meridians along the equator. Ellipses are then drawn passing through the poles and the proper points on the equator to represent the meridians. The parallels are then drawn parallel to the equator. This projection is being used more and more. It is pleasing to the eye and has the great advantage of showing the entire earth. There is a slight exaggeration in polar regions, and quite a distortion of shape.

Conical Projection.—In the *conical* projection the point of projection is the center of the globe and the projection is made upon a cone touching the globe along any desired parallel. The cone is then slit

along a meridian and spread out. It is evident that this projection is accurate at the parallel of contact, becoming very inaccurate toward the poles, one of which cannot be shown.

By using different parallels of contact as bases, it is possible to map large areas accurately on a large scale. This *polyconic* projection is used in the United States Topographic Maps. On such maps the top parallel is slightly shorter than the bottom one.
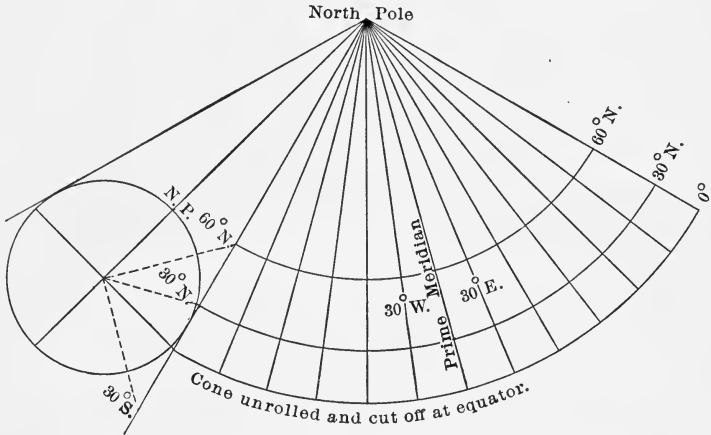

FIG. 29.—CONICAL PROJECTION, BASED ON PARALLEL 30° NORTH

GLOBES AND MODELS

The surface of the earth can, in some ways, be best represented by maps, in other ways best by models or by globes. *Globes* have the advantage of representing the whole earth, in its exact shape, and with all regions in their true relative positions and in their true relative sizes. Globes are generally on too small a scale to show much detail.

Elevations and depressions of the surface of the earth are technically known as *relief*. Relief is best represented by *models*. The relief of the earth is relatively so slight that models of large areas fail to give a correct idea of the surface unless an exaggerated vertical scale is used. This is because horizontal distances on the landscape are foreshortened, whereas vertical distances are not.

TOPOGRAPHIC MAPS

Maps on which the physical features are represented are called *topographic maps.* On the United States Topographic Maps water features are represented in *blue;* culture features, the work of man, in *black;* and relief features in *brown,* by means of contours.
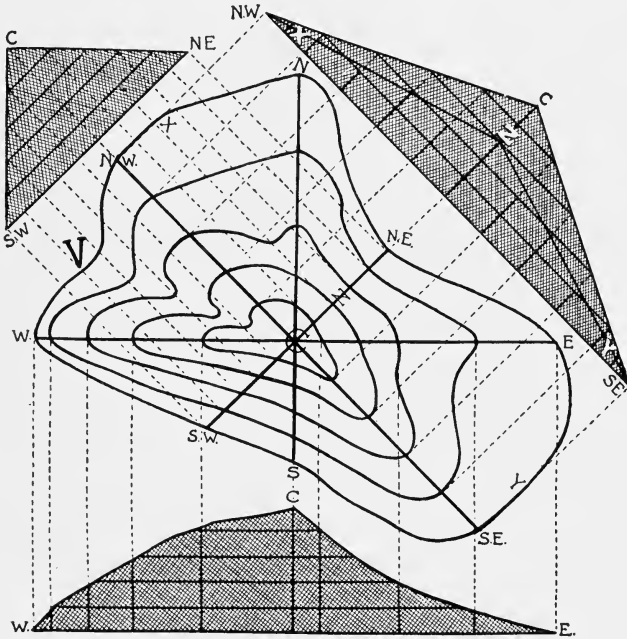
FIG. 30.—CONTOUR MAP OF AN ISLAND WITH THREE PROFILES

The *number of spaces* between contours shows that point *Z* is 3 contour intervals above sea level.

From *C* toward *N E* the contours are *close together.* The profile indicates that the slope is *steep.*

From *C* toward *S E* the contours are *far apart,* indicating a *gentle* slope.

From *C* toward *S W* the contours are *equidistant,* indicating a *uniform* slope.

From *C* toward *W* the slope is gentle, becoming steep, and is convex to sky.

From *C* toward *E* the slope is steep, becoming gentle, and is concave to sky.

The *re-entrant* contours along line *C V* indicate a *valley.*

The *outcurving* contours along *C W* indicate a *ridge* or *spur.*

Contours are lines connecting places of equal elevation. Each one shows where the new shore line would be if the sea level should

change a certain distance vertically. The difference in level between adjacent contours is called the *contour interval*. On most of our Government maps the contour interval is 20 feet; but it is only 5 feet on certain portions of the flood plain of the Mississippi River, and is sometimes 250 feet in mountains that are very high and steep. The significance of contours is brought out by cross sections called *profiles*.

Hachures.—Relief is also represented on maps by differences in color and by means of hachures. *Hachures* are lines drawn to represent the path water would follow in flowing down a slope. There are many different systems of hachures; in one much used the lines are short and thick where the slope is steep; and long, fine and far apart where the slope is gentle. (See Fig. 142, page 292.)

QUESTIONS

1. Compare the advantages and disadvantages of maps, models, and globes.

2. Why are map projections necessary?

3. Compare the advantages and disadvantages of three projections.

4. Name the projections used in the various maps of this book.

5. Note carefully the method of projecting and draw, with a 6-inch diameter, an orthographic equatorial projection of the globe you use, numbering the meridians and parallels. Trace in one of the continents, as South America or Africa, *from the globe*.

6. Proceed similarly for orthographic polar projection.

7. Proceed similarly for cylindrical projection.

8. Choose those pupils who have done the best work to construct on large sheets of manila paper large scale maps to be hung on schoolroom walls when needed. The backs of maps already mounted may be used for this. Waxed crayons or colored chalk crayons dipped in melted wax are cleaner than ordinary colored chalk.

9. If in Fig. 30 the contour interval is 20 feet, how high is the point *C*? How long is the island if the vertical and horizontal scales are the same? Draw a profile through the center from *N N W* to *S S E*, and another from *W N W* to *E S E*.

10. Put into a basin a stone shaped like a mountain and fill the basin so that the tip of the stone just shows. Draw the location of this point very carefully on a piece of paper placed beside the basin. Lower the level of the water an inch and draw very carefully the shoreline of the stone. Remove another inch and so continue. Draw to the same scale

as in drawing a view of the stone from one side. Label the view and the contours.

11. Trace your contours very lightly on another piece of paper, using carbon paper or holding the papers against a window. Change the contour map to an hachure map.

12. Using the same color scheme as on a United States Topographic Map, show by contours, etc., two peaks of different height, a river, a lake, a steep slope, a gentle slope. Label properly and locate two points A and B in sight of each other, and two other points X and Y not in sight of each other.

CHAPTER VI

TERRESTRIAL MAGNETISM

Space about magnets is known as the *Magnetic Field.* If a small magnet, known as a magnetic needle, is carried into the magnetic field of a large steel magnet or an electro-magnet, the needle will turn and set itself in a definite position in relation to the magnet. It has been found that the whole earth is surrounded by a magnetic field, and that magnetic needles set themselves in definite directions in relation to the earth. If we should follow the direction in which the magnetic or compass needle points, we would be going along a *magnetic meridian.* These magnetic meridians converge and meet in a locality north of Hudson Bay, latitude 70° N., and longitude 97° W., known as the *North Magnetic 'Pole;* and also in the Antarctic regions in latitude 72° S., and longitude 150° E., known as the *South Magnetic Pole.*

The north magnetic pole of the earth being 20 degrees from the geographic north pole and the south magnetic pole about 18 degrees from the geographic south pole, it is seen that the magnetic meridians do not have the same direction as the meridians of longitude. It follows that the north-seeking end of the compass does not indicate true north in most places on the earth. The departure or variation of the needle from a true north is called *magnetic declination.*

Lines connecting places having the same declination are *isogonic lines,* and lines connecting places of no declination are *agonic lines.* There are many isogonic lines drawn on magnetic charts of the world, but only three agonic lines. One agonic line crosses the United States from Lake Superior, through Ohio and Kentucky to South Carolina. On this line the compass needle points due north. At all places in the United States east of this line, the

needle points west of north. West of this agonic, at all places in
the United States, the compass needle points east of north.

In the state of Maine the variation of the needle is more than
20° west; in the state of Washington more than 20° east, and
in Alaska more than 30° east.

By consulting map (Fig. 32) for the magnetic variation of any
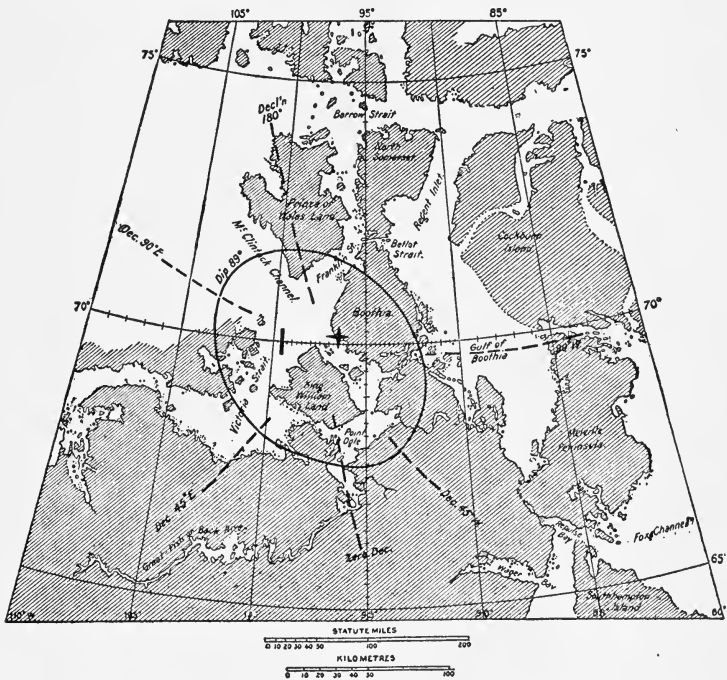place and then making the necessary correction, the compass may

FIG. 31.—LOCATION OF THE NORTH MAGNETIC POLE

be used for determining true north. Explorers find the magnetic
needle of little value in pointing out direction in unmapped re-
gions, such as areas about the North and South Poles.

The Mariner's Compass.—This instrument consists usually of
several magnetic needles placed side by side, fastened together,
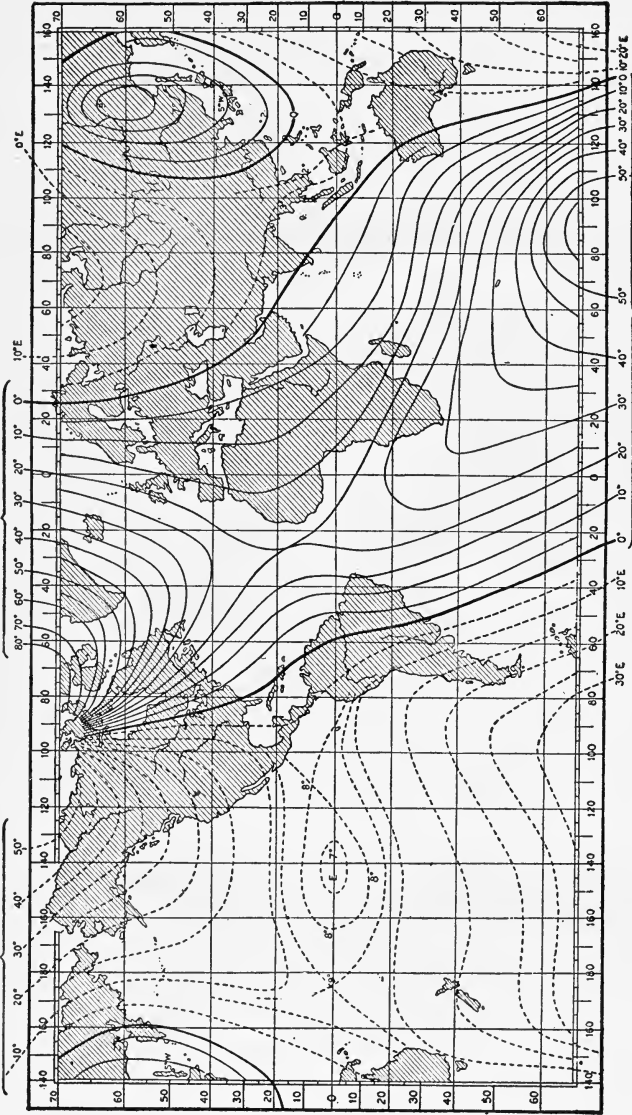
FIG. 32.—ISOGONIC LINES ON A MERCATOR MAP PROJECTION

and placed under a circular card. The needle and card are placed in a basin and supported at the center upon an agate point. The whole is suspended in such a way that it is always in a horizontal position, nothwithstanding the rolling of the ship.

Inside the compass box is a black line called the Lubber Line, placed in the direction of the ship's bow. The compass card contains 32 rays, each indicating a direction or point of the compass. Naming the 32 points is called " boxing the compass."

FIG. 33.—MARINER'S COMPASS

PART II

THE AIR

CHAPTER VII

PROPERTIES AND FUNCTIONS OF THE AIR

Introduction.—No part of his environment is of more immediate concern to man than the air he breathes. If it is pure he is strong. Vitiate it and he sickens. Withdraw it, but for a single hour, and he dies.

No other part of his environment has had so great an influence in helping or retarding him in his struggle for existence or in his effort to improve his condition. How he dresses, what he produces, and what he eats are matters chiefly of weather and climate. Too great heat and too great cold are alike prohibitive of higher aspirations for better things.

The savage Blacks of equatorial Africa and the Eskimo of the frozen North are both low in the scale of civilization; the first because the enervating climate destroys ambition; the second because providing for mere physical needs exhausts his energies, leaving no opportunity for cultivation of the higher qualities. Both must adapt themselves to their climatic environment; neither can change it.

Definition.—The earth's atmosphere, or air, is the outer gaseous part of the earth. It envelops the solid and liquid parts, extending to a height of probably more than two hundred miles, and fills all mines, caves, and underground passages. As ground-air it penetrates all soils, and by the movements of the water it is carried to the greatest depths of rivers, lakes, and seas.

Properties.—Pure air is an invisible gas, colorless, odorless, and tasteless; very compressible and perfectly elastic. It is very mobile, and like all matter, has weight. Though under ordinary conditions gaseous, it may easily be made to assume the liquid state.

The compressibility and elasticity of the air make possible its substitution for steam in driving machines. This use is particularly important in deep mines, where the long distances it must be carried results in condensation of the steam.

The inertia of the air causes a resistance to motion through it, retarding the speed of the runner, the automobile, and the express train. When the air is in motion its inertia causes pressure on objects not moving with it, which varies as the square of the velocity.

Composition.—Air is essentially a *mechanical mixture* of nitrogen, oxygen, carbon dioxide, and argon. Water vapor, water particles and dust are usually present in it. The relative amounts of the first four are nearly constant, while the last three are extremely variable.

Nitrogen and oxygen bear to each other about the ratio of 78 to 21 by volume, and 76 to 23 by weight. Carbon dioxide constitutes about three hundredths of one per cent of the air, varying slightly with locality and season. Of argon little is known, its existence not being known until within recent years. Argon constitutes about one per cent of the air. It was formerly included with nitrogen.

Essential Composition of the Air

Nitrogen	78.00%
Oxygen	21.00%
Argon	1.00%
Carbon Dioxide	.03%

Distribution of Components.—In obedience to the principle of *diffusion* (ready and spontaneous mixing) the gases of the air make a fairly uniform mixture. Local conditions may temporarily disturb this adjustment, but on the whole the air of one region of the earth is like that of any other.

Carbon dioxide, being one of the products of volcanic action, is most abundant in regions of active volcanoes. Being likewise a product of decomposition and combustion, it is more abundant in cities, especially in manufacturing cities, than in the country; and more abundant in winter than in summer. The use by growing

plants of carbon dioxide tends to decrease still further its summer percentage.

Water vapor, though always present in the air, is not an essential component. It is one of the most variable constituents of the air, and is in general more abundant over the sea than over the land, in low than in high altitudes, and in summer than in winter.

Water and ice particles in the air, known as cloud, fog, mist, rain, snow, hail, and sleet, are limited to the lower air, reaching an altitude of only a few miles.

Dust in the air is of two kinds, organic and inorganic. Organic dust includes microscopic animals and plants, pollen, fibers of wood and cloth, and the soot of smoke. Inorganic dust consists chiefly of powdered minerals and rocks derived from the land and caught up by the winds. Dust is more abundant over the land than over the sea, and is confined to the lower air. It is more abundant in cities than in the country, and in dry than in rainy weather, the dust particles being carried down by the falling rain drops.

Mountain health resorts are sought partly because of the greater dryness of the air, and partly because of its freedom from dust and the disease germs that constitute part of the organic dust of the air at lower altitudes.

Ozone, sometimes considered a constituent of the air, is really oxygen under peculiar conditions. By passing an electric spark through air the oxygen is in part changed to ozone, which, however, changes back to the more stable condition of oxygen.

The invigorating quality of the air after a thunderstorm is thought to be due, in part at least, to the ozone produced by the passage of lightning flashes through it. The percentage of ozone increases with the altitude.

Function of the Air.—Although the most important uses of the air are those of its individual components, yet the air as a whole has important functions. By virtue of it flight of birds and man is made possible, and sounds are transmitted. By air in motion ships and wind-mills are driven, life-giving and disease-producing germs are carried, and the seeds of many plants are fertilized and distributed. Rain is distributed over the lands, and waves and

ocean currents are produced. Tornadoes and hurricanes, with all their destructive power, are but air in violent motion.

As a carrier of waste from higher to lower levels, thereby wearing down the lands, and in the accumulation of *sand dunes* and *loess* deposits, the air is an important geological agent. Its presence in the *mantle rock* promotes *disintegration* of the minerals and the production of soil.

One of the chief purposes in cultivating crops is to increase the amount of ground-air. When the surface is packed by rains and remains unbroken by cultivation, air penetrates the soil with difficulty, and growing crops languish.

Function of Oxygen.—The oxygen of the air is the supporter of combustion. By its chemical union with other elements heat is evolved. This process, called *oxidation*, may be slow, as in the rusting of metals, in which case the heat radiates as rapidly as produced, and there is no perceptible increase of temperature; or it may be rapid, as in the burning of wood, coal, or oil, resulting in an increased temperature, and often in the production of light. By combination with carbon in the blood of animals oxygen supplies the heat necessary to animal life.

The readiness with which oxygen unites with most other chemical elements makes it active in promoting the disintegration of rocks and minerals. It is an important agent in the decomposition of dead animal and vegetable matter, thus serving as a purifier of the air. In the form of ozone its activity is increased.

Oxygen is more soluble in water than are the other constituents of the air. The percentage of oxygen in air enmeshed in water is therefore greater than in ordinary air, its ratio to nitrogen by volume being 34 to 66 instead of the ordinary ratio of 21 to 78. It is this enmeshed air, obtained at the surface and carried by currents to the greatest depths of all lakes and seas, that makes life possible, even in the profoundest *deeps*.

Function of Carbon Dioxide.—The carbon dioxide of the air, though of no direct use to animals, is essential to the life and growth of plants. Through the action of sunshine and the *chlorophyl*, or the green matter, of the plant, carbon dioxide, absorbed mainly

through the leaves of the plant, is broken up, the carbon retained and the oxygen returned to the air. The carbon thus obtained unites with other substances brought in solution in the sap, thus manufacturing plant food and contributing to the plant's growth. Dissolved in water, carbon dioxide contributes to the growth of aquatic plants. It is the most effective of the gases of the air in decreasing the intensity of the sun's rays, and in checking radiation of heat from the earth.

Since plants use carbon dioxide in the day time it is well to have growing plants in the living room, the air on their account containing a slightly increased per cent of oxygen. On the other hand they should be excluded from sleeping apartments at night, since they use some of the oxygen and none of the carbon dioxide.

When plants decay, or are burned, the carbon stored up in their tissues is returned, usually, to the air in the form of carbon dioxide. Under certain conditions, however, as submergence in water, or burial out of contact with the oxygen of the air, the carbon of the decaying plant may contribute to a future store of mineral fuel in the form of coal, oil, or gas.

Function of Nitrogen.—Since nitrogen constitutes more than three-fourths of the weight of the air, without it the air would be less than one-fourth its present density. Flight for most forms would then be impossible, and moving air as an agent for driving machinery and wearing down the land would be correspondingly weakened.

Another important function of nitrogen is its use as a plant food. It is a necessary element of the food of all plants, and like most other elements is taken through the roots in solution. If the soil is lacking in this element no plant will thrive.

Unlike oxygen and carbon dioxide, nitrogen is not taken by the plant directly from the air *as nitrogen*, but comes by way of the soil from some soluble compound of nitrogen. Some nitrogen is obtained in the form of *nitric acid*, carried down from the air by falling rain drops. This supply was formerly supplemented chiefly by the application of fertilizers, often in the form of expensive *nitrates* imported from distant regions.

We have learned, however, that certain plants, of the family to

which the clovers belong, are " nitrogen gatherers." These plants serve as hosts for minute organisms, which, attaching themselves to the roots of the plant, gather and store upon the roots in little nodules the nitrogen from the ground-air.

Cowpeas, clovers, vetches, beans, and alfalfa are now extensively grown, alike for their value as forage crops and for the nitrogen they add to the soil. The entire growth above ground may be removed and yet the soil be left richer in nitrogen than before the crop was grown.

Function of Water Vapor.—The water vapor of the air is the source of clouds, fogs, and of all forms of precipitation. Without it the earth would become parched, and life impossible. It is lighter than dry air, and its presence makes the air lighter. Like carbon dioxide it absorbs *insolation* (radiant energy from the sun) and heat radiated from the earth. Condensed as cloud it is more effective in protecting the lands from the direct rays of the sun and in checking radiation of heat from the earth. Precipitated as rain it supplies growing plants with necessary water; and as snow retards radiation and protects crops from the intense cold of winter. This function of snow is very important in the wheat-growing regions of the Northwest.

Function of Dust.—Perhaps the most important function of dust is its *diffusion* (irregular scattering) *of light*. Without such diffusion objects would be visible only by reflection, as they now are at night; and the change from day to night and from night to day would be sudden, without twilight or dawn.

At certain seasons a considerable part of the dust of the air is plant pollen. Many plants require pollen from other plants, and without the wind-borne pollen these would not be propagated.

Putrefaction and fermentation are largely due to the organic dust of the air. Flesh and vegetables in high altitudes do not decay readily but simply dry out and shrivel up. This is due to the freedom of the air from dust germs. Some Indian tribes in these regions mummify their dead by simply exposing them in the air and sunshine.

The germs of many diseases are distributed as air-dust; and flesh wounds heal more readily when the dust germs are washed away and excluded from the wound.

Every dust particle in the air is a nucleus about which water vapor may condense; consequently dust in the air promotes cloud formation and rainfall. Some have even taken the extreme view that without dust in the air no rainfall would be possible; but this has been disproved by experiment.

Of esthetic interest is the fact that the sky owes its beautiful and varying colors, for the most part, to the dust in the air. Gorgeous sunrises and sunsets occur when the air is laden with inorganic dust, or with the smoke from forest fires.

Origin of the Air.—If the Nebular Hypothesis concerning the origin of the Solar System be accepted, the air may be considered a *remnant* of a formerly denser atmosphere. In this earlier atmosphere many of the elements which now make up the lands and seas existed as gases in an intensely hot condition. With loss of heat by radiation these elements changed to the liquid or solid state. Many of the elements of the primitive atmosphere were thus withdrawn, leaving the present remnant, the air as we know it.

If we accept the Planetesimal Hypothesis of the origin of the Solar System, we believe that the air has been driven out from the interior of the earth by the increasing temperature and pressure. The gases thus driven out escaped to outer space while the earth was small and its gravitative attraction weak, and remained as part of the earth only after the earth's attraction became strong enough to hold its gaseous envelope.

Future of the Air.—Whatever the origin of our earth or of its gaseous envelope, the earth is continuously losing heat. We may therefore look forward to the time when it will have the temperature of outer space, excepting only the surface that is turned toward the sun.

Experiment proves that most gases can, with sufficiently low temperatures, be liquefied and solidified. We also learn, from a study of the other members of our system besides the earth, that the smaller ones, such as the earth's moon, seem to have no atmosphere. These smaller members have cooled most, and if they ever had atmospheres their present low temperatures have probably resulted in making their atmospheres part of their solid masses.

We may therefore infer that with further loss of heat by the earth the terrestrial seas must in time become solid; and eventually the air

itself become in turn liquid and solid. Upon such an airless earth life, as we know it, could not exist; and the earth would then appear, to an observer upon another planet, the lifeless globe that our moon now appears to us.

QUESTIONS

1. Why is it not correct to say "the air surrounds the earth"?

2. How can you show that the air has weight? That it penetrates the soil?

3. In what particulars is country air usually purer than city air?

4. In what sense does rain purify the air?

5. Why will plants thrive better than animals in hot, marshy lowlands?

6. Why are trips to the mountains and sea voyages recommended for convalescents?

7. How can you prove that there is dust in the air; and how can you decrease the dust in your bed-chamber without stopping ventilation?

8. Why will milk that has been heated before bottling not sour as quickly as that which is bottled without heating?

9. Why do dairymen cool their milk before shipping; and why is ice used to keep milk sweet? What is the principle of "cold storage"?

10. Why will a candle lighted and lowered into a narrow deep bucket so quickly be extinguished? Why are lamp burners ventilated?

11. Why do we ventilate our houses? What would be the result if we did not? Explain the horror of the "Black Hole" of Calcutta.

12. How do you know there is water vapor in the air?

13. Why should a wound be thoroughly cleansed before binding up? What is the principle of *disinfection and sterilization?*

14. Why is it necessary to thoroughly dry our steel cutlery, and not so necessary with our silverware and china?

15. Why do fires in open fireplaces and in stoves connected with flues burn better than fires built in the open air?

16. How can the nitrogen of the soil be increased most economically?

CHAPTER VIII

TEMPERATURE OF THE AIR

Sources of Heat.—So evident is it that the sun is the chief source of heat that the statement of the fact seems to need no demonstration. The temperature of our days increases with increasing length of the period of sunshine and with the nearer approach of the sun to our zenith, whereas our coldest season is that in which the nights are longer than the days, and the sun's noon position is low above the horizon. The hot belt of the earth is that which receives nearly vertical rays, while the frozen regions near the poles have only slanting rays.

At first thought the sun appears to be the only source of heat; yet we know there are other sources. One of these minor sources, the interior heat of the earth, is of considerable importance, notably in deep mines, and in the production of volcanos and hot springs.

The surface of the land varies in temperature from day to night and from summer to winter; but if we descend below the surface the variation is less and less. A depth is finally reached, varying with the latitude, at which the temperature does not change, and below this depth the temperature grows warmer the deeper we go. On this account we conclude that the interior of the earth is *intensely hot*. On the other hand, if we ascend in the air we find that the temperature grows colder, and at the height of only a few miles freezing temperatures, even in summer, are reached. Reasoning from this basis we conclude that outer space is *intensely cold*.

From our knowledge of cooling bodies we know then that *the earth must be a cooling body*, sending its heat in every direction into outer space, and bringing about equal amounts to every part of the surface of the land.

Unimportant amounts of heat are received from the stars, and reflected from the other planets and the moon.

Insolation.—*The radiant energy that comes to us from the sun is called insolation.* It does not come to us *as heat,* but manifests itself in many ways, *e. g.* as light and electricity. Only the insolation which is *absorbed* by any body is changed to heat and warms the body.

As solar energy passes out from the sun-center in all directions, it is evident that only a very minute fraction of it will be intercepted by so small a body as the earth, at an average distance of about ninety-three millions of miles. Of the amount thus intercepted but a small portion is absorbed and transformed into heat; yet upon this minute part of the total solar energy all of our life-interests and activities depend.

Disposal of Insolation.—When insolation is received, it is disposed of in three ways: by *reflection,* by *transmission,* and by *absorption.* As before stated, it is only the *absorbed* insolation that affects the temperature of the body.

Each kind and condition of matter disposes of insolation in a distinct way. Some substances are good reflectors, some good transmitters, and some are good absorbers. Experiment has shown that in general, gases are the best transmitters, liquids the best reflectors, and solids the best absorbers.

The absorptive power of a body may be materially modified by a change of color or of surface. Dark colors and irregular surfaces generally promote absorption, while light colors and smooth surfaces promote reflection. By increasing the reflecting power of a body we decrease its absorbing power.

The following table sets forth, comparatively, the treatment of insolation received by land, water, and air:

	Land	Water	Air
Reflector..............	Fair	Good	Very poor
Transmitter............	Poor	Fair	Very good
Absorber..............	Good	Poor	Poor

Loss of heat by *radiation* is in direct ratio to the absorbing power of a body; a good absorber being a good radiator, and a poor absorber a poor radiator. If the reflecting power of a body be increased its radiating power will be lessened. Radiation is continuous.

Heat in a body may be distributed by passing from particle to particle in contact; this process is called *conduction*. Solids are mainly heated in this way, but differ widely in their power of conduction.

In liquids and gases, *e. g.* water and air, the most important method of distributing heat is by *convection*. By this process particles in contact with a heated surface are warmed and expand, and after expansion are lighter, volume for volume, than the surrounding particles. The heavier particles then sink, under the greater pull of gravity, and the lighter are crowded away from the heating surface, the heavier being heated in turn. This process, depending as it does upon gravity, requires that the heating surface be below the substance to be heated.

The principle of convection is applied in the heating of our houses and in the construction of flues and chimneys.

The land and water, being heated from above, are never warmed to very great depths; while the air, being chiefly heated at the bottom, by contact with the land and water, is warmed more rapidly and through a much greater thickness.

How the Air is Heated.—The power of absorption of the air, though small, increases with increase in density, increase in carbon dioxide and water vapor, and in the number of dust and liquid water particles present. Each dust and water particle, being a better absorber than air, becomes itself a center of warming. Therefore, when insolation comes to earth it passes through the rare upper air with little loss by absorption. As it penetrates farther into the denser and dustier air more and more of it is absorbed, and the air is more and more heated. The air absorbs from one-half to three-fifths, depending upon its cloudiness, of vertical insolation passing through it.

The air is heated most at the bottom, not only because of the

increased absorbing power of the lower layers, but also because of their contact with the warmer land and water surfaces.

Another very important aid in the heating of the lower air is its convectional mixing. The air in contact with the warmer land or water surfaces is warmed and expands. The cooler, heavier air above sinks and takes its place, to be in turn warmed and replaced by cooler air from above. This mixing is for the most part confined to a stratum of air five or six miles in thickness. As long as the land and water are warmer than the air resting on them, convectional mixing will continue a factor in the warming of the lower air.

The convectional ascent of heated air may be observed above a lighted gas jet, a hot stove, or a bonfire. Our rooms may be ventilated by admitting cool air at the bottom and permitting the escape of the heated air above.

How the Air is Cooled.—When insolation ceases, as at night, conditions are reversed. Absorption, in excess of radiation during the day, is at night exceeded by radiation, and the air is cooled. Not that radiation does not continue during the day, for it is greatest when the temperature is highest, but the air does not begin to cool until radiation is more rapid than absorption.

Since a good absorber is a good radiator, that part of the air which was most heated during the day is most cooled when insolation ceases. As a consequence, the rare, upper air is but little cooled, while the lower air is cooled most. Each dust and water particle, a center of warming during insolation, becomes a center of cooling when insolation ceases.

One important factor in the warming of the air, *convection*, is wanting when the air begins to cool. Being most cooled at the bottom, the lower layers of air are heaviest, hence there is no tendency toward convectional mixing. In order to have *cooling* by convection it would be necessary to have the air cooled most at the *top*. On this account the lower air *warms up faster than it cools down*.

The coldest hour of the day is from 4 to 6 a. m., and the warmest from 1 to 3 p. m., depending upon the season. Thus it takes

from seven to nine hours for the air to *warm up,* while from fifteen to seventeen hours are required for it to *cool down.*

Temperatures Determined.—The temperature of the air, with reference to certain chosen temperatures, is determined by the *thermometer.* The temperatures of reference are those at which pure water freezes and boils under a pressure of approximately 14.7 pounds to the square inch. This is the average pressure of the air at sea level.

The action of the thermometer is based on the fact that most substances *expand* uniformly with *heating,* and *contract* uniformly with *cooling.* The measure of expansion or contraction may be taken as a measure of the amount of heating or cooling.

Two general classes of thermometers are made, *liquid* and *non-liquid.* Almost any liquid or metal may be used. In the United States and other English-speaking countries, two scales for thermometers are in common use: the *Fahrenheit* (F), and the *Centigrade* (C). Their relation to each other and the method of converting readings of one to readings of the other are shown in the accompanying figure and table.

Fig. 34 shows both Fahrenheit and Centigrade scales. It will be observed that the two scales agree at − 40. Freezing point is 32 on the F., and o on the C., and boiling point 212 and 100 respectively. It will thus be evident that a change from 32 to 212 degrees on the F. thermometer is equivalent to a change o to 100 on the C. This relation may be thus expressed:

$$180° \text{ F} = 100° \text{ C}$$
$$9° \text{ F} = 5° \text{ C}$$
$$1° \text{ F} = \text{⅝}° \text{ C}$$
$$1.8° \text{ F} = 1° \text{ C}$$

C	F
100	212
90	194
80	176
70	158
60	140
50	122
40	104
30	86
20	68
10	50
0	32
−10	14
−20	−4
−30	−22
−40	−40
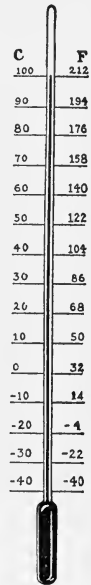
FIG. 34

History of the Thermometer.—The thermometer was invented by *Galileo,* early in the seventeenth century. Soon after its invention it was graduated into 360 parts, corresponding to the number of degrees in a circle, hence the name *degrees* applied to these divisions. The name

has been retained for the divisions of modern thermometers, though very differently and variously graduated. It was never significant.

Fahrenheit was the first to adopt definite temperatures as a basis for graduation. According to his scale the boiling point of water was found to be 212°, and the freezing point 32°. In the Centigrade thermometer 100° is taken as the boiling point and 0° the freezing point.

The accuracy with which the instrument may be read depends upon the length of the degree, and this in turn depends upon the relative capacities of bulb and tube. It is essential to accuracy that the tube be of even bore. Why?

Mercury and alcohol are commonly used in liquid thermometers, partly because of their even expansion at all ordinary temperatures, and partly because of their low freezing points. Mercury freezes at −40° F., and alcohol at about −200° F. In the winter in high latitudes the temperatures are too low to be recorded by mercury thermometers. On the other hand mercury is the better suited for high temperatures, since its boiling point is 660° F., while that of alcohol is only about 173° F., or lower than the boiling point of water.

Maximum Thermometer.—It is often desirable to know the highest temperature attained during a given period. For this purpose the *maximum* thermometer is used. This is a modification of the ordinary liquid thermometer by a slight constriction in the bore just above the bulb. This narrowed bore, though wide enough to allow the expanding liquid to press through, is too narrow for the liquid column, of its own weight, to pass back as the temperature falls. The thermometer thus continues to indicate the highest temperature attained.

The clinical thermometer used by physicians is a maximum thermometer. To set the instrument for a new reading the column of liquid must be made to unite by swinging or jarring the instrument.

Minimum Thermometer.—The minimum thermometer, for registering lowest temperatures, is simply an ordinary alcohol thermometer, with colorless liquid, containing a short double-headed pin. The heads of the pin are slightly smaller than the bore, in order that the alcohol may pass by the pin.

For registering a minimum temperature the tube is placed in an inclined position, so that gravity cannot pull the pin down the tube; but

when gravity is assisted by the surface tension of the liquid, when the upper end of the contracting column comes in contact with the upper head of the pin, the pin is pulled down the tube. When, with rising temperature the liquid column begins to lengthen, it passes over and by the pin, but cannot push the pin against gravity up the tube. The upper end of the pin thus registers the lowest or minimum temperature attained.

To set the instrument for registering a new minimum the thermometer is held, bulb upward, until the pin sinks through the liquid to the end of the column. The instrument is then placed in the inclined position in which it ordinarily rests.

Thermograph.—To obtain a continuous record of the temperature a self-registering thermometer, or *thermograph* is used. The
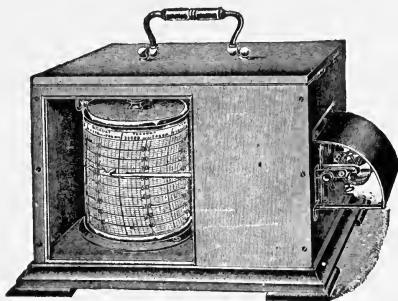
FIG. 35.—THERMOGRAPH

varying temperature is recorded by a pen, moved by a system of levers. The pen rests against a disc or cylinder of paper which is moved by clock-work. A continuous trace of the pen is made
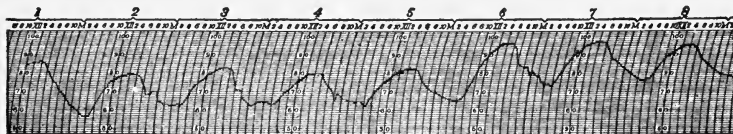
FIG. 36.—THERMOGRAPH RECORD FOR ONE WEEK
Note daily variation of temperature, and hour of highest and lowest temperature.

which, by reference to two sets of lines ruled upon the disc or sheet, *temperature lines* and *time lines*, shows the temperature at

any time. The thermograph takes the place of the maximum and minimum thermometers.

The record made by the thermograph is a *temperature curve* for the period of time covered by the record. (See Fig. 36.)

Approximately accurate temperature curves may be made from observations of the thermometer taken every two hours. From the daily averages monthly curves, and from the monthly averages annual temperature curves may be constructed.

Distribution of Insolation.—The amount of insolation received by a given area of land or water in a given time, as during one complete rotation of the earth, depends mainly upon the following variables:

1. Length of insolation period, or the number of hours of sunshine;

2. The angle at which the insolation rays are received;

3. Condition of the air as regards dust and cloudiness;

4. Distance from the source of insolation, the sun;

5. The length of the path of the rays through the atmosphere.

Length of Insolation Period.—Because the earth's axis is inclined to the plane of its orbit the insolation period is not the same for all places, nor for the same place at all times. Most places upon the earth have the period of rotation unequally divided between sunshine and shadow.

At the equator the period of insolation is always twelve hours. In all other latitudes it is only at the equinoxes that the insolation period is twelve hours; being longer than twelve hours when the sun is on the same side of the equator as the observer, and shorter than twelve hours when the sun and observer are on opposite sides of the equator.

The higher the latitude the greater the length of the *continuous* insolation period. Within the polar circles it varies from no insolation in *mid-winter* to twenty-four hours of insolation in *midsvmmer*, for each rotation.

Relation of Latitude to Greatest Length of Day or Night

Latitude	Greatest Length of Day or Night	Latitude	Greatest Length of Day or Night
0°	12 hrs. oo mins.	50°	16 hrs. 04 mins.
5°	12 " 16 "	55°	17 " oo "
10°	12 " 40 "	60°	18 " 15 "
15°	12 " 52 "	65°	20 " 48 "
20°	13 " 12 "	66.5°	24 " oo "
25°	13 " 34 "	70°	64 days
30°	13 " 54 "	75°	103 "
35°	14 " 20 "	80°	133 "
40°	14 " 48 "	85°	160 "
45°	15 " 20 "	90°	187 "

Other things being equal the amount of insolation received varies as the length of the insolation period. There is, therefore, at summer solstice a constantly increasing amount of insolation, during one rotation, from the equator to the polar circle of the summer hemisphere; and a constantly decreasing amount from the equator to the polar circle of the winter hemisphere.

Angle of Insolation.—Since the earth's shape is globular, the angle at which the sun's rays strike at any place varies with the latitude and with the time of day. This angle is zero at sunrise and sunset at any station, and is a maximum at noon.

Because of the inclination of the earth's axis and revolution the angle of the sun's rays varies at any station from day to day. Vertical noon insolation occurs at the equator at the times of the equinoxes; and at the tropics, alternately, at the times of the solstices. During the year vertical noon insolation occurs twice at every station within the belt, forty-seven degrees wide, lying between the Tropics. This belt is sometimes called the *torrid zone.* No place outside this zone ever receives vertical insolation, the maximum angle being less and less with increase of latitude, reaching 23½° at the poles.

Hence, in so far as the *angle* of insolation determines the *amount* of insolation received during one rotation, the maximum amount is always received upon or between the Tropics. The average for the year is greatest at the equator and least at the poles.
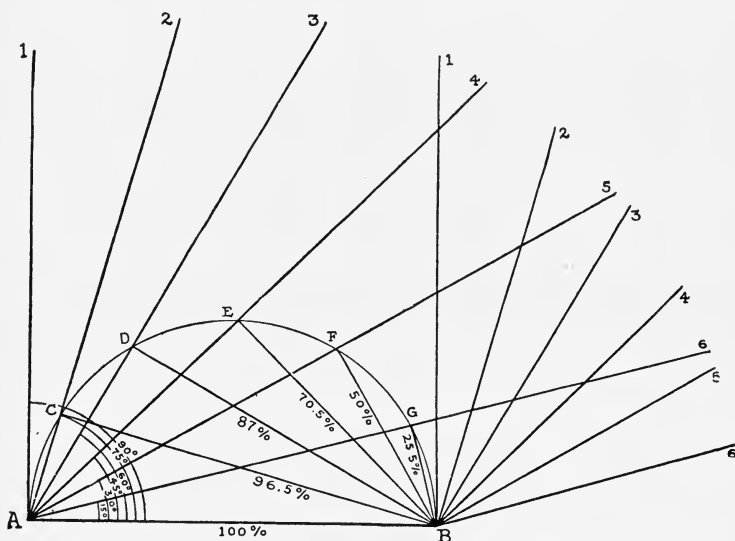
FIG. 37.—SHOWING RELATION OF ANGLE OF INSOLATION TO INTENSITY OF INSOLATION
Surface AB, which receives 100% of insolation when vertical, receives but 25.5% when the angle of insolation is 15°.

Condition of the Air.—The two most variable constituents of the air are likewise those which most intercept insolation. These are, in the order of their importance, cloud-particles and dust. Clouds and dust in the air intercept insolation, and thus prevent land and water surfaces from being as much heated as they would otherwise be. For this reason those places where cloudiness prevails have a more constant temperature than places with prevailingly clear skies. Cloudy days are less warm in summer and less cold in winter than are clear days; and the insolation on the mountain top is more intense than in the valley.

Distance From Sun.—The amount of insolation received varies inversely as the square of the earth's distance from the sun. While this factor has a scarcely perceptible value as between any two places upon the earth, at any given time, the difference in distance being never as much as four thousand miles, yet as between winter and summer the value is considerable. The earth is about three million miles nearer the sun at perihelion, about January first, than at aphelion, about July first. In consequence a place receiving vertical insolation January first receives about 5% more insolation than one receiving vertical insolation July first.

Length of Path Through Air.—Oblique rays pass through a greater thickness of air than do vertical rays; and whereas vertical rays lose half of their intensity, rays approaching tangency lose more than 90%.

Intensity of Insolation at Different Angles

Altitude of the Sun	Relative Length of Path of Ray Through Atmosphere	Intensity of Insolation on Surface Perpendicular to Rays	Intensity of Insolation on a Horizontal Surface
0°	44.70	0.00	0.00
10°	5.70	0.31	0.05
20°	2.92	0.51	0.17
30°	2.00	0.62	0.31
40°	1.56	0.68	0.44
50°	1.31	0.72	0.55
60°	1.15	0.75	0.65
70°	1.06	0.76	0.72
80°	1.02	0.77	0.76
90°	1.00	0.78	0.78

While the poles alternately receive more insolation than any other portion of the earth, for a brief period about the summer and winter solstices respectively, owing to continuous insolation there, all the conditions combine to give to places at the equator about two and one-half times the amount of insolation annually received at the poles.

Distribution of Heat Over the Earth.—The distribution of heat over the earth does not agree with the distribution of insolation, though in general following it, since the same factors govern the distribution of both. It should be remembered that heat is caused by *absorbed* insolation, and whatever factors enter into the control of absorption to that extent affect the temperature of the absorbing substance.

Distribution of Insolation

	LATITUDE					
	0°	20°	40°	60°	90°	—90°
Vernal equinox......	1.000	0.934	0.763	0.499	0.000	0.000
Summer solstice.....	0.881	1.040	1.103	1.090	1.202	0.000
Autumnal equinox...	0.984	0.938	0.760	0.499	0.000	0.000
Winter solstice......	0.942	0.679	0.352	0.053	0.000	1.284

Increasing obliquity of the sun's rays is accompanied by a more rapid *decrease* of *heat developed* than of *insolation received.* It results in an *increased per cent of insolation reflected* and consequently a *decreased per cent absorbed.* It is found that while water reflects only 2% of *vertical* insolation, it reflects about 65% when the sun is only ten degrees above the horizon. On this account the early morning and late afternoon rays, and the rays received in high latitudes, have little effect in increasing temperatures. For this reason alone the polar regions could never be warm; and the low minus temperatures reported by our Arctic and Antarctic explorers as occurring there in mid-summer are in part accounted for.

When we consider also the fact that in the polar regions the lands and frozen seas are for much of the year covered with snow and ice, both very poor absorbers, and that the heat produced by absorption must first be used to *melt* the ice-cap, we may better appreciate the low temperatures which prevail there.

The northern hemisphere, where the continents are massed, is warmer in summer and colder in winter than the southern hemi-

sphere, which is mostly water. This is due to the fact that land is a better *absorber* and better *radiator* than water, and the further fact that it requires more heat to warm the water than the land.

Dark colored rocks and soils, being better absorbers than light colored ones, are warmer under sunshine and colder when insolation is withdrawn. This, in a measure, controls the character and amount of plant growth, and affects the distribution of heat.

The direction and character of winds and ocean currents, to be explained, are likewise important factors in the distribution of heat over the earth.

All things combine to give to regions along the equator the greatest total amount of heat, and to make its distribution through the year most equable there.

Shifting of Heat Equator.—This zone of greatest heat near the geographical equator, and of varying width, is known as the *doldrum belt*, or simply the doldrums. The line in the midst of this belt, passing through places having the highest temperatures, is called the *heat equator*.

Since the sun's vertical ray shifts during the year over a zone forty-seven degrees wide, so the doldrums and heat equator shift, though over a narrower zone.

The temperature of a place continues to increase so long as more heat is received than is lost by radiation. The change from warming up to cooling down occurs, during the day, ordinarily an hour or two past noon, though most heat is received at noon; and the highest temperature of the year occurs usually some weeks after the longest day, although most heat is received on that day.

The doldrum belt and heat equator, therefore, do not attain their extreme positions north and south at the times of the solstices, but weeks after. Places between the Tropics, having vertical insolation twice a year, have two maxima and two minima during the year, and experience their highest maximum temperature shortly after vertical insolation upon the sun's return toward the equator.

Average Position of Heat Equator.—The heat equator shifts farther, and remains for a longer time, north of the terrestrial equator than it does south of it. This is in part because the sun is seven days longer north of the equator than south of it; and in further part because of the forms of the continents and ocean basins. Owing to the positions and outlines of the continents more of the warm ocean currents are turned into the northern oceans than into the southern, and these make the northern hemisphere on an average the warmer.

Moreover, the Pacific basin, being almost closed at the north, thus practically shutting out the cold polar currents that freely enter the North Atlantic, makes the North Pacific a warmer ocean than the North Atlantic. The average position of the heat equator is, therefore, more northerly in the Pacific than in the Atlantic.

Shifting Most Over Atlantic.—Being a better absorber and better radiator than water, land has a higher temperature in summer and a lower temperature in winter than the sea in the same latitude. This excessive warming and cooling is most pronounced in its effects in the northern hemisphere, where the great land areas are; and is also more pronounced over the relatively narrow Atlantic than over the broader Pacific.

The accompanying table shows the approximate widths and extreme positions of the doldrum and trade wind belts during the year in both the Atlantic and Pacific oceans:

	ATLANTIC OCEAN		PACIFIC OCEAN	
	March	September	March	September
N. E. Trades......	26° N– 3° N	35° N–11° N	25° N– 5° N	30° N–10° N
Doldrums.........	3° N– 0°	11° N– 3° N	5° N– 3° N	10° N– 7° N
S. E. Trades......	0° –25° S	3° N–25° S	3° N–28° S	7° N–20° S

Isotherms.—Lines drawn through places having the same temperature are called *isotherms*. They may represent the distribution of temperatures at any given time, or they may represent the averages for any desired period, as a week, a month, or the entire year. Such lines, while very irregular, have in the main a *general* east-west direction. This is as we should expect, inasmuch as *length of insolation period* and *angle of insolation*, the most important factors in determining the distribution of heat, are constant

along any given parallel. The minor factors in the distribution of heat are responsible for the departure of isotherms from the parallels.

Isotherms are *continuous* lines, and for a limited area may appear upon the map as closed curves. From their definition two isotherms cannot intersect. The heat equator is *not* an isotherm, though it extends around the earth in the same general direction as isotherms. It may cross isotherms.

Temperature Gradient.—If we pass from one isotherm to the next of higher or lower temperature, we must pass through all intermediate temperatures. While we may pass along an indefinite number of routes, it is evident that the shorter the route the more rapid the change of temperature. The *shortest* route, which gives the maximum rate of change, is the direction of the *temperature gradient*.

Temperature gradient may be defined as: *The rate of change of temperature measured in F. degrees, in a distance of one latitude degree*, or about seventy miles.

The more closely the isotherms are crowded the more rapid the change of temperature, or as we say, *the steeper the gradient;* while widely separated isotherms indicate *gentle gradients*.

Isothermal Charts.—If the isotherms of any region be drawn the result is an *isothermal chart*. Daily, monthly, seasonal, and annual charts are commonly made.

Isothermal charts are graphic representations of temperature readings where *time* is *constant* and *place variable;* whereas temperature curves are records with *place constant* and *time variable*.

Vertical Distribution of Heat.—If we ascend through quiet air, as in a balloon, we shall find that, as a rule, the temperature of the air *decreases*; descending, the temperature *increases*. This change, due to difference of altitude, is about 1° F. for every 300 feet, and is known as the *vertical temperature gradient*.
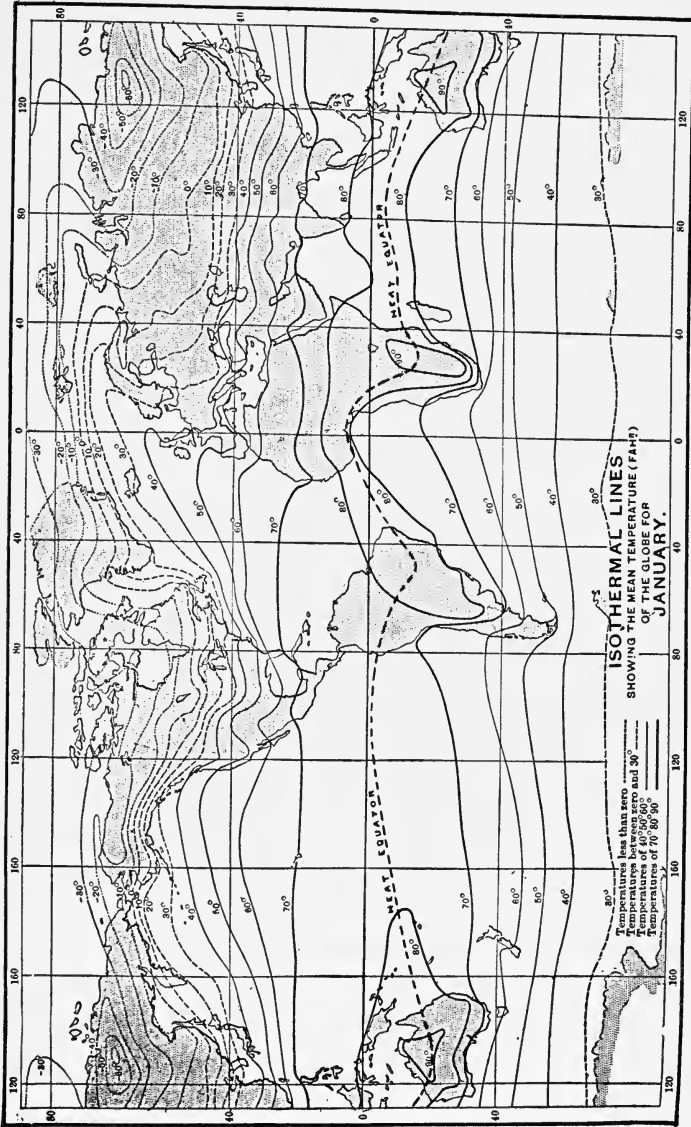
FIG. 38.—ISOTHERMS OF WORLD FOR JANUARY, ALSO HEAT EQUATOR

Observe that heat equator lies for most part south of geographic equator, though nearer to it toward the eastern side of oceans, and actually north of it in the eastern Atlantic
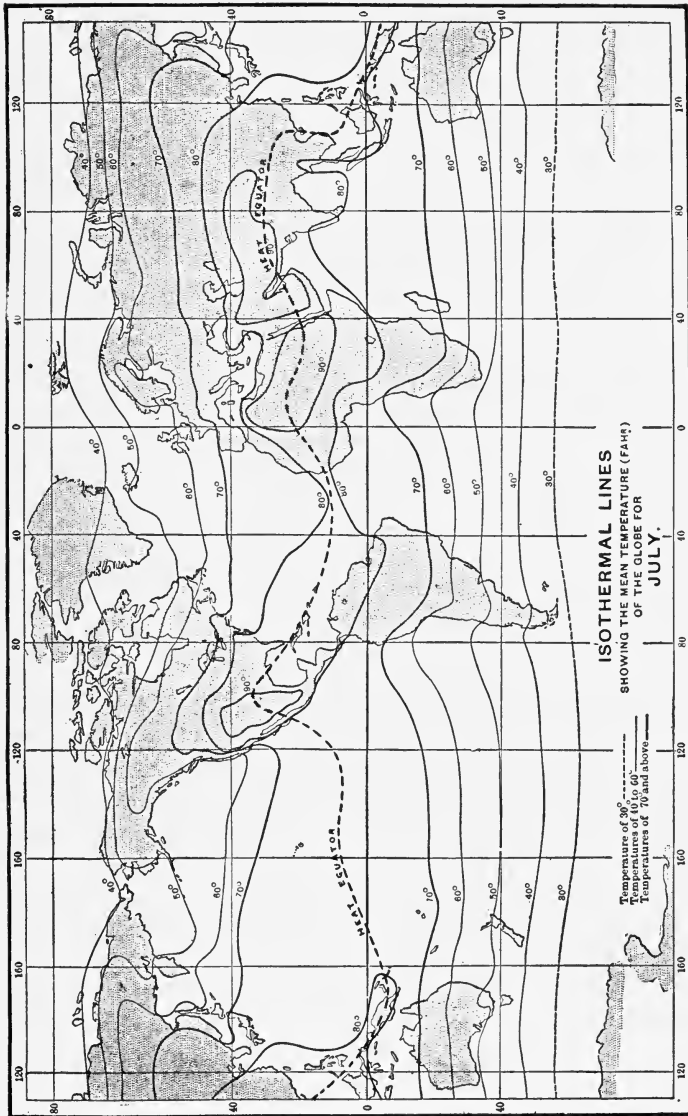
FIG. 39.—ISOTHERMS AND HEAT EQUATOR FOR JULY

Observe that heat equator lies mostly north of geographic equator, and farthest north over continents.

QUESTIONS

1. If the interior heat of the earth were the chief source of heat, what part of the earth's surface would be hottest?

2. What reason have you for thinking that the sun, rather than some other outside source, is the chief source of our heat?

3. What per cent of the sun's radiant energy is received by the earth? Does Mercury, Venus or the Earth receive the largest per cent?

4. Why are dark shades of clothing better suited to winter than to summer? Why are dark colored soils earlier ready for seeding than light colored?

5. Why do we heat our kettles from below; and why place the radiators that heat our rooms near the floor rather than near the ceiling?

6. Aviators find the air at the height of a few thousand feet always cold; why is this?

7. The higher we ascend in the air the more intense the insolation; then why are the tops of high mountains always cold?

8. Why do lakes and rivers cool down so much more quickly than they warm up? Why do shallow lakes freeze over more quickly than deep?

9. Why is the temperature of Denver more equable than that of St. Louis? Chicago more equable than Minneapolis?

10. Why is a uniform bore necessary in the tube of an accurate thermometer? Why is the tube expanded at the bottom?

11. How can you use the thermometer to determine altitude?

12. Why do flowers bloom and the trees put forth their leaves so much earlier on the south than upon the north slopes of mountains and hills?

13. Why is a cloudy day in winter warmer, and in summer cooler, than a clear day?

14. Why is it warmer in summer in the latitude of St. Louis than at the equator?

15. Why is the warmest hour of the day later in summer than in winter, and why is the coldest hour earlier?

16. Why is there less difference between the two maximum temperatures during the year than between the two minimum, at places over which the vertical ray of the sun shifts?

CHAPTER IX

WEIGHT AND DENSITY OF THE AIR

Pressure and Weight.—It is a well-known fact that at any point within a liquid or a gas pressure is equal in all directions. On this account one moves freely about in the air, although it is pressing upon every square inch of the body with a pressure of almost fifteen pounds, or more than a ton to the square foot. Nevertheless this great pressure causes us no inconvenience, because it is balanced by an equal pressure from within. Pressure of the air is *pressure per unit area.*

The pressure of the air sustains, at sea level, a vertical column of water about 34 feet high, and a vertical column of mercury about 30 inches high. This fact is applied in the lifting pump, the siphon, and the barometer.

A cubic foot of air at sea level weighs about 1.25 ounces. In a room 14 ft. long by 12 ft. wide by 10 ft. high there are more than 125 pounds of air; and the weight of the air above an acre of ground is almost 50,000 tons. The weight of the air above any horizontal surface is equal to the pressure upon that surface, weight being simply *pressure downward.*

Density of the Air.—In gases, pressure, density, and volume bear a definite relation to each other. As the pressure *increases* the density also *increases*, and the volume *decreases* in the same ratio. This is not true of liquids or solids. As a result of this relation the air is densest at the bottom.

So rapidly does the density of the air decrease as we ascend in it, that at an altitude of about 3.6 miles the air is only half as dense as at sea level. This means that *half* of the air is within 3.6 miles of the surface of the sea; and since many mountains are more than three miles high, their summits reach above one-half of

the entire *mass* of the air. Withing the next three miles we pass through almost one-half of the remaining half of the air; so that three-quarters of the air is within 6.8 miles of the surface of the sea. If the air were of the uniform density of the lower air, it would extend only about five miles above sea level.

Measurement of Pressure.—For the purpose of measuring the pressure of the air the *barometer* has been devised. Its construction depends upon the principle that a given *weight of air* will balance an equal weight of *any other fluid;* or counterbalance an equal *pressure* exerted in any other way.

Two types of barometer are in common use, the liquid and non-liquid. In the liquid barometer the air sustains a column of liquid, commonly mercury, in a tube from which the air has been withdrawn. In the non-liquid or aneroid barometer, the pressure of the air is counterbalanced by the resistance of a thin metal diaphragm.

The simple mercury barometer consists essentially of a glass tube at least thirty-four inches long, closed at one end, filled with mercury and placed vertically, open end down, in a cistern of mercury. The tube is graduated in some linear unit, as the millimeter or tenth of an inch, the surface of the mercury in the cistern being the zero of the scale.

The mercury sinks in the tube, leaving a few inches of the upper end of the tube a vacuum, that is, with no air pressure on the mercury column. The column of mercury is sustained by the pressure of the air upon the open surface of mercury in the cistern. When this pressure increases the mercury rises in the tube, and when it decreases the mercury sinks.

At sea level the length of the mercury column is about thirty inches; hence we commonly say the air pressure at sea level is thirty inches, understanding that the pressure is measured by the weight of the column of this length, as *pressure* cannot be measured in *inches*.
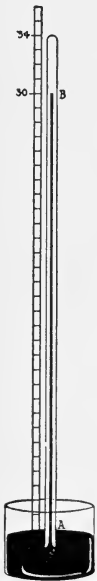
As it is the *vertical* length of the column of mercury that measures the pressure of the air, it is necessary, when taking a reading, to hold the instrument in a vertical position. For this purpose, and to protect the instrument, the tube and cistern are firmly bound together to a rigid frame, arranged for suspension.

The *aneroid* barometer consists essentially of a pile of hollow metallic discs, from which the air is exhausted, and to which an index is attached. This index moves over a surface upon which there are graduations to represent the various pressures. The discs are made of very thin metal, supported by coiled springs within, and respond to slight changes in air pressure. Because of its convenience the aneroid is much used in taking altitudes. Both pressure in inches and altitudes in feet are usually shown.

Variation in Barometer Reading.—At sea level, as we have seen, the average reading of the barometer is about thirty inches. As the instrument is carried up through the air, in a balloon or in ascending a mountain, it is found that the barometer reading is lower by about one inch for each thousand feet of ascent. This is because of the air that is left below, only the air *above* affecting the barometer.

Fig. 41. — Standard Barometer

This is only approximately true, for with increase in altitude there is a decrease in the density of the air. Whereas a fall of *one* inch results from carrying the instrument from sea level up 910 ft., a fall of *two* inches requires an ascent of 1,850 ft. The higher the altitude the greater the distance through which the instrument must be carried to register a fall of one inch.

Fig. 42.— Aneroid Barometer

Height of the Air.—Estimates of the thickness of the air envelope, based upon barometer readings, are unreliable, inasmuch as we do not know at what rate the density of the upper air changes. While one-half of the air lies within 3.6 miles above sea level, we have reason

to know that the air in considerable density exists at a height of about two hundred miles. Meteors have been observed at that height.

Lows and Highs.—If a stationary barometer be read from hour to hour it will be noted that its readings vary continuously. This seems to be due chiefly to a succession of surges in the air, called *lows* or *highs* as the barometer falls or rises. Lows are also called *cyclones* and highs *anti-cyclones*.

As we go outward from the center of a low we observe that the barometer readings are higher in all directions; and in passing out from the center of a high the readings are lower. It follows that about lows and highs systems of lines may be drawn through places having the same barometer reading. *Lines drawn through places having the same barometer reading are called isobars.*

Because of the mobility of the air, and the many conditions that affect pressure, isobars are not apt to be either regular or parallel, although about lows and highs that are strongly developed isobars are closed curves.

The isobars about a high may be aptly likened to the *contours of a hill* in a *topographic map*, the high by analogy being an *atmospheric hill;* and those about a low to the *contours of a depression*, the low being an *atmospheric hollow*.

Inasmuch as the density varies directly as the pressure, the air is denser about a high than about a low.

Pressure Gradient.—Just as the temperature gradient line is the shortest distance from one isotherm to the next, so we may get the *pressure gradient* line at any place by taking the shortest distance between the isobars at that place. Numerically expressed, the *pressure gradient is the number of hundredths of an inch change of pressure, in a distance equal to one latitude degree*, or about seventy miles. Crowded isobars, therefore, signify *steep* pressure gradients, and widespread isobars *gentle* gradients. We shall see that the direction and strength of the wind are closely related to the pressure gradient.

If a continuous record of the air pressure is desired, an instrument called the *barograph* is used. It is usually an aneroid ba-

rometer with a pen-bearing arm in the place of the index. The pen-point rests against a disc or sheet of paper that moves at a constant rate, as in the thermograph. The two systems of lines are *time* and *pressure* lines.

The record of the barograph is a *pressure curve*, and the charted pressures of any region, as shown by the isobars, make an isobaric or *pressure chart*.
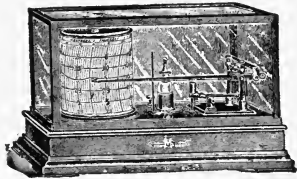
FIG. 43.—BAROGRAPH

Pressure Belts.—The distribution of pressure over the earth is intimately associated with the distribution of heat; and as the equatorial regions are regions of high temperature, they are, as a result, regions of low pressure. The air being excessively heated, is pushed away from over these regions, leaving them deficient in pressure. On either side, in the region of the Tropics, the pressure is increased, thus giving a high pressure belt in each hemisphere.

Poleward from the tropical high pressure belts the pressure, as
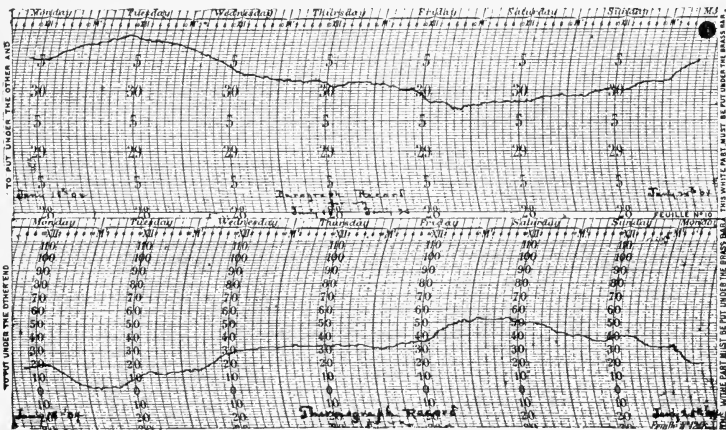
FIG. 44.—BAROGRAPH AND THERMOGRAPH RECORDS FOR ONE WEEK

Note their Relation. As the barometer rose the thermometer fell, and as the barometer fell the thermometer rose. Daily variation of temperature obscured by the variation due to the passing high and low pressure areas.
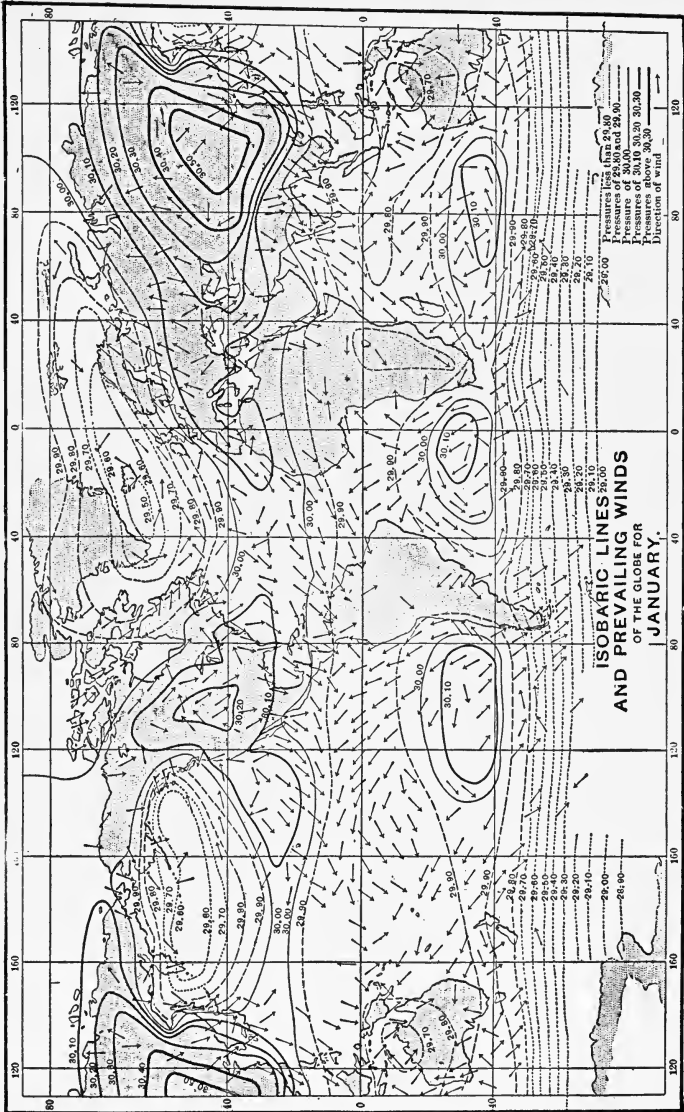
FIG. 45.—DISTRIBUTION OF PRESSURE DURING THE NORTHERN WINTER

Observe that in the Winter Hemisphere the continents are high pressure areas and the oceans low pressure, whereas in the Summer Hemisphere the opposite is true.
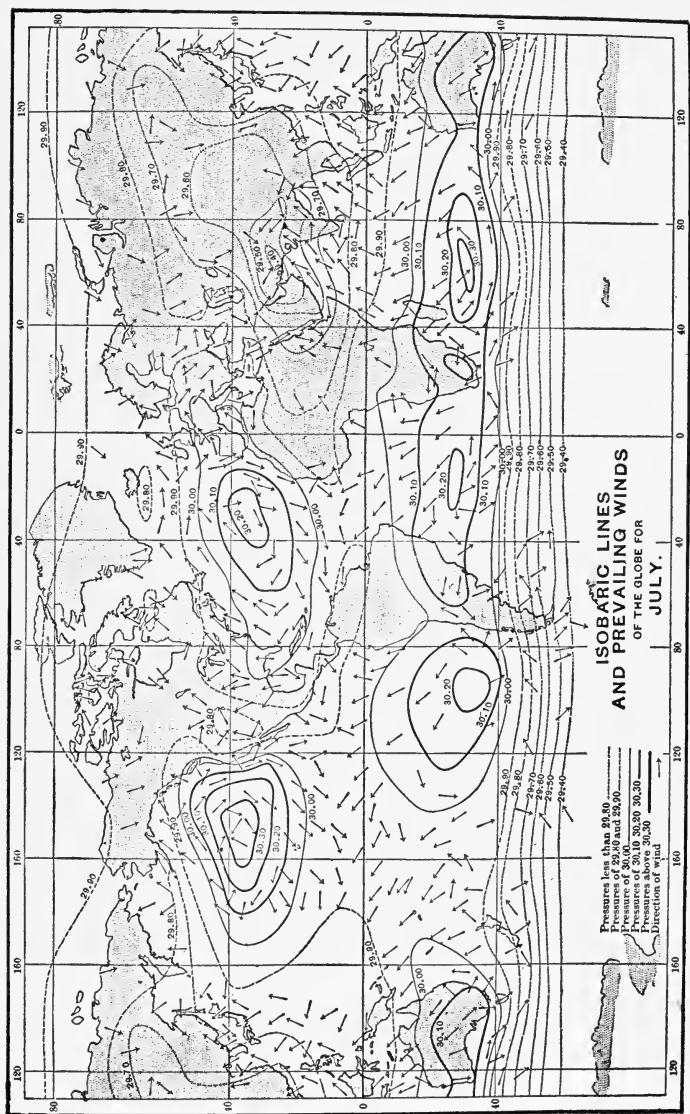
Fig. 46.—Distribution of Pressure During the Northern Summer

Now the continents in the Northern Hemisphere are low pressure centers and the oceans high.

a rule, decreases; and the polar areas are thought to be relatively low pressure areas.

As a result of this arrangement of pressure, the isobars of the world have a general east-west trend, and shift with the shifting belt of equatorial heat.

Uses of the Barometer.—As before stated, the aneroid barometer is used in the determination of altitudes, because of its convenience in carrying. Aviators and balloonists carry aneroids, this being often the only means by which the altitude reached by them can be known, as they are obscured by the clouds from the view of observers upon the land.

But a much more important use of the barometer is in forecasting the weather. Pressure is one of the factors which determine the weather; and in forecasting the weather a knowledge of the distribution of pressure over the country is necessary.

QUESTIONS

1. In a closed vessel, filled with air, the pressure upon the inner surface *decreases* with decrease of temperature, whereas in the open air pressure *increases* with decrease of temperature; why is this?

2. What is meant when we say the pressure of the air is 30 inches?

3. Why does the air at any place vary in pressure?

4. How may the barometer be used to measure altitude?

5. Why must a liquid barometer be held in a vertical position when read? Why is it not necessary to hold an aneroid in a definite position?

6. Why is it not necessary that the bore of the barometer tube be regular as in the thermometer?

7. What is the general relation between barometer change and change of thermometer?

8. Why is mercury so generally used in the construction of liquid barometers? What is the objection to using water?

9. Why do standard barometers have a thermometer attached?

10. Why do the high pressure belts of the " horse " latitudes shift?

CHAPTER X

. MOVEMENTS OF THE AIR

Winds Defined and Explained.—The air, being part of the earth, by necessity partakes of the earth's motions of rotation and revolution. Entirely distinct from these motions are those sometimes regular, but more often fitful and irregular movements of the lower air, called *winds*.

A wind may be defined as *an approximately horizontal natural movement of the lower air.* Winds should be sharply distinguished
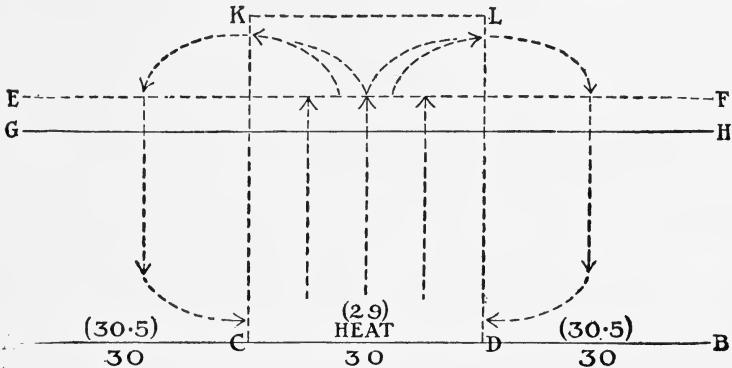
FIG. 47.—SHOWING HOW WINDS ARE STARTED
Numbers below A B indicate barometer reading before heating; those above A B barometer reading after heating.

from vertically moving air; likewise from the upper-air movements, both of which are called currents.

The air is so mobile that any object moving through it sets a considerable volume in motion; and the least inequality of pressure disturbs its equilibrium. The most important cause of the unequal distribution of pressure, and therefore of winds, is the unequal distribution of *heat* over the earth.

Figure 47 and its explanation are easily applicable to earth conditions, and to the explanation of winds.

A B represents any surface, above which the air extends to the height G H.   Suppose a limited area, as C D, is heated in excess of the surrounding surface.   The air above C D expands, and if we consider only the expansion upward, the column of air above C D lengthens to K L. Being unsupported laterally the air in the column above the level of G H flows away until the upper surface of the air is again level at the height E F.   Some air above C D having flowed away, the pressure upon this surface is *less* than before heating· whereas the pressure upon A C and B D is *greater*.

As a result of the rearrangement of pressures, A C and B D are *highs*, away from which the lower air moves laterally; and since C D is a *low* the movement is more pronounced toward this area.   Above C D the inflowing currents meet and rise, thus completing the circulation. The circulation continues just so long as C D is heated in excess of the surrounding areas.

If we consider the separate steps in the development of the circulation described they may be stated as:

1. Local excessive heating;
2. Expansion of the column of air above the heated area;
3. Overflow aloft from, and inflow at the bottom toward, the heated area;
4. Ascent of the inflowing currents above the heated area, or low;
5. Descent of the outflowing currents.

It is only the surface movement of this circulation that is called *winds;* all other parts are *currents*.

Terrestrial Winds.—If we consider the foregoing figure a vertical section of the air along a meridian at the equator, we have an explanation of the systematic winds of the earth.

The area C D represents the doldrum belt along or near the equator, which, by reason of vertical insolation, is most heated. The movement of the air above this belt being chiefly upward, this is a belt of light winds, or calms.

The poleward overflow aloft leaves this region a *belt of low pressure*, and at the same time produces on either side, somewhere between the latitudes of 25° and 35°, a *belt of high pressure*. Above these belts of high pressure the movement of the air is chiefly downward, and these, like the doldrum belt, are also belts

of light winds or calms. They are known as the *Horse Latitudes*. Out from these high pressure belts the winds blow toward the equator, and with less pronounced strength toward the poles.

Excessive heating along a belt near the equator results from: (1) The globular shape of the earth; (2) Rotation about an axis which remains parallel to itself; (3) The source of heat being a body distant from the earth.

Since most of the planets agree in these three particulars, it follows that the circulation described for the earth must be common to all planets with atmospheres. On this account the winds produced by this circulation are sometimes called *planetary winds*.

Deflection of Winds.—It was long ago discovered that winds do not follow a straight course; but in the northern hemisphere turn to the *right*, and in the southern hemisphere to the *left* of such a course. The statement of

FIG. 48.—TERRESTRIAL WIND BELTS

Owing to the inclination of the earth's axis, and revolution of earth around the sun, the *wind belts shift.* The figure shows their extreme northern and southern positions. Where they overlap we have the monsoons of the sub-tropical and sub-equatorial belts. Note the *bending* of the trades where they run across the equator, to be explained later.

this systematic deflection is known as Ferrel's Law, and all winds obey this law. It governs alike the *constant* winds that blow out from the belts of high pressure calms, and the *irregular* winds that blow about high and low pressure areas. Because of this deflection *winds do not follow the barometric gradient.*

Deflection of winds from a straight course *results from the rotation of the earth.*

In explaining the relation between deflection of the winds and rotation, two facts are important:

1. The rotational velocity of places upon the earth decreases poleward;

2. The inertia of matter makes it impossible for a particle once set in motion, of itself, to change its direction or motion.

In I in the figure below, if a marble be started from the center along the radius C A, with sufficient velocity to carry it to the edge of the table in one second, if the table be at rest the marble will leave the table at A. If, however, at the instant the marble is set in motion the table be set rotating in a counter-clockwise direction at such rate as to change the
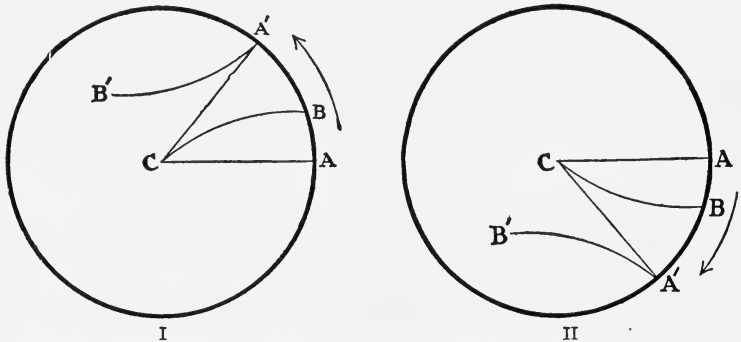
FIG. 49.—ILLUSTRATING THE DEFLECTION OF THE WINDS FROM A STRAIGHT COURSE, DUE TO THE *Rotation* OF THE EARTH

position of radius C A to that of C A′ in one second, the marble will follow the curved path, leaving the table at B. The marble's *inertia* has made it take the curved path, deflected continuously to the *right* of a straight course as it moved into regions of *greater* rotational velocity.

If instead, the marble be started from A along A C at the instant the table is set rotating, in one second it will have traversed the path A′ B′. The inertia of the marble has again made it take a curved path, deflected to the *right* of a straight course, as it moved into regions of *less* rotational velocity.

On any straight line that may be drawn upon the table, along which the marble may be started, the marble will either *approach* the center or *recede from* it; and since in both cases the counter-clockwise direction of rotation causes a right-handed deflection, the marble will in all cases be deflected to the right of the straight course along which it is started.

The rotation of the earth, as seen from above the north pole, is counter-clockwise; and winds in the northern hemisphere behave in an analogous way to that of the marble described above in I.

As seen from above the south pole the earth's rotation is clockwise, and deflection is to the *left* of a straight course, as shown in II.

The deflective effect of rotation may be illustrated by pouring water on a rotating globe. If the globe be held with its axis vertical, and rotated in a direction corresponding to that of the earth, the minute streams will be deflected to the right of the meridians along which they start so long as they are in the northern hemisphere, and to the left after they cross the equator. If started from the south pole of the globe they will suffer first left-handed deflection, changing to right-handed upon crossing the equator into the northern hemisphere.

The only winds which do not suffer deflection are those *along the equator*. Set moving in any other direction or in any other latitude they suffer deflection according to Ferrel's Law. The deflective effect of rotation increases with the latitude, and in any latitude varies inversely as the velocity of the wind. It should be remembered that the rotation of the earth *has no power to set the air in motion*, and its deflective power exists *only after motion is started*.

Two important laws governing winds are:

1. Winds always blow from a region of higher pressure to a region of lower pressure, with a velocity which varies with the pressure gradient;

2. On account of the rotation of the earth winds turn to the right of the pressure gradient in the northern hemisphere, and to the left of the pressure gradient in the southern hemisphere.

Description of Wind Belts.—The wind belts depend upon the pressure belts, and these in turn are determined by the distribution of heat. Since the heat belts shift, in like manner the pressure and wind belts shift.

The *Doldrums* are so named because of the light winds and calms that characterize this belt. It is a belt of high temperature, and consequently low pressure. The winds move obliquely in toward the doldrums from both sides. The low pressure is of convectional origin, and the rapid ascent and cooling of the air give rise to frequent and abundant rains.

The *Trades* are the winds that blow from either side obliquely in toward the doldrum belt. They derive their name from their constancy of duration and direction, qualities important to sailing vessels engaged in trade. In the northern hemisphere they are called *northeast trades*, and in the southern, *southeast trades*. They have their origin in the high pressure belts of the horse latitudes,

and move toward the low pressure belt of the doldrums. Instead of following the steepest gradients, along the meridians, as they should do if there was no rotation, they are deflected, in accordance with Ferrel's Law, to the right in the northern hemisphere, and to the left in the southern.

In order to reach the doldrum belt the trade-winds sometimes have to cross the equator. When northeast trades cross to the south of the equator they become *northwest* winds; whereas southeast trades crossing the equator become *southwest* winds. These "hooked" winds are due to the difference in the deflective influence of the earth's rotation north and south of the equator.

The *Horse Latitudes* are belts of high pressure next to and poleward from the trades. The air that is warmed, and by convection rises in the doldrums, moves away poleward at high altitudes. Its overflow aloft, and consequent piling up in the regions of the horse latitudes, causes the high pressure and descending currents in these belts. As a result of its descent the air is warmed by compression, and its capacity for water vapor is increased. These belts are therefore prevailingly dry. The trade-winds begin here; likewise the less regular winds that move away toward the poles.

The *Prevailing Westerlies* flow away from the horse latitude belts toward the poles, being deflected to the east by the rotation of the earth. They are named from their direction, and in their upper parts are continuations of the overflow above the trades. The prevailing westerlies are neither so constant in duration nor in direction as the trades.

As the prevailing westerlies approach the poles obliquely and along converging courses, in each hemisphere there is developed a *circumpolar whirl*. These winds spiral about the north polar region in a left-handed or counter-clockwise direction, and about the south polar region in a right-handed or clockwise direction.

As a result of the spiral inflow toward the poles it is believed the *polar regions* are *areas of low pressure*. The *centrifugal force* resulting from the whirl tends to heap the air out around the polar center, and to produce a *circumpolar ring* of high pressure. From this ring the winds

move away into lower latitudes. The frequent northeast winds observed on the northern coast of Alaska are thus explained.

Both temperature gradient and pressure gradient, between the equator and the Arctic regions are steeper in winter than in summer. As a consequence the circumpolar winds are strongest in winter. This may account for the frequency and violence of our winter cyclones.

Because of the excessive cooling of the northern continents in winter, the North Atlantic and North Pacific oceans are warmer than the northern continents and are therefore *centers* of *low pressure*. About these centers the winds spiral in a way comparable to the circumpolar whirl; and from these secondary centers winter cyclones are projected. Those from the Pacific often move southeastward into Canada and the United States.

Shifting of the Wind Belts.—The pressure belts and wind belts follow the shifting of the belt of greatest heat. As a result of this shifting, places near the border of the various wind belts lie alternately in two belts. Southern Florida, southern California and northern Mexico lie alternately in the trades and the horse latitudes; and the Amazon Valley, usually in the doldrums, is periodically swept over by the trades.

This shifting of the wind belts has the effect of widening the belts which at some time during the year lie under the low pressure and the high pressure calms. To these widened belts the names sub-equatorial and sub-tropical are respectively given.

Places so situated as to have seasonal change of wind are said to have *monsoon winds*, or simply *monsoons*. While many places, both in the sub-tropical and sub-equatorial belts have monsoon winds, perhaps the most pronounced and best known monsoons are those of the northern Indian Ocean, and the adjacent lands to the north and east.

During the northern summer the heat equator migrates far into the heated continent of Asia. Then the southeast trades, which run to the doldrum belt, cross the geographical equator, and in the northern hemisphere become, according to Ferrel's Law, southwest winds. In winter the heat equator migrates southward, and

over southern Asia and the northern Indian Ocean the strengthened northeast trades blow.

Continental Air Drifts.—The land has a higher temperature than the sea in the same latitude in summer, and a lower temperature in winter. As a result the continents are areas of *low*
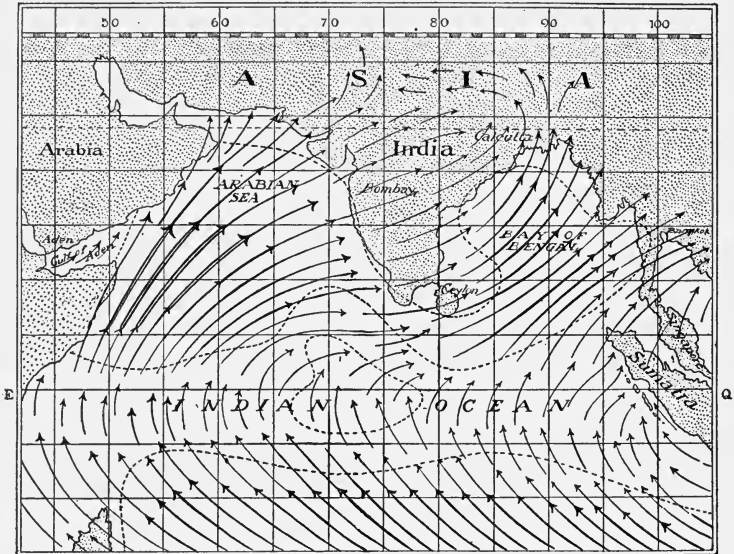
FIG. 50.—WINDS OF NORTHERN INDIAN OCEAN FOR JULY

pressure in summer, and of *high pressure* in winter. Following this adjustment of pressure there is a general *outward* drift of the lower air from the continents in winter, and an *inward* drift toward the continents in summer.

These movements, which in a strict sense are monsoons, are never so called, but are sometimes called *continental* winds. They are so easily obscured by other winds as to be scarcely noticeable of themselves; and their chief office is to modify other winds. Thus upon our western coast the *westerlies* are *weakened in winter* and *strengthened in summer;* whereas upon our eastern coast they are *strengthened in winter* and *weakened in summer.*

Land and Sea Breezes.—The winds that blow alternately from and to the land, at and near the seashore, are called *land* and *sea breezes.* When the land is colder than the sea the breeze blows
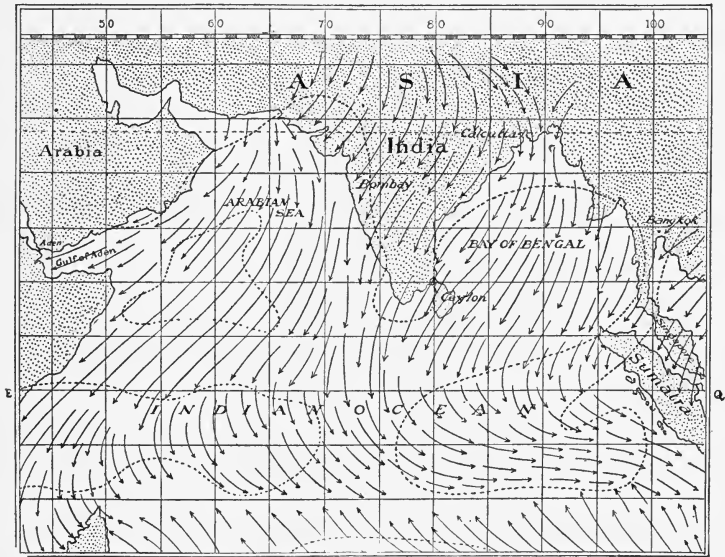
FIG. 51.—WINDS OF NORTHERN INDIAN OCEAN FOR JANUARY

from the land and is called the *land breeze;* and when the land is warmer than the sea the breeze blows *from the sea,* and is called *sea breeze.* The land breeze blows during the night, as the land is then an area of relatively *high pressure;* and the sea breeze blows during the day, the land being then a region of relatively *low pressure.*

Advantage is taken of this twice daily change of breeze by fishing and pleasure craft that depend upon sails to carry their fleets away from and to bring them back to land. Similar *land* and *lake* breezes are felt along the shores of our great lakes and inland seas.

If the land should remain throughout the twenty-four hours colder than the sea, then there would be a continuous land breeze. This often occurs in winter, especially when the land is covered with snow. On the

other hand, in mid-summer it sometimes happens that the land does not cool down during the night below the temperature of the adjacent sea; then the sea breeze continues throughout the night.

Mountain and Valley Breezes.—Another similar change of breeze may be noted upon the slopes of mountains or of deep valleys. The top of the mountain, or of the dividing ridge, being first warmed by the rays of the rising sun, convectional ascent begins there. As the slopes and the air in contact with them are warmed to lower and lower levels, the warmed lighter air finds an easier escape obliquely up the slope and through the convectional chimney above the summit than vertically through the overlying stratum of inert air. This obliquely ascending current is felt upon the slope as a *valley breeze*.

At night radiation is most rapid from the mountain summit or ridge crest, and the cooled air from the upper slopes, being heavier, moves down the slopes toward the valley. This is the *mountain breeze*. The alternation of mountain and valley breezes may be interrupted in the same way as described for land and sea breezes.

Avalanche winds occur in valleys between steep mountain slopes, and are caused by the moving mass of snow and rock on the mountain side. Being compressed in the narrow valleys, these winds sweep with almost irresistible force down the valley.

Cyclonic Winds.—In temperate latitudes by far the most important winds are those *unperiodic* winds, caused by the *irregular* distribution of pressure in *lows* and *highs*, and known as *cyclonic winds*. These lows and highs are best understood if considered as *local* disturbances in the terrestrial winds. Thus considered, their general drift with the winds of the belt in which they occur is accounted for.

Cyclonic winds move obliquely in toward the center of a low, spiraling about the center in a counter-clockwise direction in the northern hemisphere, and in a clockwise direction in the southern hemisphere. They move spirally out from a high, turning in a clockwise direction in the northern hemisphere and in a counter-clockwise direction in the southern.

Although their origin is obscurely understood, some lows are known to be of convectional origin; others are probably not. This has given rise to two classes of cyclones, *convectional* and *non-convectional*.

Land varies indefinitely in its power to absorb insolation, owing to its almost infinite variety of composition, covering, and form. If any given

limited area is heated in excess of the surrounding region, the air above this area expands, overflows aloft, and the area becomes a *low*, while the surrounding region has *increased* pressure. The overflow from adjacent lows may unite and produce a *high*. On the other hand, the air over a given area, as a snow-covered region, may be excessively cooled and condensed. Then the upper air from the surrounding region flows in upon it, producing a *high*, surrounded by a ring of lower pressure. Such lows and highs are of *convectional* origin.

It seems probable that non-convectional cyclones originate in two ways. In high latitudes, about the margins of the circumpolar whirls, and in the northern hemisphere about the margins of the North Atlantic and North Pacific eddies, smaller eddies of air are developed; analogous to the eddies that arise about the perimeter of a strong water whirl. These are sometimes called *driven* cyclones, and are most frequent and best developed in winter when these great eddies are strongest. In lower latitudes, even within the tropics, cyclonic whirls may result from the *friction* between great poleward moving and equatorward moving masses of air. Such cyclones are called *frictional cyclones*. They may originate in the higher currents, and sink to the bottom of the air fully developed.

Movements of Lows. — Four distinct movements with reference to lows must be noted: the *oblique movement* of the winds *toward* the low center, their *ascent* as the center is approached, *spiral outflow* above, and the *forward movement* of the low itself.

Wherever their place of origin, most lows finish their course in the zone of westerlies, following the general direction of these winds. In the United States three general paths are followed, as the cyclone originates in the *northwest*, in the *southwest*, or in the *southeast* within the tropics. Those originating in the northwest move first southeasterly, until they reach the axis of the Mississippi Valley, when they change to a northeasterly course for the remainder of their journey across the continent. Those having their origin in the southwest move systematically northeastward across the continent. Tropical cyclones having their origin in the region of the West Indies move first northwestward, until they reach the high pressure calms, north of which they conform to the course of the westerlies. These usually cross the high pressure belt over or near the land, the belt being less well developed there.

All cyclones, sooner or later, conform to the course of the westerlies. The upper air currents in all latitudes move to the northeast; and it is probable that the spirally ascending column of air at the cyclone center reaches to these upper currents.

Strength of Cyclonic Winds.—The velocity of the wind increases as it approaches the center of a low; and if a strong spiral movement is developed the velocity is greatly increased. On the other hand, the winds *start* from the center of the high, and are therefore weakest there. Consequently, the strength of the wind *increases* with the approach of a *low*, and *decreases* with the approach of a *high*.

Because of their greater strength, cyclonic winds obscure all other winds in regions where they occur. The winds poleward from the horse latitudes are chiefly cyclonic.

When the low pressure area is very small the spiraling winds may attain excessive velocity, and become destructive. Such wind storms are known as *tornadoes*, and in their greatest strength the winds are so strong as to carry away the instruments for their measurement. Velocities of more than one hundred miles an hour have been measured. Similar storms in the West Indies are called *hurricanes*, and in the East Indies *typhoons*.

Cyclones within the tropics, of wide extent, sometimes have within the whirl of destructive winds an area of clear skies. This area, called the "eye of the storm," may be as much as one-tenth of the diameter of the cyclonic area. Vessels passing through the eye of the storm experience equally strong winds in the front and in the rear of the cyclone, though from opposite directions.

Shifting of Winds.—When a station lies near the path of a low or high the winds at the station shift in a systematic way as the barometric disturbance passes. In the *westerlies* of the northern hemisphere, where the disturbances advance from west to east:

1. If a *low passes north of the station*, the first effect is to induce *easterly* winds. These *veer* (change *with* the sun) through the southeast, south, and southwest to some westerly quarter as the disturbance advances easterly.

2. If a *low passes south of the station*, the winds, northeasterly at first, *back* (change *against* the sun) through the north, northwest and west to a southwesterly direction.
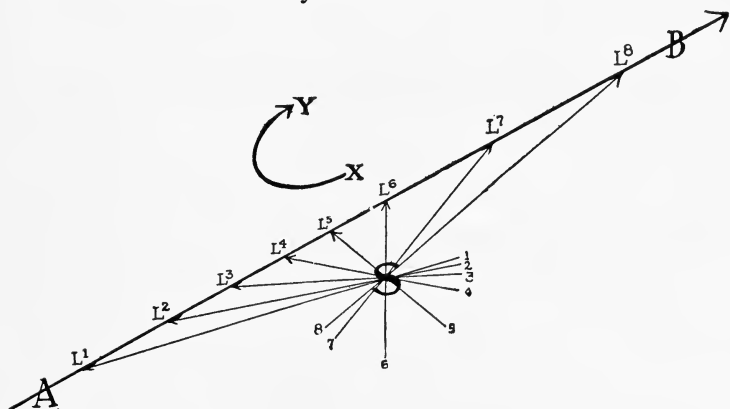
FIG. 52.—A B is the path of the center of a low which passed north of the station S. The successive winds are numbered in order. The curved arrow X Y is the composite of the sheaf of arrows passing through S toward the center of the low.

3. If a *high passes north of the station*, the winds, at first westerly or northwesterly, *veer* to northerly and northeasterly winds in succession.
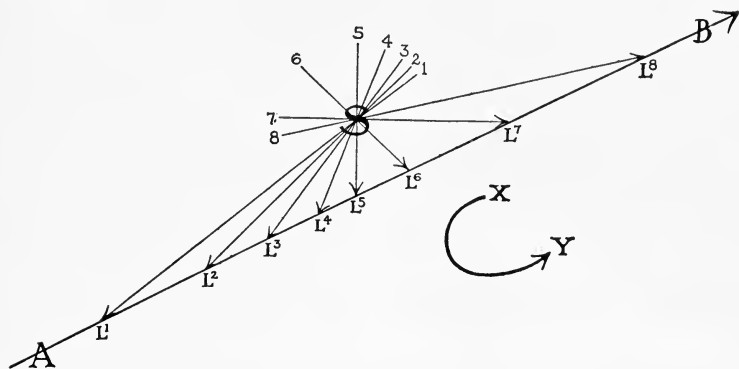
FIG. 53.—The path of the center, A B, is here south of the station S. As above, the curved arrow X Y is the composite of the sheaf of arrows through S.

4. If a *high passes south of the station*, the wind *backs* from the southwest through the south, southeast, and east in turn.
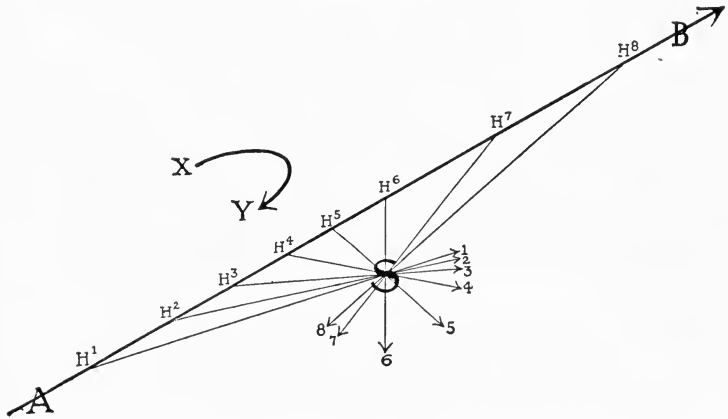
FIG. 54.—In Fig. 54 a high passes north of the station S, and the succession of winds, blowing out from the center of the high, is shown by the sheaf of arrows through S. The curved arrow X Y shows their composite.
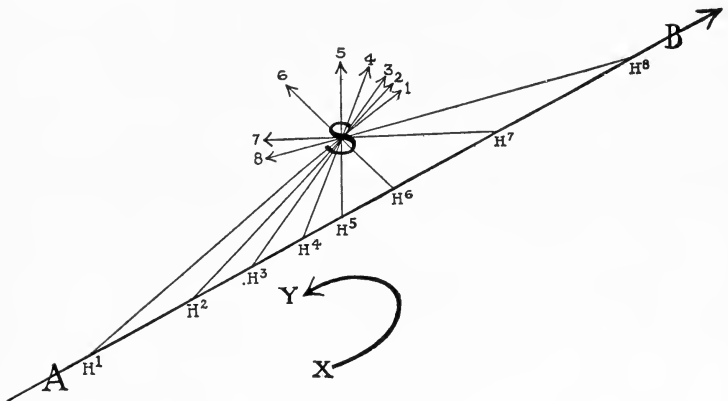
FIG. 55.—The path of the center of the high is south of S, and the sheaf of arrows and their composite illustrate the backing of the wind.

Should the disturbance pass *centrally* over the station the wind will hold steadily as a northeasterly wind if the disturbance is a low, or as a westerly wind if the disturbance is a high, as the disturbance advances, changing suddenly through a calm to the opposite point of the compass as the center of the disturbance passes.

In any other wind belt the direction of shifting may be determined by noting the direction in which the disturbance advances, and considering the direction of movement of winds about highs and lows in that belt. For any given station the direction of shifting is systematic and uniform for a given set of conditions.

Special Winds.—In every part of the world winds of special character and of exceptional occurrence are known, to which local names are given. Some of these are *warm* winds, others are *cold;* some owe their character to *change in latitude*, others owe theirs to a *change in altitude.*

The change in temperature due to change in latitude is, on an average, about 1° Fahrenheit for each degree of latitude, whereas the temperature change in ascending currents of air is about 1.8° F. for 300 feet. Therefore, any transfer of air, either in *latitude* or *altitude*, is accompanied by a change in temperature, both of the transferred air and of the region to which it is transferred.

Generally speaking, winds blowing from lower to higher latitudes are *warm* winds, while those blowing from higher to lower latitudes are *cool*. Winds descending from higher to lower altitudes are generally *cool* or *cold* winds, though their temperature rapidly rises as they descend and makes them *warm*, while those blowing up a slope are apt to be *warm*.

Among *warm winds* may be mentioned:

The *Hot Wave*, of western central United States. It blows in summer from the west or southwest, sometimes continuing for days, and withers all growing vegetation.

The *Sirocco*, a south wind from the Sahara desert, felt as far as the north shore of the Mediterranean Sea. It is commonly dry and dust laden.

The *Simoom*, an intensely hot, dry, and generally sand-laden wind of

the Arabian desert. It is probably a convectional whirlwind, similar to the dust-laden whirlwinds of all dry, hot climates. It lasts usually less than ten minutes, and often forms sand-spouts.

The *Chinook*, an American wind, which moves down the slopes of mountains toward a low pressure area at their base. Though starting upon its descent as a *cold* wind, it warms by compression in its descent, and if the mountain is high it may reach the base as a *warm* or even *hot* wind. In all cases, because of its dryness, it evaporates or melts the snow fields over which it blows, and often causes destructive avalanches, by melting the snow on the steep slopes. It is of frequent occurrence along the eastern bases of the Rocky and Sierra Nevada mountains. Many valleys here are kept practically free from snow; and their temperatures are so mild as to make shelter for stock in winter unnecessary, and to · permit grazing throughout the year. The Chinook is scarcely noticeable in summer.

The *Foehn* is the European wind of the Chinook type, common on the northern slopes of the Alps, where, in the north-south valleys it hastens the ripening of grapes in the fall; and in winter rapidly melts the snows in its path. This has earned for it the name of "snow-eater."

To the class of *cold winds* belong:

The *Norther*, of southwestern United States. It is the cold inflow of winds from the north, at the rear of the winter cyclone. A fall of temperature of fifty degrees in two hours has been noted.

These winds often cause great suffering, loss of live stock, and even loss of human life.

The *Blizzard*, the American name for a cold wind of high velocity, accompanied by snow. It is common east of the Rocky Mountains, and often causes great loss of life among stock.

The *Bora* and *Mistral* are European cold winds.
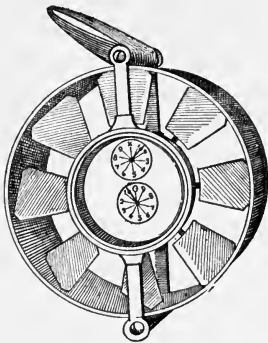
FIG. 56.—ANEMOMETER

Velocity of Winds.—Winds are sometimes classified according to their velocity. The velocity of the wind is measured by means of the *anemometer*, and is expressed in miles per hour, or feet per second.

When the wind reaches a velocity of 100 miles or more per hour the instruments are usually carried away. Therefore, we have no record of the velocity of the wind in our most violent tornadoes.

The accompanying table gives the ordinary names for winds, their approximate velocities in miles per hour, and a common and easy way of judging them:

Name	Distinctive Characters	Velocity
Calm	Flags limp, leaves unmoved	0
Light breeze	Moves leaves of trees	1–5
Fresh wind	Moves branches of trees, blows up dust	5–15
Brisk to strong	Sways branches of trees, makes white caps	15–25
High wind	Sways trees, moves twigs on ground	25–35
Gale	Breaks branches of trees, dangerous for sailing	35–75
Hurricane wind	Destroys houses, uproots trees	75–100

QUESTIONS

1. Why does the wind blow? Why is there not always wind?

2. What determines the direction and velocity of the wind?

3. Interpret "no wind" in terms of pressure gradient.

4. Why are summer days, as a rule, more apt to be windy than summer nights? Than winter days?

5. Why are the "trades," on the whole, stronger than the "westerlies"?

6. Why are upper currents stronger than surface winds; and winter winds stronger than summer?

7. Why are the "trades" more regular over the sea than over the land?

8. Why are the upper currents in all latitudes westerly currents?

9. Why do winds spiral about "lows"? Why are not equally strong whirls developed about "highs"?

10. Why are southern California and southern Florida more apt to have westerly winds in winter than in summer?

11. Why are storms that come from the southwest often called "northeasters"?

12. Why do cyclones in the eastern United States move so generally toward the northeast?

13. Why do thunderstorms occur so rarely at night?

14. What should be the direction of shifting of the wind with passing "lows" and "highs" at Havana, Cuba? At Buenos Aires?

15. Why, in the natural ventilation of our rooms, do we admit the air at the bottom of the room, whereas in forced ventilation the air is admitted at the top? Which is better?

16. Why is a room better ventilated when windows are both raised from the bottom and lowered from the top than when merely raised or lowered?

17. Why do fires burn better in cold than in warm weather?

18. Why is a flue less liable to smoke after the fire is well started than when it is first lighted?

19. Why do snow-drifts and sand-dunes accumulate behind an obstacle rather than in front of it?

20. Why do aviators avoid flights over cities and deep canyons?

CHAPTER XI

MOISTURE OF THE AIR

How Obtained.—The moisture of the air is obtained by *evaporation* from moist surfaces. *Evaporation is the process by which solids and liquids are changed to vapor.* While evaporation is chiefly from water surfaces, yet scarcely any land surface is so dry that it does not supply some moisture to the air. The lower air is never wholly free from moisture, the amount present depending chiefly upon the temperature of the air. Evaporation takes place at all temperatures. The moisture of the air is for the most part in its invisible form, that of water vapor; but it becomes visible when, by cooling, the vapor changes to the liquid or solid state as clouds. Real steam issuing from a boiling kettle is invisible. So-called steam, the visible cloud seen a few inches away from the spout, is composed of minute *particles* of water, and not water *vapor*.

Humidity of the Air.—The air at all temperatures has a certain *capacity* for water vapor. Other conditions remaining the same, the higher the temperature the greater the capacity. To satisfy this " thirst " of the air evaporation goes on. If the temperature is low, or the capacity of the air is nearly satisfied, evaporation is slow; and when the capacity is fully satisfied, evaporation ceases. The air is then said to be *saturated*.

The condition of the air as regards the amount of water vapor present is called its *humidity*. The actual amount of water vapor in a given volume of air, as the number of grains of water vapor in a cubic foot of air, is its *absolute* humidity. The amount of water vapor present, divided by the amount the air is capable of holding at the time, is its *relative* humidity. Relative humidity is expressed in per cents.

If the air at a given temperature has six grains of water to the cubic foot of air present, and its capacity is ten grains to the cubic foot, its absolute humidity is " six grains per cubic foot," and its relative humidity is 60%. When the air is saturated its relative humidity is 100%. The temperature of saturation is called the *dew point.*

Condensation.—As evaporation is promoted by increase of temperature, so it is retarded by any lowering of temperature; and when the air is saturated evaporation stops, or if it continues condensation goes on at an equal rate.

Saturation may result from continued evaporation without change of temperature, or from a lowering of the temperature; and when the air is saturated, any lowering of the temperature results in a change from the vapor to the liquid or solid state, depending upon the temperature at which the change takes place. This change is *condensation.* It is condensation, *not* of the *air*, but of the *water vapor* of the air.

The cooling which causes condensation may result from:

1. Loss of heat by radiation, chiefly to the land or water from the lower air, when *fogs* are apt to result;

2. Contact with cold surfaces, when *dew* or *frost* may form;

3. Horizontal mixing of cold and warm currents, when *clouds* or *precipitation* may occur;

4. Mechanical cooling by expansion, incident to ascending currents, producing clouds or yielding precipitation.

The last is probably the most effective cause of condensation. Air in rising *expands* and is *mechanically* cooled, at the rate of 1.8° F. for every 300 feet of ascent. This rate is the same whether the air rises by convection, or is *forced* to ascend by reason of winds blowing against a rising land surface.

When air descends, as at the center of a high, or on the leeward slope of mountains, it *warms up* at the same rate.

The doldrum belt, the regions of lows, and the windward slopes of mountains are, therefore, apt to be rainy, while the high pressure calm belts, the regions of highs, and the leeward slopes of mountains have prevailingly clear skies.

If saturation is reached at a temperature lower than freezing, with further cooling the water vapor changes at once to the solid state, without passing through the liquid state; but if saturation occurs above the freezing point, the condensed product is liquid. As water vapor may change immediately to the solid state, so ice may evaporate without melting.

It is a familiar fact that snow gradually disappears from the land during days when the temperature does not rise to the freezing point; and a wet garment hung in the air may *freeze* dry. Roads in winter become dusty though continuously frozen.

Effects Upon Temperature.—In order to change ice or water to vapor, heat is absorbed, or becomes *latent*. This heat is used in the mechanical task of driving the *molecules* of ice or water apart, and is lost, as far as affecting temperature is concerned. The vapor formed is of the *same* temperature as the substance from which it came. The heat necessary for evaporation is obtained from surrounding objects, chiefly from the lower air, so that evaporation has the effect of *cooling the air*. Evaporation is always a *cooling* process with respect to surrounding objects.

The custom of fanning to cool one's self is an illustration of cooling by evaporation, the constantly changing air in contact with the moist skin taking up the moisture more rapidly.

A thermometer suspended in front of a rapidly rotating fan registers a slightly increased temperature, there being no evaporation from its surface, and the air being slightly compressed against the thermometer. If, however, the thermometer bulb be wrapped in a thin piece of *moist* muslin, the draft from the fan causes a marked lowering of the thermometer.

Gasolene, bay rum, or any easily vaporized liquid, when rubbed upon the hands cools them; and the high fever temperatures may be cooled by alcohol baths. The flesh may be *frozen* by the application of *ether*.

The principle of cooling by evaporation is used in the construction of the *psychrometer*, an instrument for the determination of the humidity of the air. It consists simply of a wet and a dry bulb thermometer. By keeping the bulb of one thermometer constantly moist, evaporation from the moist surface cools the mer-

cury in the enclosed bulb. The wet bulb thermometer, therefore, commonly shows a lower temperature than the dry bulb. The more rapid the evaporation the greater the difference in the readings of the two thermometers, and the drier the air. Little difference in the readings indicates slow evaporation and a humid air.

FIG. 57.—PSYCHROMETER

When evaporation ceases, as when the air is saturated, the two thermometers show the same readings.

When the reverse process takes place, and vapor is changed to liquid or solid, the *latent heat of evaporation* is released; and the heat thus liberated becomes available for affecting temperature. Surrounding objects are then warmed. Condensation of water vapor is, therefore, a *warming* process.

A burn from steam at 212° F. is much more severe than a burn from water at the same temperature, since a great amount of heat is liberated in reducing steam to a liquid without changing its temperature.

Distribution of Water Vapor.—Since most evaporation takes place at the bottom of the air, it follows that the lower air is of higher *absolute* humidity than the air at greater altitudes. Also the air over the oceans and other water surfaces is more humid than the air over the land. But by diffusion and by vertical currents the water vapor is distributed generally through the lower air to a height of about seven miles.

Although there is *more* water vapor in the lower air, the *relative* humidity of the lower air is not usually so high as that at greater altitudes, because of the lowering of temperature with increase of altitude. Clouds and rain are usually the result of condensation in the upper air, since the air cools in rising, due to expansion. This
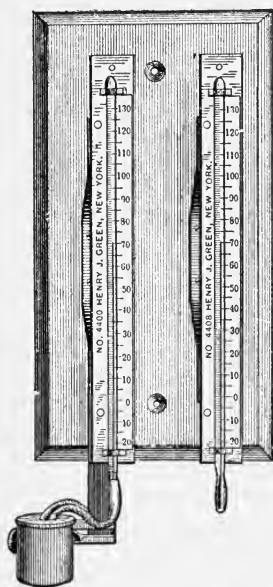
is perhaps the most important, though not the only cause of condensation of water vapor.

The relative humidity of the air varies, not only with change of place or of altitude, but it also varies from hour to hour at any place. It is highest at the coolest hour of the day, usually in the early morning, and decreases as the day advances and the air warms up. It is lowest at the warmest hour of the day, from one to three o'clock P. M., after which hour it slowly rises.

Dew and Frost.—When air at temperatures above the dew-point is cooled to saturation by *contact* with objects below the dew-point, condensation upon the cooling object occurs. If saturation occurs *above* freezing, the condensation is liquid, and we call it *dew*. If saturation occurs *below* freezing, the vapor changes at once to ice, without visible liquefaction, and this is called *frost*. Dew and frost *form; they do not fall. Frost is not frozen dew,* frozen dew being transparent pellets of ice.

These forms of condensation are most common on or near the surface of the ground. At a height of five feet there may be no frost or dew formed on plants when the ground and objects near it, as the grass, are white with frost or wet with dew.

Anything that checks the cooling of the ground and lower air tends to prevent the formation of dew and frost. The ground beneath trees and shrubs is often protected from dew and frost when these form freely upon the unprotected ground. A cloudy sky, by checking radiation, prevents excessive cooling and hinders the formation of dew or frost. Likewise wind, by constantly changing the layer of air next to cold surfaces, hinders cooling and condensation. It is rare to have frost or dew on cloudy or windy nights.

It is a commonly recognized fact among dwellers in the country that clearing skies, and the " laying " of the wind toward nightfall, may bring frost at those seasons when early planted or late maturing crops would be injured by it.

Many orchardists protect their trees from frost by building *smudges* among the trees. The smoke cloud thus produced,

hanging above the orchard, checks radiation as a blanket would, and thus often prevents frost.

When condensation begins, the liberation of latent heat tends to check further cooling; so if saturation occurs much above freezing, frost is unlikely because freezing temperatures are not apt to be reached.

Housewives often protect their flowers from frost, on cold nights, by exposing shallow pans of water in the warm room with

FIG. 58.—CIRRUS CLOUD

the plants, and thus greatly increasing the humidity. When the room cools saturation will be reached at a temperature well above freezing; and the liberated latent heat, as condensation goes on, may suffice to keep the temperature above freezing. In a few cases this principle has been applied on a large scale for the protection of orchards.

Clouds.—When the vapor in the air is condensed above the surface of the ground, into particles of water or ice so small that they remain suspended in the air, the product of condensation is called *cloud*.

If the cloud is so low that it reaches the land or water it is called *fog*.

Clouds are classified chiefly by their form. The thin, feathery, white clouds, seen high in the air, and frequently on fair days, are *cirrus* clouds. These filmy clouds are, for the most part, composed of ice spicules, and are the highest clouds. Their average summer altitude is about 6 miles; and they generally move east-

FIG. 59.—CUMULUS CLOUD

ward at the rate of about 60 miles an hour. In winter their average height is about 5 miles, and their eastward motion is about 100 miles an hour.

Cirrus clouds are often precursors of storms, being the high-level overflow in front of the cyclone center.

Cumulus clouds are the massive piles of cloud, with an even base, and resembling piled-up fleeces of wool, or volumes of condensed steam and smoke from a locomotive. They are the result of rising currents of air, usually of convectional origin, and are, therefore, storm clouds. They are sometimes called *thunder-heads,*

and are land clouds rather than sea clouds, day rather than night clouds, and are more commonly in motion than at rest.

The average summer height of cumulus clouds exceeds a mile, whereas their winter height is somewhat less; and their summer and winter velocities are about 6 and 9 miles an hour respectively. Their even bases are usually from one-fourth to one-half mile high.

Nimbus is the name given to any cloud from which rain or snow falls or may be expected to fall. These clouds are of very variable height, being, on the whole, higher in summer than in winter. Their height decreases toward the poles.

Nimbus clouds are of an even grayish tint, sometimes completely overcasting the skies for hours and even for days continuously.

Stratus is any low-lying cloud spread out in parallel sheets or bands. It is a night rather than a day cloud, and more common over the sea and in valleys than over the higher lands. It includes fogs. The bands of clouds seen at higher levels may be designated by such compound names as *cirro-stratus* and *cumulo-stratus*.

Fog is the cloudy condensation near, or resting on, the land or sea. It usually results from warm, humid air passing over cold surfaces. In winter, winds blowing from the sea upon land are apt to produce fogs. An east wind upon eastern coasts, and a west wind upon western coasts are the chief sources of fogs.

Fogs are more frequent in valleys than on the slopes or tops of hills and mountains. The cooler, heavier air accumulates in the valley, where there is likewise more moisture; and these two conditions combine to produce the fogs in valleys and lowlands.

The fogs of Newfoundland are known to all navigators of the North Atlantic. The warm and cold ocean currents or drifts which meet there are accountable for the fogs. When the winds are from an easterly quarter their temperatures are lowered and their moisture condensed as they pass over the cold *Labrador current* to the west. Another cause of much of the Newfoundland fog is the ice brought down from the Arctic regions by the Labrador current. These icebergs are apt to be centers of dense fogs, especially in summer.

The fogginess of great cities, as London, and particularly of

manufacturing cities, is greatly increased by reason of the particles of soot issuing from chimneys. Each soot particle is a center of cooling and condensation.

Rain and Snow.—When condensation takes place in the air, and the condensed particles become heavy enough to sink through the air, the process is called *precipitation*. If saturation occurs above

Fig. 60.—VALLEY FOG

freezing, the product is *rain;* if below freezing, *snow.* As in the production of frost, so in snow, the water vapor passes at once from the vapor condition to the solid. Rain and snow bear the same relation to each other as do dew and frost. *Snow is not frozen rain.*

Although clouds almost invariably precede rain and snow, precipitation *without* clouds may occur. Such cloudless rain, usually in very fine drops, and more resembling mist, is called *serein.*

Snowflakes are *crystallized water vapor*, and are built up on patterns resembling beautiful six-rayed stars. The size of the flake as well as the exact pattern seems to depend upon the temperature at which the flake is formed.

In all latitudes an altitude may be reached at and above which

the precipitation, even in summer, is chiefly in the form of snow. At a slightly lower level more snow falls than melts during the year, with the result that there is perennial snow. The lower limit of perennial snow is known as the *snow line*. It is about 16,000 feet above the sea at the equator, and descends gradually toward the poles, reaching sea level within the polar circles.

Sleet and Hail.—If raindrops pass through increasingly colder air in their fall, and are frozen into small pellets of ice, the product is *sleet*. As this arrangement of temperature is most apt to occur in winter, when the land is colder than the lower air above it, sleet is a winter phenomenon. *Sleet is frozen rain.*

In summer, especially on hot afternoons, and near the center of a cyclonic storm, large pellets of ice called *hail* often fall. Upon examination hailstones prove to be made of concentric layers of ice. This structure, together with their often great size, suggests that they are frozen raindrops enlarged by successive condensations and freezings upon their surfaces. Their often spongy texture indicates that snow may also enter into their composition. Hail is chiefly a summer phenomenon.

Hail storms are sometimes very destructive. Their paths are usually only a few miles in width, and fortunately not of great length; for often growing crops, orchards, and even forests are destroyed. Leaves, bark, and branches are stripped from trees; young animals are killed, and windows and roofs broken by the hailstones.

It has been suggested that hail is rain frozen by being carried in strong ascending currents to higher, freezing altitudes. The occurrence of hail near the storm center, where the convectional ascent is strongest, supports this claim.

It is also suggested that the meeting of cold and warm masses of air may result in *horizontal stratification*, warm and freezing layers alternating; and that raindrops formed near the top of such a stratified cloud are *frozen and enlarged in passing through it*. The addition of snowflakes, formed in the colder layers of the cloud, would explain both their sponginess and size. Hailstones more than nine inches around have been reported.
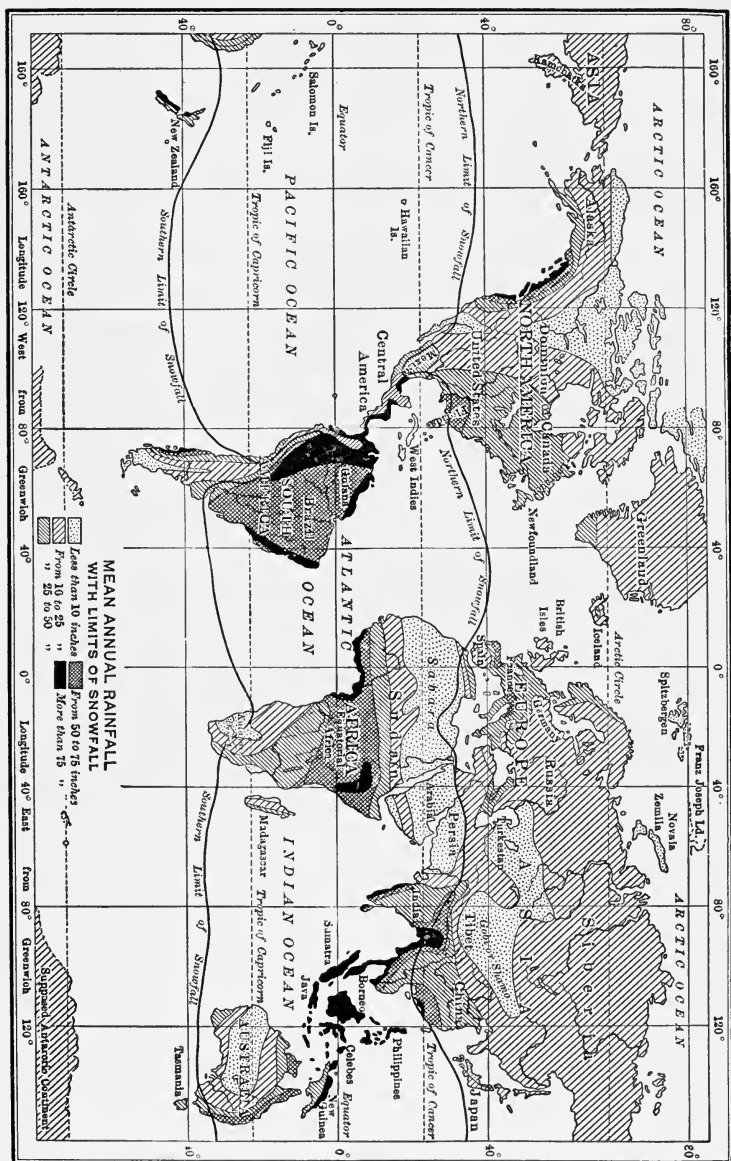
FIG. 61.—MAP OF WORLD, SHOWING MEAN ANNUAL RAINFALL

MEAN ANNUAL RAINFALL
WITH LIMITS
OF SNOWFALL

Less than 10 inches
From 10 to 25   ,,
,,   25 to 50   ,,
From 50 to 75 inches
More than 75 ,,

Sheet-Ice.—Sometimes, in winter, rain falls, but immediately upon touching the ground or trees it is changed into ice. This occurs when the lower air is just above the freezing point, while the ground and all solid objects near it, being better radiators, have cooled to a temperature below freezing. This is called *sheet-ice.*

During such ice storms ice encases the twigs and boughs of trees and shrubs; and sometimes the weight of ice is sufficient to break the branches. Such storms are especially destructive if strong winds occur before the ice disappears. Telephone and telegraph lines are often broken down.

QUESTIONS

1. Precipitation increases for a time, then decreases with increase of altitude upon the slopes of most mountains; give reasons.

2. Why is it that if we determine the humidity of the air when it is raining we rarely find the air saturated?

3. The relative humidity decreases, usually, as the day advances, until 1 or 2 o'clock; explain. Does the absolute humidity decrease in the same way?

4. Why is the relative humidity of the air 10 feet above the ground usually higher at night and lower during the day than that of the air 100 feet above the ground?

5. Why is the absolute humidity greater over, and near, the sea than inland?

6. Why does one become so much more quickly chilled in a wet garment than in a dry one?

7. Why, in winter, does frost form on the window panes of an occupied room, but does not, if the chamber is unoccupied? Why will thorough ventilation of the occupied room prevent such formation?

8. Why do fogs form over lakes before they form over the surrounding lands? How are such fogs dissipated as the day advances?

9. Rain may often be seen falling from clouds, yet not reaching the ground; what becomes of it?

10. Why is there no distinctly wet or dry coast under the equator?

CHAPTER XII

LIGHT AND ELECTRICITY OF THE AIR

Introduction.—We see the sun at rising as a golden sphere, at mid-day a globe of dazzling white, and at setting, if the air is dusty, it may disappear below the horizon as a ball of fiery red. As we ascend the mountain slope the noon-day sun takes on a bluish tinge; and we are told that balloonists, in their highest ascents, see a distinctly blue sun.

The ever-changing color of the sun, as it mounts toward the zenith, or shines through clear or cloudy air, is the result of the irregular *reflection* of the light. White light is composed of many colors, each having its distinct length of *ether* wave, and because of these different wave lengths white light may be separated into its component colors. The shortest waves are blue, and like ripples upon water are easily turned aside by obstacles in their path; the longest visible rays are red, and these, like the great waves of the sea, pass by obstacles which send back shorter waves. Hence it follows that an object may appear one color by *reflected* light, and quite a different color by *transmitted* light.

A glass of soapy water, viewed from above, looks *bluish* white, but when the sun is seen *through* the water its color is *red* or *reddish yellow*. The short blue waves are turned back, whereas the longer reds pass by the minute solid particles in the water.

Color of the Sky.—The dust and cloud particles in the air reflect the shorter waves, and transmit the longer; and the freer the air from dust and cloud, the more completely do light waves of all lengths pass through it. To an observer looking toward the sun the irregularly reflected or *diffused* light is lost, and only the longer waves reach the eye. If the shortest blues alone are scattered, as when the air is moderately clear, the combination of the remaining

colors gives the sun a yellowish tinge; but if the light passes through a very dusty air, or through a considerable thickness of cloud, the sun takes on a distinctly reddish tinge.

If the eye is turned away from the sun the *diffused* light is received; and as the blue rays are in excess in diffused light, the *sky* appears blue. The less the admixture of other colors with the blue the deeper the blue; and for this reason the sky, as seen from a balloon or mountain top, above the dust-laden stratum of air, appears intensely blue.

If the air is very dusty many other colors are diffused with the blue, and the sky assumes a whitish glare. The sky is bluer at sea, and after a rain, because the air is freer from dust. It is believed that if we were to rise above all the dust and cloud particles the sky would have the blackness of night; and the stars would shine as brilliantly by day as by night.

Refraction in the Air.—As a ray of light is bent in passing obliquely from one medium to another of different density, so all the sun's rays are bent in passing through the atmosphere, excepting only the vertical ray. This bending, called refraction, increases with increasing obliquity of the ray, being greatest when the sun is on the horizon, and least when on the meridian of a place. At sunrise and sunset it is sufficient to displace the sun the width of its disc; and as its effect is always to *increase* the *altitude* of the sun, the entire disc of the sun appears to be above the horizon when in reality below it.

The effect of refraction is to increase the length of the day in all latitudes. While this increase amounts to only a few minutes at the equator, at the poles it amounts to about four days. At the time of the equinoxes the sun is wholly above the horizon at *both* poles. The day at *each* pole is thus lengthened by about four days, the polar night being shortened by this amount. Another effect of refraction is to give the sun, at rising, an elliptical appearance, flattened vertically.

Looming.—Normally the air is densest at the bottom, becoming rarer with increase of altitude. Sometimes the lower air, for a thickness of a few feet, is abnormally cooled and denser than the air ten or twenty feet

higher. This is apt to occur in the early morning in summer, particularly over the land, owing to the rapid radiation of the land at night, and the cooling of the air near it.

Rays of light coming from an object that rises *above* the cooled stratum of air to an observer *within* it are bent *downward;* and the object is seen as occupying a position higher than is real. Sometimes objects appear suspended in air, in their normal upright position; but more often they are merely elongated upward. This is *looming*.
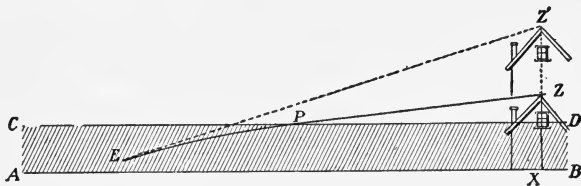
FIG. 62.—LOOMING

In Fig. 62 above the surface *A B* the air to the height of *C D* is abnormally cooled; coldest at the bottom, and becoming warmer and rarer above *C D*. From the object *X Z* which rises above *C D* rays come to the observer at *E*, within the denser layer of air. These rays are bent downward upon entering the denser layer, making the part of the object above *C D* appear to occupy a higher position. If the object is distant, only the upper part is seen; but as the object is approached it descends, until finally seen as an elongation of *X Z*.

Looming is an early morning or winter phenomenon, and ships at sea are often discovered while yet below the observer's horizon.

Total Reflection.—When a ray of light passes obliquely from a denser to a rarer medium, the ray is bent *away* from a perpendicular to the surface of the media at the point of passage. There is an angle of obliquity, varying with the densities, beyond which the ray will not pass from the denser to the rarer medium, but will be *totally reflected* from this surface back into the denser medium. This angle is called the *critical angle*, and this phenomenon is known as *total reflection*.

Mirage.—The interesting phenomenon of *mirage* depends upon the principle of total reflection in the air. Often in deserts or upon arid plains, during a hot summer day, the air resting upon the land becomes greatly heated, and rarer than the air above. If the day is calm, considerable difference in density may be developed before convectional motion sets up. When this condition of things exists, travelers often see distant objects reflected as from a water surface. In reality the reflection is from the upper surface of the rare stratum of air.

In Fig. 63, *C D* is the upper surface of a thin, rare layer of air overly-

ing *A B*, and distinctly rarer than the air above. A distant object, as *X Z*, rises above *C D*. The angle at which the rays from the object strike the surface *C D* is greater than the critical angle, and the rays are totally reflected. The object is then seen as in the position *X Z'*, as reflected from a water surface. The object and its image are both seen.

This species of mirage is peculiarly a land phenomenon, and is seen in hot weather, and oftenest in low latitudes.
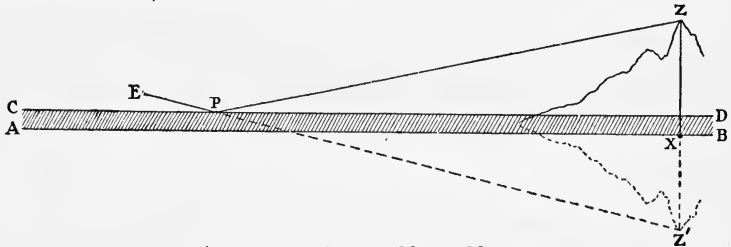
FIG. 63.—HOT WEATHER, MIDDAY MIRAGE

Another species of mirage is seen over the sea as well as upon land, occurring in winter, and most frequently in high latitudes.

In Fig. 64 the air up to the height of *C D* is distinctly colder and denser than the air above *C D*. This dense stratum is of such thickness that a vessel or city may be wholly immersed in it. Rays from the distant object strike the under surface of the rare overlying layer at such an angle that they are totally reflected to the observer at *E*. He thus sees the reflection of the object in the inverted position shown, *above* its *real* position.

The city of Baton Rouge, Louisiana, was thus seen by observers thirty miles away; and travelers in Arctic waters frequently report seeing vessels thus inverted and suspended in air. This usually occurs near the land, and is due to an outrush of cold air from the snow-covered land over the adjacent sea. Being heavier, it underruns the less dense air.

Halos.—Sometimes, in front of a cyclone, when the cirrus clouds that outrun and foretell the coming storm stretch across the sky, light or colored rings are seen encircling the sun. These rings, of varying diameter, are called *halos*. They are believed to result from *refraction* and *reflection* of light, by the ice crystals that make up the cirrus cloud; or *diffraction* by these crystals, or by the dust and cloud-mist at lower levels. If the cloud sheet is thick the rings are nearer the sun. Similar rings and luminous areas are observed about the moon.

Sometimes a more complex system of intersecting rings occur, which, though too dim to be seen throughout their whole extent, are visible at their points of intersection or tangency, where they appear as bright or

colored spots. These spots are systematically arranged with reference to the sun, and are known as *mock suns* or *sun dogs*.

Halos and mock suns are commonly thought to portend coming storms. They are particularly bright and their occurrence frequent in high latitudes.
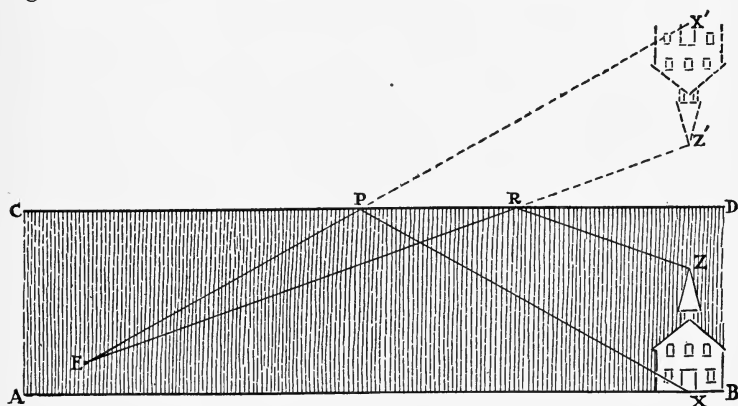
FIG. 64.—COLD WEATHER, EARLY MORNING MIRAGE

The illuminated areas encircling street lamps on foggy or misty nights are analogous to the halo, as are also the brilliant borders of dense cloud masses lying between the observer and the sun.

The Rainbow.—If an observer stands with his back to the sun while rain is falling in front of him, there often appears the arc of a circle, made up of parallel bands of colored light, called the *rainbow*. It results from *refraction* and *reflection* of light by the raindrops.

By refraction and dispersion the white light is decomposed into its constituent colors. Red, being the least refracted, lies upon the outer side of the bow, while blue, being most refracted, occupies the inner side. The angle formed by drawing lines from the eye to the ends of the bow's diameter is usually about 82 degrees, and the center of the bow lies upon the straight line passing through the sun's center and the observer's eye. On this account the bow is usually less than a half circle, unless seen from some high point, as a mountain peak.

Though commonly a daytime phenomenon, rainbows are sometimes produced by moonlight.

Colored bows, and even complete circles, analogous to rainbows may be observed in the spray of fountains and waterfalls.

If favorably situated, with a sheet of calm water at his back, one may see two distinct and intersecting bows, the shorter produced by the direct rays from the sun, the longer by rays reflected from the water surface.

A less distinct *secondary* bow, outside the more brilliant one, and with the order of the colors reversed, is sometimes seen. This bow is usually more than 100 degrees in diameter.

The *primary* bow is thought to result from rays of light entering near the side of the drop, being refracted upon entering, totally reflected from the back surface of the drop, and again refracted upon leaving the drop. This disperses the colors, so that we receive but one color from any drop. The red is given by drops farther away from the line passing through the sun and the observer's eye than the drops that produce the blue; hence the red is on the outside of the bow. Since all drops which send a given color to the eye lie at the same angular distance from this line, it follows that the bands of color and the entire rainbow are arcs of circles, whose center lies upon this line.

The *secondary* bow is thought to be produced by raindrops which receive the rays in such a way that they are *twice reflected* within the drop before leaving it. This double reflection accounts at the same time for the dimness of the bow, its greater diameter, and the reversal of the order of the colors from that of the primary bow.

Lightning.—Every year records a considerable loss of life and property in the United States from *lightning*. Men and animals are killed, trees and houses shattered and often set on fire, and hay and grain stacks burned. Lightning storms, commonly called "thunderstorms," are usually associated with an overheated condition of the air, locally, and are most common in the afternoon of hot summer days. They occur not infrequently at night, and may even occur in winter; but their cause seems always to be found in a rapid convectional overturning of the lower air.

The air is always electrified, but it is only when clouds are forming rapidly, as in the ascending currents near some storm center, that discharge takes place. This discharge, known as the *lightning flash*, may be between clouds, or it may be from cloud to earth. When downward those objects which rise highest, as buildings and trees, are most in danger of being struck by lightning, these being better *conductors* than air.
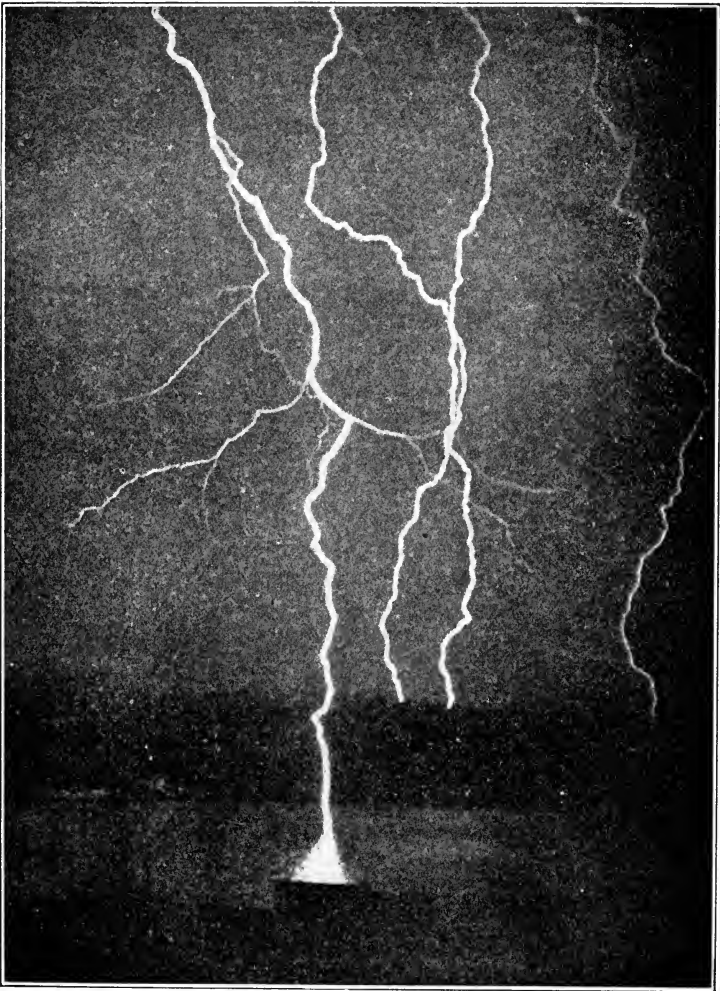
FIG. 65.—PHOTOGRAPH OF LIGHTNING FLASH

In those sections of the country where wire fences are extensively used great numbers of stock are annually killed by lightning, from collecting near these fences during thunderstorms.

The wire serves as a conductor of the lightning horizontally, often for considerable distances, being finally led to the ground by the fence posts, which are thereby shattered. Telegraph and telephone poles are shattered in a similar fashion. The belief that " lightning does not strike twice in the same place " is a dangerous error. The fact that lightning strikes in any given place argues the existence there of *favorable* conditions.

Protection from Lightning.—The fear of lightning, and the desire for immunity from it, have led to the adoption of many protective measures. Perhaps the most common artificial protection is the *lightning rod*.

As all solids are better *conductors* of electricity than the air, buildings and trees are more often struck by lightning than the open surface of the ground near them. The greater the number of buildings or trees among which the discharge may be divided, the less the individual liability. On this account a house in the city has greater immunity from lightning than the isolated farm house; and any tree in the forest is safer than the "lone tree" upon the prairie.

Where country houses are surrounded by shade trees these offer perhaps the best protection from lightning. Each individual tree becomes a means for *silently* discharging the passing clouds of their electricity, thus preventing heavy and destructive discharges.

The lightning rod, as a protection against lightning, has been in use almost ever since the discovery of the nature of lightning. Its use is based on the theory that metal, being a better conductor of electricity than the building, by affording an easier route, will prevent the discharge from passing to the building itself. It is also thought that the numerous points which rise above the building may quietly drain away the electric charge from the clouds, and thus prevent a *destructive* discharge.

The lightning rod consists, usually, of a metal ribbon or flattened tube, commonly of copper or galvanized iron, laid over the roof of the building, with frequent branches rising from six to ten feet in air. These branches end in one or more sharp points; and the rod should extend sufficiently deep into the ground to reach moist earth. If it ends in a cistern of water so much the better. The greater the number of branches rising above the building the better, as the discharge is thereby more divided.

Perhaps the greatest security from lightning is obtained by encasing the structure in a network of wire.

Kinds of Lightning.—*Zigzag* lightning is a very common form. The course of the flash is probably a sinuous one, and only appears angular

when seen along the direction of its path. *Ramified* or *branching* lightning may begin and end in a multitude of branches, uniting in a trunk flash between. This kind of flash takes place between clouds. *Heat* lightning, and *sheet* lightning, probably the same, are believed to be the illumination of cloud masses so far away that the accompanying *thunder* is not heard. *St. Elmo's Fire* is the name given to the discharge of
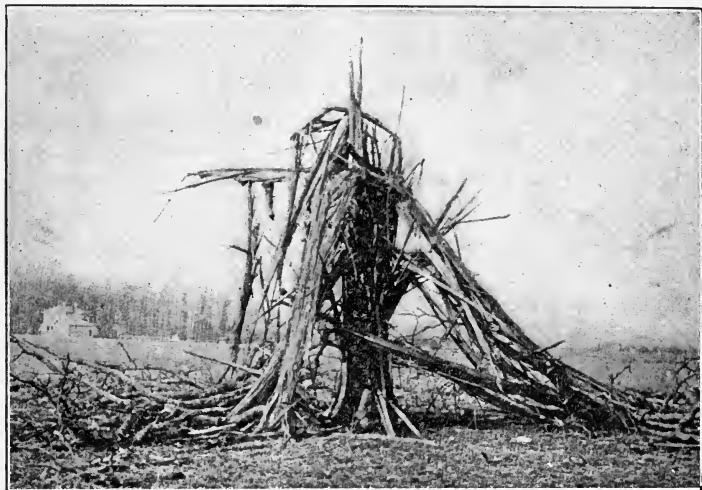
FIG. 66.—TREE DESTROYED BY LIGHTNING

atmospheric electricity as a brush of bluish flame, often observed at the ends of masts and spars of ships, at tree-tops, or house-tops, or any pointed object. A crackling sound accompanies it, similar to that of the artificially produced electric spark.

Thunder.—The production of thunder may be likened to the production of the noise accompanying the explosion of gunpowder. Along the path of the lightning flash the air is intensely heated and pushed away. The collision of the returning air particles, causing but a crackling, of high pitch, in the case of a few short sparks, becomes a crash of lower pitch in the case of a lightning flash, which is but a great number of longer sparks. The quick succession of crashes following along the path of the flash unite to produce the roar; and the roar, when echoed and re-echoed from cloud masses, gives the *rolling* so often observed to follow brilliant flashes of lightning during thunderstorms.

Relation of Lightning to Rain.—The condensation of the moisture in the air forms cloud particles, and the clumping of these particles, by

reason of their mutual attraction, forms raindrops. With increase in size of the raindrops the electric charge of the drop is increased, and lightning discharge is made possible.

It would seem that lightning, for the most part, precedes the rain. When the raindrops begin to fall each carries down with it a minute charge, and in this way the cloud mass is discharged. Further production of lightning is then impossible. The heaviest fall of rain in a thunder shower often follows closely the most brilliant lightning and heaviest thunder. So while lightning mainly precedes the rain, it seems probable that they are mutually cause and effect.

The Aurora.—This is the beautiful electrical display, common in high latitudes, though often seen in northern United States. In the northern hemisphere it is called *Aurora Borealis*, and in the southern, *Aurora Australis*. It is believed to be due to the discharge of electricity into the rare upper air, and seems to bear some relation to *sun spots*. The Aurora lessens the gloom of the long polar night.

As seen in the United States the Aurora, also called *Northern Lights*, usually consists of a more or less distinct arch of light, extending east and west, and crossed at right angles by streamers of colored light which radiate from a point in the northern horizon. The arch is highest above the *magnetic meridian;* and the streamers of red, yellow and green light change their position and length, and are called "the merry dancers."

Brilliant aurora displays are often accompanied by severe electrical and magnetic disturbances throughout the country. The telegraph and telephone services are often interrupted for hours; and the magnetic compass sometimes becomes so variable as to be useless.

QUESTIONS

1. Why do we not ordinarily observe the phenomenon of "looming" at midday?

2. Would the phenomenon of "looming" be dispelled by ascending into the air?

3. In the mirage resulting from the lower air being cooler than that above, need the object, the image of which is seen, be visible?

4. It is a common notion that the greater the number of stars visible within the halo rings about the moon, the greater the number of days before the storm, which these rings presage, will arrive; what scientific grounds exist for this belief?

5. How did Franklin discover the identity of lightning with the artificial electric spark?

6. Why should we avoid the shelter of tall trees in a thunderstorm? Why do we disconnect our telephones during thunderstorms?

WEATHER AND CLIMATE

Weather and Climate Defined.—*Weather* is the condition of the air at a given time and place with reference to temperature, moisture, state of the sky, and winds. These conditions, called *weather elements*, are constantly changing; and as a consequence, for most places in temperate latitudes, the weather is proverbially fickle.

As the day advances, after sunrise, the temperature normally rises, reaching its maximum between one and three o'clock P. M., after which it falls till near sunrise the following day. With these changes in temperature come changes in the relative humidity, and usually changes in wind direction and strength.

Climate is the *average* condition of the air with reference to temperature, moisture, state of the sky, and winds; or it is *average* weather. While in weather we consider current temperatures, in climate maximum and minimum temperatures are of more importance.

We use the term weather in referring to atmospheric conditions at any given instant; also for such short periods as a day, a week, or a month. We even speak of " summer " or " winter " weather; but when we apply the term to these longer periods we refer rather to the *average* conditions during these periods.

Pressure, though exercising a controlling influence upon weather elements, is not itself commonly counted among them.

Weather Changes.—Although the variability of the weather is proverbial, yet there are important controls, which, by reason of their orderly sequence, give a certain degree of system to the succession of weather changes. The most important of these are:

1. The alternation of day and night, due to rotation;

2. The annual succession of winter and summer, due to revolution;

3. The more or less systematic passage of lows and highs.

The first two are fairly regular in period and value at any place, though widely differing for different places; whereas the third varies in both period and intensity.

The daily and annual changes of the weather are more pronounced near sea level than at higher altitudes, in the interior of the continent than near the coast, and in high than in low latitudes. As a rule the temperature rises and the absolute humidity increases during the day and in summer, both being lower at night and in winter.

Convectional cyclones are more frequent over the land than over water, and more vigorous in summer than in winter and in the daytime than at night; whereas non-convectional cyclones are most frequent and intense in winter. Both classes of cyclone are probably more highly developed, and likewise of longer duration, over the sea than over the land.

In the United States during March and April, when the land is warming up most rapidiy, it is a common occurrence to have days of blustery winds succeeded by nights of calm. This is due to the rapid warming and convectional overturning of the lower air during the day.

Weather in the Tropics.—Night has been called the " winter of the tropics." This is because the variation in weather conditions from day to night is greater than from winter to summer.

In the *doldrum* belt the days are uniformly warm, owing to the nearly vertical rays of the sun; and the rapid convectional ascent of the air in the morning is usually followed later in the afternoon by torrential downpours of rain, followed in turn by cloudless nights. The nearly equal day and night, combined with the low percentage of cloudiness, accounts for the great daily range of temperature. Cyclonic interruptions are of secondary importance.

In the *trade-wind* belts, over the sea, there is a constancy of weather conditions not found elsewhere. The extreme range of temperature scarcely exceeds ten degrees; and the wind blows continuously from the same direction, and with about the same strength day and night. On land the range of temperature in-

creases, and over both land and sea there is little rainfall, except where the winds are compelled to rise over the ascending land. This is due to the fact that the trades grow warmer as they advance.

Regions on the borders of the trades have monsoon changes of weather. If next the doldrums, there is the alternation of the light winds and abundant rains of the doldrums, and the constant winds and light rains of the trades. If next the high pressure calms, then the characteristic conditions of the trades alternate with the prevailing calms of the horse latitudes.

Weather Outside the Tropics.—In the zone of *prevailing westerlies* weather changes are irregular, and mainly of cyclonic control, with marked differences in the two hemispheres. In the southern hemisphere, where there is little land to interrupt them, the westerlies attain a constancy approaching that of the trades; and so high a velocity that they are called the " Roaring Forties." In winter the cyclones are more frequent and succeed each other with almost periodic regularity.

In the northern hemisphere, where the land is massed, there is a strong contrast between the weather of the land and water areas of the prevailing westerlies, the land areas having much greater extremes of weather conditions, both daily and seasonal.

In the *frigid* regions, although temperature changes are determined chiefly by the appearance and disappearance of the sun, the other weather elements are controlled mainly by the passage of cyclones.

Weather Prediction.—After a thorough understanding of the relative values of the factors determining weather in any region it is possible to predict, with a high degree of accuracy, the changes of weather likely to occur. The degree of accuracy attainable varies with the season and with geographic position. Under the doldrums and trade winds, where the diurnal change is dominant, weather prediction may be made with an assurance almost amounting to a certainty that it will be fulfilled. Indeed, the weather changes there are so regular and certain that the weather is not a topic of conversation.

In regions where the control of the weather is mainly cyclonic, it is not possible to predict with nearly so high a degree of accuracy. Yet even here the relative values of the factors are so well known, and the systematic movement of cyclonic disturbances so well understood, that predictions may be made with the reasonable expectation that a large per cent of them will be fulfilled. These predictions for any station must take account of: (1) The systematic movement of cyclonic disturbances, their strength of development and place of origin, and direction and rate of movement; (2) The season; and (3) Local topography.

Weather in the Cyclone.—To understand the weather conditions which prevail about lows and highs it is necessary to remember the directions of the winds about these disturbances, and the effect upon the humidity of the air resulting from a change of temperature.

In the United States cyclones, as we have seen, move eastward, and the winds blow in toward the cyclonic center, in counter-clockwise spirals. At any station the wind will not, as a rule, be blowing *directly toward* the center, but a little to the *right of it.* Therefore, in front of the cyclone the winds are blowing from a warmer to a cooler latitude, and their relative humidity is increased. As they approach the center of the low the air rises, and its humidity is further increased by cooling from expansion. This may be sufficient to bring the air to saturation. As a result of these conditions *a rising temperature, with cloudiness or precipitation,* generally characterizes the front of the low, and may be predicted as a well-developed cyclone approaches.

In the rear of the cyclone the winds are moving from colder into warmer regions, and as a result the relative humidity of the winds is lowered. As they near the center of low and begin to rise, their temperature falls as a result of expansion; but the cooling must first counteract the warming due to their moving into warmer latitudes before their relative humidity reaches that possessed by the winds when they were inaugurated.

As a result of this difference in conditions in front of and behind the cyclone the increase in humidity, due to ascent, may

bring the air in front of the cyclone's center to the saturation point, and yet not saturate the less humid air in its rear.

Consequently *falling temperatures and clearing skies* may be expected after the center of a well-developed cyclone passes.

The direction of the shifting of the wind depends, as we have seen, upon the position of the path of the cyclone's center, whether
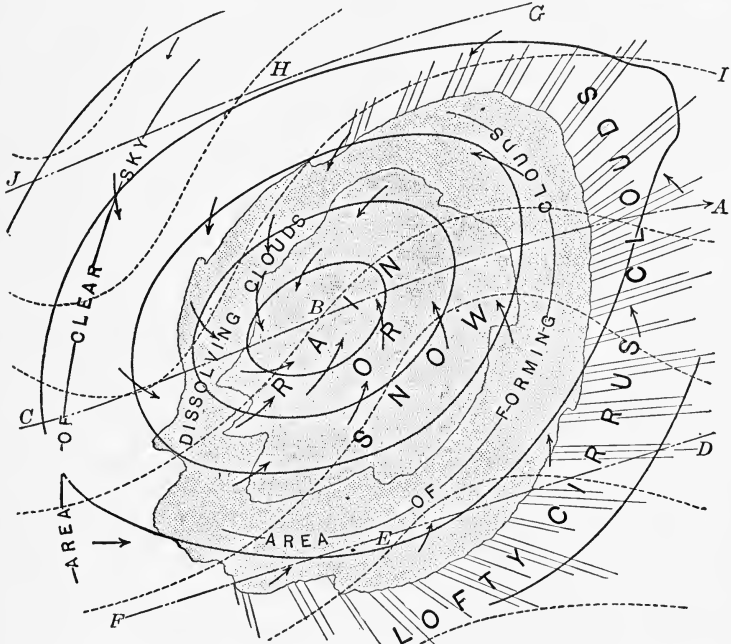
FIG. 67.—An Ideal Low, Showing the Distribution of the Weather Elements About Its Center. (After Davis)

D E F, A B C, and G H J are paths of observers through the storm area where the storm passes north, centrally over or south of the observer respectively. Note the succession of winds each will experience, also the probability of precipitation for each. Observe that the southerly winds in front, and the northerly winds behind the storm center, give the isotherms a general north-east-south-west trend, and the observer will not experience a very severe change of temperature. If the storm passes centrally over him he will experience a lull in the wind near the center, after which the wind springs up from the opposite direction and increases in strength.

north or south of the station. Ordinarily the *strength* of the wind increases as the cyclone approaches, and decreases as the cyclone recedes.

In winter the strong indraft of cold air in the rear of a cyclone, if accompanied by snow, is known as a *blizzard.*

Weather in the Anti-Cyclone.—Since the movements of the air about a high are the reverse of its movements about a low, it follows that the conditions as regards temperature and humidity which prevail about a high are likewise the reverse of those which prevail about a low. In front of a high the winds are northerly, and behind a high the winds are from some southerly quarter, while at the center of the high the air is sinking. Consequently fair and cooler weather is predicted, usually, as the high approaches, and rising temperatures with possible cloudiness or even precipitation as the high recedes.

Since the winds *start* from the center of the high, unlike the low, the winds *weaken* as the high approaches, and *strengthen* as it recedes. As with the low, the direction of the shifting of the wind is determined by the position of the station with reference to the path of the center of the high.

In winter, if a high follows closely in the wake of a well-developed low, the fall in temperature may be abnormal. If it is as much as 20 degrees F. in 24 hours, reaching a temperature of zero or lower, it is called a *cold wave.* In the southern part of the United States the term is applied to changes that are somewhat less than 20 degrees, and that reach a somewhat higher minimum.

Thunderstorms and Tornadoes.—In summer, after a day or so of excessive heat, the rapid convectional ascent of the air about a low may set up, locally, a more limited though more intense cyclonic whirl. The rapid condensation of vapor in the rising and cooling air may give rise to, or be accompanied by, brilliant displays of lightning and heavy thunder. Such storms are known as *thunderstorms*. Torrential downpours of rain may follow quickly after the most brilliant discharges of lightning; but it is a notable fact that the lightning flashes become rapidly less frequent after the rain begins to fall.

Thunderstorms are usually summer and day-time phenomena, though they sometimes occur in winter and at night. They are much more common in front of lows than behind them. In the

United States they occur most frequently in the southeastern quadrant of the low pressure area.

If the local whirl thus developed is destructive in violence, it is called a *tornado*. The destructive path of a tornado is rarely a mile in width, and usually but a few miles in length; more commonly it is but a few hundred yards in width. Within that narrow path the violence of the wind is such that few structures above ground are strong enough to withstand it. In those States in the Middle West, where tornadoes are most frequent, underground structures called " cyclone-cellars " are built. These seem to offer the greatest security from danger.

Tornadoes progress normally in a northeastern direction, at a rate of twenty or thirty miles an hour; whereas the spiraling winds about the tornado center may attain a velocity of more than one hundred miles an hour. Tornadoes are most frequent in the afternoon of hot summer days, and seem to need for their development a fairly *level land* surface; hence we do not have them in mountain regions, nor do they occur upon the Pacific coast. The broad, level Mississippi Valley seems best suited of all places in the United States for their development.

Weather Service.—For the purpose of a more thorough study of the weather, and more accurate prediction of weather changes, the United States Government has established a weather service extending to all settled parts of the country. This service, which is the work of the *Weather Bureau*, a division of the Department of Agriculture, has its central office in Washington, D. C. Its corps of observers, paid and voluntary, to the number of more than three thousand, are distributed throughout the country. Regular observations of the weather are made at more than two hundred stations, as nearly as possible at the same instant, 8 o'clock A. M. and P. M. 75th meridian time, and are reported by telegraph to the central office at Washington, and to each other. The most important observations are: *pressure; temperatures*, current, maximum and minimum; *direction* and *strength* of the *wind; amount* and *kind* of *precipitation* during the past 24 hours, and *percentage of cloudiness*.

Weather Maps.—When these data are collected and plotted on a map of the United States the result is a *weather map*. The daily weather map is published at the central office in Washington, and also at one or more sub-stations in every State. It not only sets forth the weather conditions existing at the time of observation, but it also serves as a basis of prediction of the weather for the
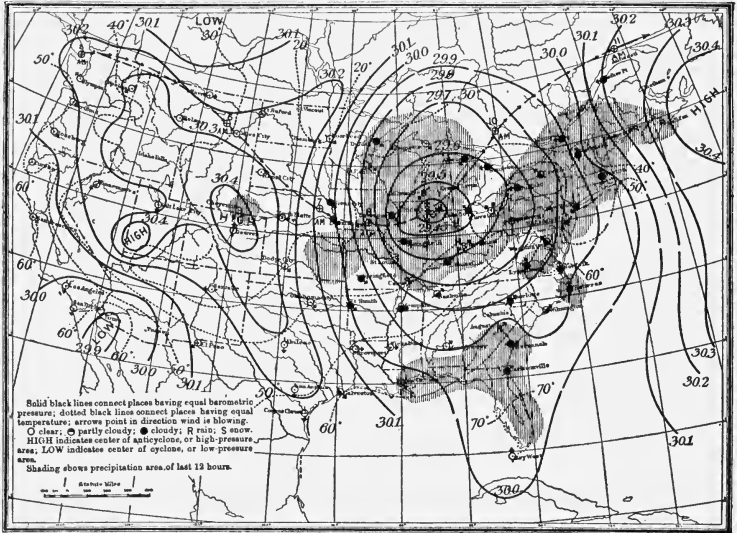
FIG. 68.—WEATHER MAP

Isotherms, dotted lines, drawn for every 10 degrees; and *isobars*, unbroken lines, drawn for every tenth of an inch. Line of arrows indicates the ordinary path across the U. S. of this type of low. Such lows usually advance at the rate of about 30 miles an hour.

24 or 36 hours following. Each local map supplements the general prediction for the entire country with a forecast for the particular locality.

To be of value for purposes of forecasting, weather maps must be distributed the day issued, since weather conditions are constantly changing.

Since our weather is mainly of cyclonic control, and since the cyclonic disturbances move eastward across the country, the weather map as a basis of weather prediction is of more value to the eastern than to the western part of the country. On the Pacific coast it is of little value,

since there are few stations further west to report coming changes. With further extension of wireless telegraphic service, the value of the weather service to our western coast will be correspondingly enhanced.

Value of Weather Predictions.—Every observer is familiar with the daily and seasonal changes of temperature; also with the fact that there are other almost equally important changes that are irregular in their occurrence. More and more people are learning to appreciate the relation of these unperiodic changes of the weather to the eastward march of cyclonic disturbances, and to appreciate the great value of our weather predictions. Each year brings a wider use of these predictions, and a more general rejection of the predictions of charlatans who make year-long forecasts.

Among the first to realize the benefits of our weather forecasts were the shipping interests of our southern and eastern coasts and of the Great Lakes. Not infrequently censuses have shown that marine property to the amount of more than $25,000,000 has been held in port because of storm warnings issued. Few masters of vessels now leave port without knowing the latest forecast of the weather.

Shippers of perishable goods are also interested in weather predictions. Estimates from shippers place the value of property saved by the warning of the *cold wave* of January 1st, 1898, at nearly $5,000,000. Farmers, planters, truck growers and fruit growers are interested in being forewarned of changes in the weather, especially when these changes mean destructive winds, floods or frosts. With the wide extension of the use of the telephone and of rural mail delivery is coming a wider use and appreciation in all fields of the great value of weather predictions.

It is our confident belief that with a more extended field of observation, and a better knowledge of upper air conditions, the present practical limit for safe predictions of 36 hours may be considerably increased. By means of kites and balloons the upper air is being explored.

Weather Signs and Proverbs.—There are two distinct classes of weather signs. The first are based on century-long observations by those whose occupations have led them to observe closely weather changes; the second class includes a mass of superstitions

that have been strangely preserved and transmitted. The signs of the first class have usually found expression in trite sayings that have come to be known as *weather proverbs*. As an aid to memory these proverbs are commonly expressed in rhyme.

Weather proverbs are usually of only local application, though many are world-wide. When local, in order to appreciate them, one must be acquainted with the local conditions.

"Rainbow in the morning, sailors' warning; Rainbow at night, sailors' delight," is a proverb that is true only in those regions where cyclonic storms move eastward. If the rainbow is seen in the morning, the storm center is apt to be westward, and its further progress will bring it nearer.

"Mackerel scales and mares' tails, Make lofty ships carry low sails," is applicable the world over. The long, wispy clouds called "mares' tails," and the sky flecked with cirro-cumulus clouds, and known as a "mackerel sky," are the result of the high-level overflow of air in front of a cyclone. Consequently they presage a *coming* storm. "Mist rising o'er the hill, Brings more water to the mill" the world over.

Climatic Controls.—Since climate is but average weather, those conditions which control weather likewise control climate. The most obvious, and perhaps the most important, climatic controls are: latitude, height above sea level, distance from the sea, position with reference to mountain ranges, and with reference to prevailing cyclonic paths.

Although climate is defined as the *average* condition of the air with reference to the various climatic elements, *it does not follow that where these averages are the same the climates are alike or even similar*.

New York City and San Francisco have about the same *average* temperature for the year, but New York has *hot summers* and *cold winters*, whereas San Francisco has *equable* temperatures throughout the year. The central Mississippi Valley has about the same *annual rainfall* as the coast of California; yet in the interior the rains are *distributed through the year*, while on the coast they are *confined to the winter months*.

Of vastly more importance than *averages* are the *extremes* of climatic conditions, and the distribution of these conditions through the year.
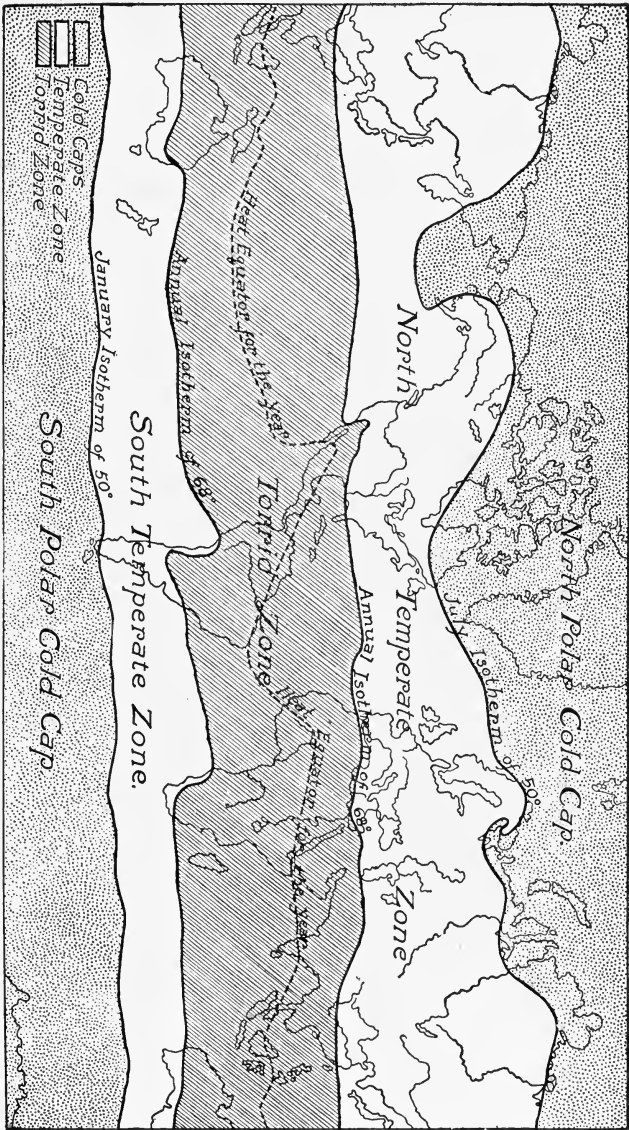
Fig. 69.—Climatic Zones

Note the widening of the temperate zone in the northern hemisphere over the continents and its narrowing over the oceans.

Climatic Zones.—Temperature being the most important climatic element, and depending, as it does, mainly upon latitude, the earth may be divided into east-west zones, each of which furnishes a distinct type of climate. Within any zone there may be considerable variation from the type, yet there is sufficient similarity to justify the division into zones.

The customary division, whereby the zones are bounded by parallels, gives us *light* zones rather than *climatic* zones; therefore, the Tropics and Polar Circles are not boundaries for torrid, temperate, and frigid climates. A more reasonable boundary is the *isotherm*. It has been suggested that the *average annual isotherm* of 68° F. be taken as the poleward boundary of the torrid zone, and the *summer isotherm* of 50° F. as the poleward boundary of the temperate zones.

The temperature of 68° F. is about the temperature we desire for our houses in winter, and the temperature necessary for so-called tropical plants; and a temperature of 50° F. is necessary for trees and for the maturing of the hardier cereals. *Warm temperatures during the growing season* are more important than *low temperatures during the dormant season.*

The temperate zone is the widest zone, and wider in the northern than in the southern hemisphere. This is due to the excess of land north of the equator, land being a better absorber of insolation than the sea. The frigid zones, or more accurately the *polar cold caps*, have a temperature, even in the hottest month, below 50° F.

The Torrid Zone.—As its name suggests, the most distinctive character of the *torrid* zone is its high temperatures. In every part, except where mountains rise into cold altitudes, the daily maximum is from 75° to 100° F., and often higher. But the other climatic elements vary so widely in this zone as to justify its division into three parts:

1. The *belt of doldrums or equatorial calms* is a belt of high temperature, light and variable winds, and abundant rainfall. The almost vertical rays of the sun heat up the lower air in the early forenoon and cause rapid convectional currents. These rise by noon to such altitudes that their cooling by expansion produces

condensation of their vapor, the formation of clouds, and in the early afternoon rain.   The rains are thus of almost daily occurrence and abundant throughout the year.   More abundant rainfall and a higher percentage of cloudiness are to be found over the sea than over the land, due to higher humidity over the sea.

The days vary little in length, and twilight and dawn are of short duration, owing to the nearly *perpendicular position of the sun-path to the horizon.*

In this belt occur the dense forests of South America, Africa, and the East Indies.

2. The *trades*, like the doldrums, have a prevailingly high temperature, but unlike the doldrums they have little rainfall.   Their most marked characteristic is the constancy of their winds.   These blow day and night, winter and summer, with a constancy of both direction and strength equaled in no other zone.   In the northern hemisphere they are northeast winds, and in the southern hemisphere southeast.   They run to the doldrum belt, where the air rises.

On land the climate of the trades depends upon the *direction of slope*, the eastward and westward slopes having unlike climates. The winds being forced up the eastward slopes may yield abundant rainfall, as upon the eastern coasts of Central America, Brazil, Africa and Australia; whereas the descending winds upon the westward slopes yield little or no rainfall, as shown by the dry western coasts of these countries.

The eastward and northeastward slopes of the mountainous islands of the West Indies and the Hawaiian group have abundant rainfall, and are heavily forested; whereas the southwestern slopes have deficient rainfall, and in some cases are almost desert.

Any low-lying land area, island or continent, under the trade winds, is apt to be desert because of its slight rainfall.   The great deserts of Africa and Australia are trade-wind deserts.   The winds moving toward the equator are *warmed*, and their capacity for water vapor is *increased*, consequently they not only yield little rainfall, but they also absorb the moisture of the regions over which they blow.
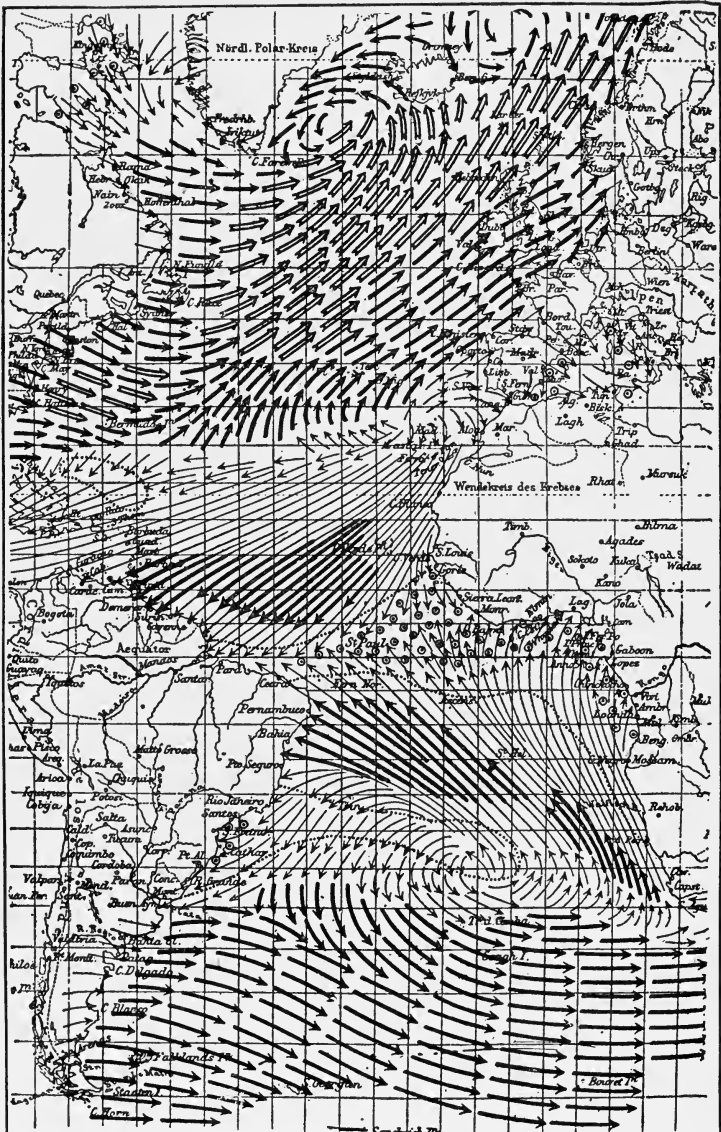
FIG. 70.—WINDS OF THE ATLANTIC OCEAN FOR JANUARY

Note the well-developed low pressure area over the northern ocean, and the equally well-developed high pressure area over the southern ocean. Account for this. Long arrows indicate *steady* winds, and heavy or double arrows indicate *strong* winds.
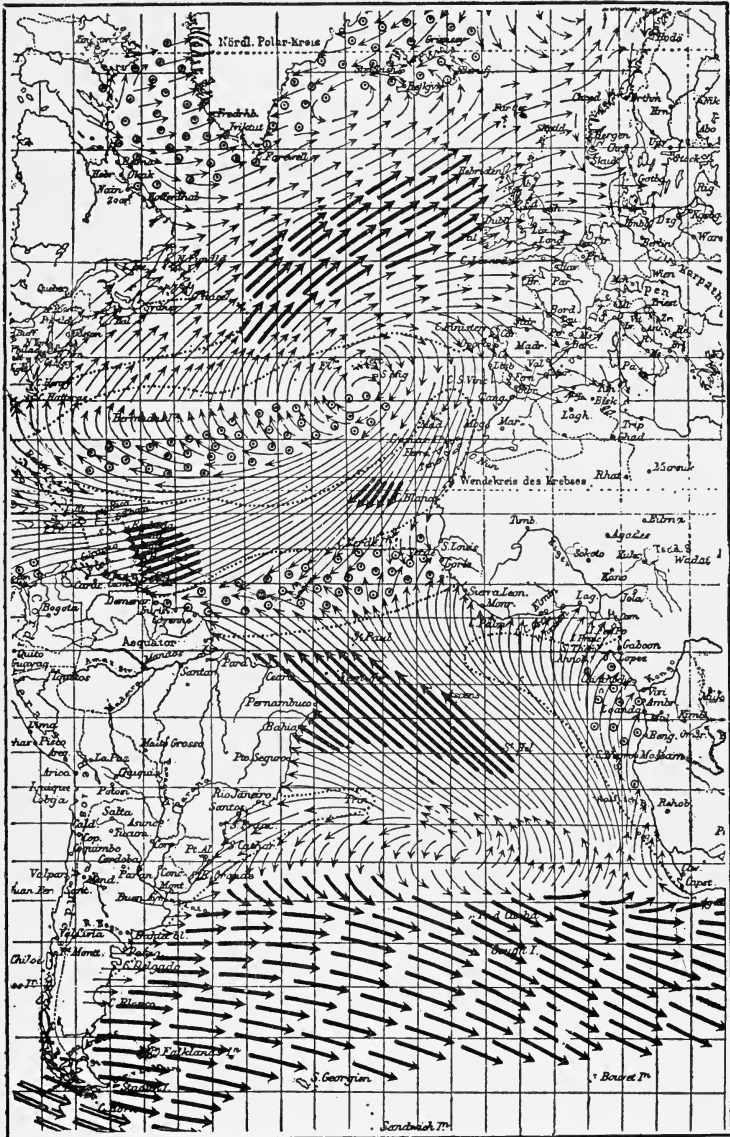
FIG. 71.—WINDS OF THE ATLANTIC OCEAN FOR JULY

Observe that the low in the northern ocean has disappeared and a well-developed high appears in the belt of horse latitudes. Find a reason for this. The high continues, though weakened, over the southern ocean.

3. With the shifting of the wind belts, regions near the border line of the doldrums and trades lie alternately under these belts. Such regions have seasonal changes of climate, and are known as *monsoon* belts. If near the equator they have *two distinct wet seasons*, when under the doldrums, and *two dry seasons* when under the trades.

While these transitional or monsoon belts extend around the earth, they are most pronounced where, as in India, the *monsoon* winds are reënforced by the *continental winds*, owing to the great continental mass lying poleward from them. When the *southwest monsoon* blows over India the "hooked" southeast trades are strengthened by the continental in-draft toward central Asia; and when the *northeast monsoon* blows, the normal northeast trades are strengthened by the outflow from the cold continent to the north. The southwest monsoon is much stronger than the northeast. Why?

Similar monsoon winds are observed upon the coasts of South America, Africa, and Australia.

The Temperate Zone.—Poleward from the torrid zone in each hemisphere lies the *temperate* zone. It comprises about one-half of the earth's surface, and shows the greatest variety and range of climatic conditions. Lying mainly under the westerlies, its weather and climate are mainly cyclonic in character, thus accounting for its variability of climate. To appreciate the climate of any part of this belt it is more necessary to know *extremes* than *averages*. In northeastern Siberia, for example, an extreme range of temperature during the year of over 200° F. occurs, the average temperature being about zero.

In general the variability of climate in the temperate zone is greater over the land than over the sea, and greater in the northern than in the southern hemisphere.

Divisions of the Temperate Zone.—On this account it is desirable to divide the temperate zones into:

1. Ocean and land areas;
2. Northern and southern belts;
3. Eastern coasts, interiors, and western coasts.

1. The *ocean areas* of this zone have smaller range of temperature, more rainfall and cloudiness, and stronger winds than the *land areas*. The oceans, being low pressure areas in winter, have their greatest rainfall at that season; whereas the continents, on the whole, receive their greatest amount of rain in summer.

2. Because of its large water area the climate of the *south temperate* belt is most equable of all the regions in the westerlies. The winds, toward its southern edge, have high velocity and blow with great regularity; and westward-bound ships around Cape Horn are delayed by these head winds.

The *north temperate* zone has a climate that has been likened to "A crazy quilt of patches," so changeable is it in its various parts. The excess of land with its varying altitudes, in this zone, breaks up whatever tendency there might be toward uniformity in climatic conditions.

3. The *eastern coasts*, though tempered by their adjacence to the sea, lying to leeward of the continents, partake of the variability of climate characteristic of the land. The succession of lows and highs that march eastward across the continents carry to the eastern coasts continental conditions. Winds and rains are the result of passing lows and highs; and rainfall is slightly more abundant in winter, when the winds from the sea blow upon the colder land, than in summer.

The climates of the eastern coasts are to a slight extent modified by the warm and cold *ocean currents* that follow them. The eastern coast of the United States as far north as Cape Cod is to some extent warmed in winter *when the wind blows from the southeast over the warm Gulf Stream;* and the eastern coast of North America north of Cape Cod is cooled in summer, in like manner, by winds from the cold *Labrador Current.* On this account we find summer resorts on the coast of New England, and winter resorts from Florida northward to New York.

In a similar manner the *Japan Current* affects the climate of southeastern Asia; while northward from Korea the coast is cooled by winds from the cold Kamchatka Current.

In the southern hemisphere the eastern coasts of *all* continents are warmed by winds from warm currents.

The *interiors* of the continents show greater extremes of temperature and rainfall than do the coasts. The summers are warmer and the winters colder than the latitude justifies. The winds and rains are cyclonic, and the rainfall is most abundant in summer, when the lands are great centers of low pressure, with inflowing winds. If the region is *plateau* it is characterized by slightly lower temperature and less rainfall than if it is *plain*.

The *western coasts* have the benefit of the tempered westerlies coming from the ocean. This gives an evenness of temperature throughout the

year not found upon the eastern coasts of the temperate zone. Rain is both more abundant and more markedly concentrated in the winter months than it is upon the eastern coasts, because in winter the colder land chills the moist winds from the ocean. Winter fogs are most frequent on this coast.

The northern and southern hemispheres differ widely in the climates of their western coasts as a result of ocean currents. Alaska and northwestern Europe are warmed many degrees above the normal for their latitude by winds from the great *warm drifts* in the Pacific and the Atlantic oceans, while Chile, western Africa and western Australia are cooled as a result of the branches along these coasts from the *cold Antarctic Drift.*

The climatic influence of warm and cold currents is much greater on windward than on leeward coasts. In the westerlies the *windward coasts* are the *western coasts*, whereas in the trade belts the *windward coasts* are the *eastern coasts*. Winds blowing over ocean currents acquire the temperatures of those currents, which they carry to the lands. Winds blowing across continents tend to carry continental conditions to the *eastern coasts* in the *westerlies*, and to the *western coasts* in the *trades*.

While the chief effect of the warm currents in the northern oceans is to *temper the cold of the western coasts in high latitudes*, a less marked but noticeable effect is to *temper the heat of the western coasts in low latitudes*, upon the return of the currents toward the equator. Southern California, western Mexico, and northwestern Africa are thus made cooler.

Between the temperate and torrid zones lies a transitional zone of high pressure and descending air currents. This belt shifts during the year with the northward and southward movement of the sun. These are, therefore, *monsoon belts*, places in them having alternately the climate of the trades and of the westerlies. Rainfall is scant, owing to the increased temperature, due to compression, of the descending currents; and the winds are never strong, since this belt is the *starting point* of both the trade winds and the westerlies.

In general, *seasons in the temperate zone are based chiefly upon temperature, whereas those of the torrid are based upon rainfall.* The transition seasons of spring and fall, though well marked in the *middle* of the temperate zone, disappear toward the poleward and equatorward edges. Mountain ranges with a north-south trend induce rainfall upon their *western* slopes, while arid or des-

ert regions are apt to lie to eastward of them. This is the reverse of conditions in the trade wind belts, where the *eastward* are the rainy, and the *westward* the dry slopes.

The Polar Cold Caps.—The *polar areas*, though called the *frigid zones*, are not belts, but an area about each terrestrial pole included within the summer isotherm of 50° F. The polar cold cap is much more extensive in the southern than in the northern hemisphere, possibly due to the great glacial ice-sheet covering the Antarctic continent, or to aphelion winter. In the Antarctic regions the boundary isotherm reaches in some places to latitude 55, while in the Arctic regions it crosses and re-crosses the Arctic circle.

These regions are rightly named *frigid*, the chief characteristic of their climate being freezing temperatures for most of the year. At no time is the temperature high. The lands, for the most part covered by ice, are frozen deserts. It is only where there are slopes favorably inclined to the sun that the snow melts and the soil is sufficiently warmed and drained to permit plants to grow. Even here the temperature is too low for trees to thrive, and mosses and lichens are the chief growth. Temperatures of $-83°$ F. have been reported.

The winds over the polar cold caps are *cyclonic*, and the cyclones are probably *driven* cyclones. The winds are often burdened with fine dry snow, which covers all land surfaces for most of the year. Over the stretches of frozen plain these winds sweep with great violence, and are comparable to the blizzards of winter climates in temperate latitudes.

Precipitation, which on the whole decreases toward the poles, is deficient here. It is mainly in the form of snow, there being some regions where rain probably never falls. Though the precipitation is light, yet it probably exceeds evaporation over the region, the excess being imported by the westerlies from lower latitudes.

Since more snow falls than melts, the land areas of Greenland and the Antarctic continent become covered with a glacial ice-sheet. When the glaciers reach down to the sea, great blocks of ice break off and float away to lower latitudes, as icebergs.

Continental and Marine Climates.—The interiors of all continents are marked by great variability of temperature. This variability decreases toward the coasts, being least upon windward coasts. In strong contrast with the climates of continent interiors is the climate of islands, which is practically that of the surrounding sea.

The sea is less heated and less cooled than the land, under the same conditions of insolation. It is a *better reflector* and *transmitter* than the land, hence less insolation is absorbed to warm the surface layers. The *specific heat* of water is higher than that of the land, hence *a given amount of heat will not raise the temperature of the water through as many degrees as it will the same mass of land.* Much of the heat absorbed by water is *used up in the mechanical work of evaporation,* leaving just so much less for raising the temperature; while on land, *the amount of evaporation is limited by the amount of moisture brought up to the surface by capillarity,* and nearly all of its absorbed heat is used to increase its temperature. Then there are currents in the ocean that distribute the heat over great distances; and there is a greater percentage of cloudiness over the sea than over the land.

All of these variables combine to give to places *surrounded or bordered by the sea* peculiarly equable climates as compared with *continent interiors* in the same latitude. The one climate we call *marine,* the other *continental.*

Mountain Climates.—As we ascend a mountain, in any latitude, all the climatic elements change from those prevailing at the mountain's base. The *temperature,* as we have seen, *falls* at the rate of about 1° F. for every 300 feet of ascent; the *absolute humidity decreases,* while the *relative humidity* generally *increases up to a certain altitude,* depending upon the latitude, *after which it also decreases; precipitation increases for a time,* as we ascend, *then gradually fails;* and with increasing altitude the *winds increase in strength and constancy.*

On the whole, all of the climatic elements become more constant with increase of altitude, and this equability is the most marked characteristic of *mountain climates.*

The windward and leeward sides of mountains, and particularly of mountain ranges, are apt to present very different types of climate. The windward, owing to ascending and cooling currents, has an excess of rainfall, while the leeward, with descending and warming winds, is apt to be dry. If in the trades, the eastern slopes receive the rainfall, whereas in the westerlies the eastern slopes are dry.

The desert of southern California in the United States, and of Atacama in northern Chile, are examples of deserts to leeward of mountains in the westerlies, and the arid western coasts of Mexico and Peru lie to leeward of mountains in the trade wind belts. The southern slopes of the Himalayas receive most of their rainfall while the southwest monsoon blows; and the northern slopes of the Atlas mountains in northern Africa are the windward and, therefore, the rainy slopes.

QUESTIONS

1. Why are weather changes more pronounced near sea level than at higher altitudes? Inland, than near the coast? In high, than in low latitudes?

2. Why do cyclones endure longer at sea than on the land?

3. Why should rainfall be more abundant behind than in front of the cyclone centers in the trade wind belts?

4. What is the direction of the wind in front of, and behind, tropical cyclones, both in the northern and the southern part of the torrid zone?

5. Why are thunderstorms more frequent in summer than in winter?

6. Why do tornadoes generally occur in the afternoon? And why do people in the United States not seriously fear a threatening cloud in the north, but do, one in the southwest?

7. Classify the weather proverbs you know with respect to their scientific basis.

8. Why do the continents in temperate latitudes have their greatest rainfall in summer?

9. Why is the climate of the north temperate zone more variable than that of the south temperate?

10. Why do the interiors of continents show the greatest extremes of climate?

11. Why do the eastern coasts in the trade wind belts have more equable climates than the western coasts of these belts, whereas the reverse is true in the belts of prevailing "westerlies"?

CLIMATE OF THE UNITED STATES

Climatic Regions.—The United States is situated in the zone of prevailing westerlies, hence its climate is chiefly of cyclonic control. However, its wide range in latitude, its great variation in distance from the sea, and the difference in altitude of the various parts give to different sections sufficiently characteristic climates to justify their separate consideration.

Minnesota and Maine, because of their higher latitude, have lower average temperatures than Louisiana and Florida; Kansas and Nebraska, lying near the center of the continent, have greater ranges of temperature and less rainfall than northern California and Maryland; and Denver, in the foothills of the mountains, has a more equable climate than St. Louis, in about the same latitude but at a lower level.

Based upon these three conditions governing climate, latitude, distance from the sea, and altitude, it has been suggested that the United States be divided into north-south *climatic regions*. Some of these regions vary considerably from north to south.

The Pacific Coast Region.—This zone extends inland from the Pacific coast about 200 miles to the backbone of the Sierra Nevada and Cascade Mountains. Like all regions situated to leeward of an ocean, it is characterized throughout by an *equable climate*. The isotherms, instead of having a roughly east-west trend, as is their usual habit, run almost parallel with the coast. The continuation of the Japan Current, the North Pacific Drift, cooled during its long journey through north Pacific waters, in its southward flow washes the entire length of coast of this region. The influence of the winds from over this current is perhaps to *increase the temperature* slightly, of the State of Washington, above the average for

that latitude, but to *lower* the temperature decidedly, of southern California.   Frost seldom occurs here in the lowlands.

In strong contrast with this sameness of temperature throughout its north-south extent is its wide difference in annual rainfall. The westerly winds come from the Pacific, moisture laden at all seasons.   In summer they blow upon land surfaces warmer than themselves and, therefore, yield no rain until they begin to rise up the mountain slopes.   In winter the cooler land induces rainfall, even over the lowlands, thus making the *winter rains* the most marked characteristic of the Pacific Coast climate.

Upon the mountain slopes the rainfall is abundant throughout the year, though most abundant in winter.   There we find the giant trees and dense forests.   On the coast of Washington, where the high mountains lie near the sea, we find the greatest rainfall of the United States, over 100 inches; whereas in southern California, with its coastal plain, and its nearness to the high pressure calms, it is less than 10 inches.

The cultivated lowlands at the south are parched during the growing season, and but for their nearness to the mountains, which makes irrigation possible, these lowlands would be of but little value.   As it is, they are among the most valuable cultivated lands in the United States.

It is claimed for these lands that they are peculiarly adapted to the production of fruits, inasmuch as the fruits *grow and ripen in sunshine*, thus giving them higher color and superior flavor.

Along the coast fogs are common, especially in winter.   Severe storms are almost unknown, thunder being rarely heard upon the coast.   Upon the mountain slopes thunderstorms break, and the lightning flashes are seen, though at distances from the coast too great for the sound of the accompanying thunder to carry.

The Plateau Region.—This region embraces the high plateau lands lying between the Sierra Nevada and Cascade Mountains on the west and the Rocky Mountains on the east.   Its most marked characteristic is its dryness.   Lying as it does to the leeward of the Sierras, the descending winds on the eastern slopes of these mountains yield little rain.   It is only after they have crossed the

greater part of the region, and begin their ascent of the western slopes of the Rockies, that rain is induced. Occasional cyclonic storms yield some rain, but over most of the region the rainfall is insufficient for agriculture, without irrigation. It varies from 20 inches in Washington to 3 inches in Arizona. The greater part of this region is too remote from the mountains to permit of irrigation, and must, therefore, remain arid and unproductive.

The skies over the plateau region are prevailingly clear, consequently the daily range of temperature is excessive. The winters are cold, and the summer days extremely hot. Cold winter cyclones sweep down from the north; and it has been suggested that the hot desert region about the head of the Gulf of California is the birthplace of most of our southwest summer cyclones.

Rainfall is nowhere in the region sufficient to support heavy forests. At the north, where most abundant, it falls mostly in winter, the growing season being almost without rain. Owing to the deep and retentive soil, so fine-grained and homogeneous that it brings *capillary* water from unusual depths, this part of the region yields abundant wheat harvests. Apples and other temperate latitude fruits are grown where irrigation is possible.

The chinook winds, which sink down the mountain slopes, warming as they advance, keep the narrow mountain valleys free from snow. On this account these valleys are much sought by both wild and domestic animals for winter grazing grounds.

The Great Plains.—This name is applied to the region of eastward sloping lands from the Rocky Mountains to about the meridian of 100° W. It grades imperceptibly eastward into the next climatic region, and is characterized over most of the region by the cold winters and hot summers, typical of continental interiors in this latitude.

Rainfall, which increases eastward with increasing distance from the mountains, is in the main insufficient for agriculture, unaided by irrigation. Much of the region is capable of irrigation, from streams or artesian wells, and by this means is becoming increasingly valuable. The rainfall is insufficient for forests, but it suffices for the growth of abundant and nutritious grasses. These are the

great natural grazing grounds of the United States.   Before the advent of the white man vast herds of buffalo roamed these plains, but disappeared with the march of civilization westward.   In their stead came herds of cattle and flocks of sheep, and that typically western product, the "cow-boy."

The seasons are variable in the extreme.   Occasional abundant harvests are gathered, only to be followed by one or more seasons of disastrous failure.   With wider adoption of the methods of "dry-farming," much more of the Great Plains region will be devoted to agriculture.

The rains and winds of the region are wholly determined by the passage of highs and lows.   The rainfall is distributed through the year, though slightly in excess in summer, and nowhere exceeds 20 inches.

This region is the continuation of the great Arctic plain, which extends unbroken southward past Hudson Bay.   With no east-west mountain range to interrupt, it is swept over by the winter cyclones from the north, which sometimes reach even to the Gulf of Mexico before turning to their final northeastward course. Owing to the level and prairie character of the region, wind velocities are often excessive.

The Central Prairie Lands.—As already stated, this region is a continuation eastward of the Plains region, there being no natural boundary between them.   It is bounded eastward by the Mississippi River.

The Central Prairie Lands differ from the Great Plains chiefly in having a more abundant rainfall, 20 inches or more.   This is everywhere sufficient for agriculture, and increases southward. On the coast of Louisiana it is 60 inches, due to the in-draft of warm winds from the Gulf, toward lows crossing the region farther north.

The climate, though typically cyclonic, is not so extreme as farther west.   At the south the influence of the Gulf in tempering both the cold of winter and the heat of summer is marked.   The annual range of temperature is 160° in North Dakota, whereas it is but half that on the Gulf coast.

Over most of this region the rainfall, 30 inches, is sufficient to support forests, and their absence over much of the region has not been satisfactorily explained. Forests border practically every stream of the region.

Various explanations of the absence of forests in this region have been proposed. The one which perhaps has received widest acceptance is the destruction of the forests by fires. Inasmuch as attempts to *extend* the forests have not been successful it would seem that perhaps the explanation of the absence of forests is to be found in the character of the soil, and deeper deposits, which are often glacial clays.

The great body of the more productive agricultural lands lies in this division, and here most of the staple food products are grown.

The winds are variable in direction, though northerly winds prevail at the north and southerly winds prevail at the south. Owing to the greater interruption by forests the winds do not here attain the average strength of the winds upon the Great Plains.

This climatic region is visited by a greater number of destructive wind storms than any other region of the United States. Tornadoes begin to occur in the Gulf States in February, though most frequent from April to September. Their time of earliest occurrence is later the farther north we go.

The Western Appalachian Slope.—This region embraces the area extending from the Mississippi eastward to the axis of the Appalachian Mountains, and from the Great Lakes southward to Tennessee. At the north the Great Lakes temper both the heat of summer and the cold of winter, so that the climate, though continental, is not so extreme as in the regions between the Mississippi River and the Rocky Mountains.

The westward trend of the Appalachians, while protecting the Gulf slopes to the southward from cyclones originating in the west, also protects the climatic region to the northward from the frequent tropical storms that come up from the West Indies. These tropical cyclones rarely cross the mountain barrier of the Appalachians.

The rainfall of the region exceeds that of the northern division of the Prairies for two reasons: there is a greater *water surface* adjacent, to yield vapor, and the prevailing westerlies are *moving*

up the slopes. The rivers are, therefore, numerous and strong, and more evenly and abundantly supplied than are those of the Prairie region. Though well distributed through the year, the rainfall is more abundant in summer than in winter. This is in part due to the greater absolute humidity of the air in summer, and in part to the more frequent passage of lows having their origin in the southwestern part of the United States. Winter cyclones more commonly originate in the northwest, and are not so likely to be accompanied by precipitation. The precipitation in winter is chiefly in the form of snow, especially in the lake region.

The winds are cyclonic, but less strong than in the Prairie region, because of the generally forested character and greater unevenness of the lands of this region.

The Atlantic-Gulf Slope.—This slope, extending from Maine to Louisiana, presents a great variety of climate. Being near the sea, neither the extreme cold of winter nor the heat of summer of regions farther inland is felt; but, being to leeward of the continent, the equalizing influence of the sea is not nearly so great as upon the Pacific slope. At the north the winters are cold, and the summers cool; while at the south the winters are temperate, and the summers, owing to the excessive humidity, are oppressive, though not so warm as farther north inland.

Ocean currents are important factors in determining the climate of the Atlantic Coast. The cold Labrador Current, coming down the New England coast, makes that coast colder as far south as Cape Cod, while the Gulf Stream influences the climate of the coast from Florida northward to Cape Cod.

Rainfall, abundant throughout this climatic region, increases generally toward the south, where it is more than 60 inches. It is well distributed throughout the year, though for the greater part of the region it is most abundant in the fall. Toward the south the maximum fall is later, in southern Florida being most abundant in winter, when the westerlies prevail. However, the southern Florida rains are not of the Pacific Coast type of winter rains, being mainly due to passing lows, and not to forced ascent over cold lands.
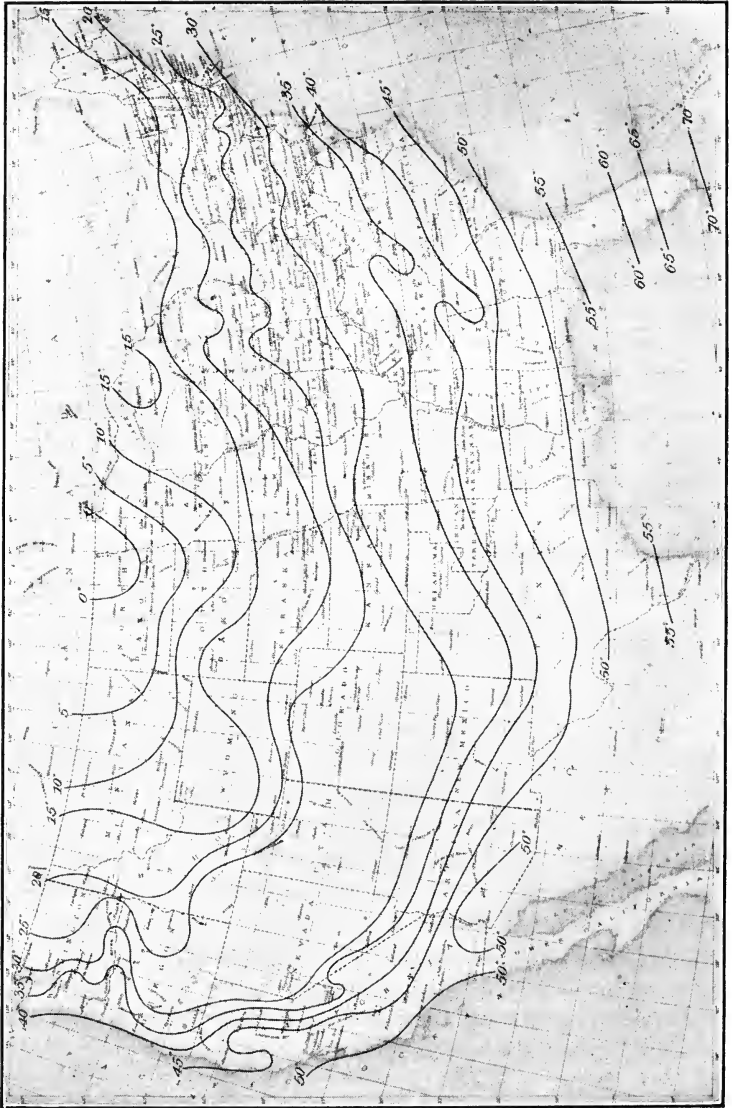
FIG. 72.—ISOTHERMS OF THE UNITED STATES FOR JANUARY. (HENRY)

Fig. 73.—Isotherms of United States for July. (Henry)

South of Cape Hatteras the coast is often swept by tropical cyclones which reach our coast from the southeast, whereas north of Hatteras the cyclones are from the west or southwest, and originate outside the tropics. Both types of storms move northeastward, their paths converging, thus giving to New York and Boston a greater number of cyclonic storms than to points either farther north or farther south.

Exceptional Conditions.—In many of his activities man is controlled not so much by *usual* as by *exceptional* conditions of climate. Our buildings are constructed to withstand the *strongest* wind, and the levees along our rivers to restrain the *highest* flood.

As we have seen, profitable agriculture is not so much dependent upon the *annual* rainfall as upon the occurrence of rain during the growing season.

In order to obtain a clear understanding of the climates of the several climatic regions of the United States, it is necessary to examine maps showing averages for given periods, and maps showing departures from these averages.

From the January chart of temperatures is seen the wide difference in the winter temperature of 70° at Key West, and of $-5°$ in North Dakota. This difference, while in part due to difference of latitude, is to a much greater extent the result of the difference between *coast* and *continent-interior* conditions. Along the Atlantic coast the change in temperature is from 70° at Key West to 10° in northern Maine, while along the Pacific coast, for the same change in latitude, there is a change if only 10° in temperature. In the contrast shown by these two coasts is seen the difference due mainly to position to *leeward of a continent* and position to *leeward of an ocean*.

The July chart of temperatures tells a very different story. No longer is the highest temperature found at Key West, but in Arizona, some 8° farther north. This is largely due to the arid character of this region, with its prevailingly clear skies. Along the Atlantic slope there is a difference of temperature of about 25° between Florida and Maine, as compared with 60° in January, while on the Pacific coast the difference for July is about the same as for January, the isotherms, as we see, running almost parallel with the coast. The interior of the continent, which is *colder* than similar latitudes upon the coast in January, is now seen to be *warmer*. The isotherms for July bend *northward* in crossing the continent, whereas those for January bend southward.

While the lines of equal minimum temperature follow, in general, the trend of the isotherms for January, the lines of equal maximum temperature are not so regular. We find the *lowest* minimum, $-63°$, in the interior of the continent, near its northern boundary, and the *highest* minimum, $40°$, at Key West. Here frost never occurs. The minimum temperatures of the Atlantic coast are from $20°$ to $30°$ lower than those of the Pacific coast in the same latitudes. Here again is shown the difference in windward and leeward coasts.

The tempering influence of the sea is well shown by a comparison of the average maximum of the coasts, about $95°$ F., with that of the interior, which is about $10°$ higher. The *lowest* maxima, about $90°$, are found in the extreme northeast and northwest coastal regions, while the *highest*, almost $125°$, occur in the interior desert region of southern California and Arizona. Maxima exceeding $105°$ are common over the Great Plains region, but the dry heat of this region is not so oppressive as that of the Gulf and Atlantic coasts, where the maxima are $5°$ lower.

The *range of temperature* is the difference between the summer maximum and the winter minimum. The greatest range is found in the northern interior, whereas the lowest range occurs at Key West. In general, range of temperature increases with increase of latitude and with distance from the sea.

The range of temperature along the Pacific coast varies little, being only $15°$ greater at Puget Sound than in southern California, whereas the Atlantic coast varies in range from $50°$ at the south to $110°$ in Maine. The range of temperature for most of the Gulf coast is about $85°$, whereas that for Montana is twice as great.

Freezing Temperatures.—The number of days with average temperature below freezing varies from none in the Pacific, Gulf and Atlantic coast regions northward to Chesapeake Bay, to 165 days in Minnesota and North Dakota. Of much greater practical interest to farmers and fruit growers, however, are the dates of occurrence of earliest and latest killing frosts.

In the fall, with the lengthening night and increasing slant of the sun's rays, there comes a time when the daily minimum falls almost to freezing. The passage of a low across the continent then is apt to be followed by frosts. These are due to the cold in-draft of north winds at the rear of the low, where the sky is clear and the winds light.

The date of occurrence of the *first* killing frost in the extreme north central part of the United States is about September first. As the winter season marches southward, and toward the coasts, the first killing frosts occur later and later in these directions, being as late as December 15th in central Florida.

In spring, when the noon altitude of the sun is increasing, and the days

Fig. 74.—Map Showing Highest Temperatures in United States. (Henry)

FIG. 75.—MAP SHOWING LOWEST TEMPERATURES IN UNITED STATES. (HENRY)
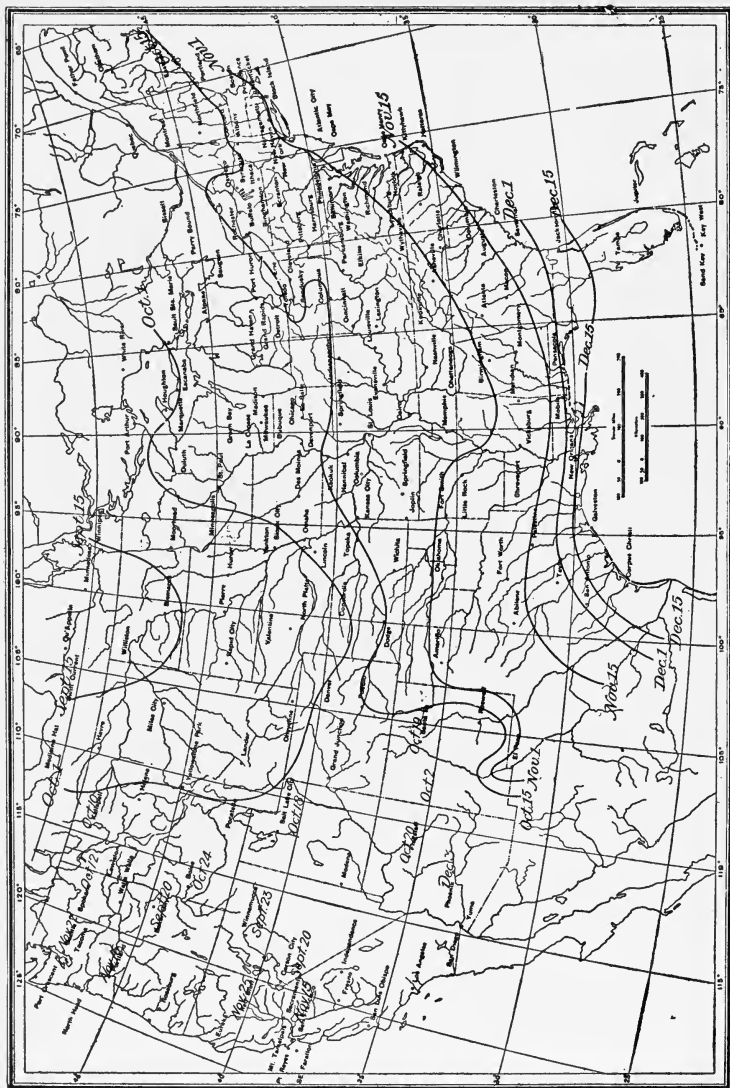
Fig. 76.—Showing Date of First Killing Frost. (Henry)

Note the march of the season south-eastward over the country east of the Rockies; also the freedom of the Pacific coast from frost. Account for this freedom.
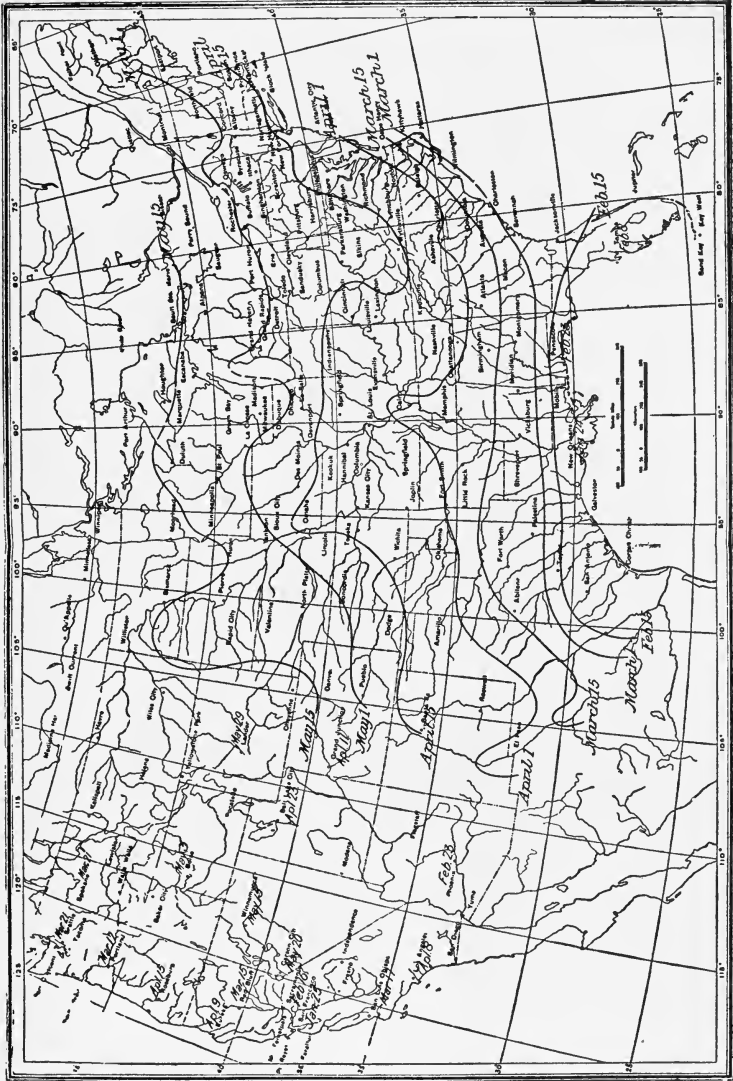
Fig. 77.—Showing Date of Latest Killing Frost in Spring.   (Henry)

Spring marches north-westward across the country.

FIG. 78.—TYPES OF RAINFALL DISTRIBUTION IN THE UNITED STATES. (HENRY)

are lengthening, there comes a time when the ordinary daily minimum ceases to fall below freezing. But for weeks after this condition is reached, a passing low, with its cold in-draft of northern winds behind, may bring freezing temperatures; and thus the time of latest killing frost be made later. At such times falling temperature and clearing skies forewarn of frost.

Since spring marches northward and landward from the coasts, the average time of latest killing frosts is earliest at the south; and in any latitude, at the coast. It occurs along most of the Gulf coast about February first, and is delayed in the extreme northern part of central United States until almost June first.

The *absolute date* of latest killing frosts is considerably later than the *average date* in all sections, being much nearer March first on the Gulf coast, and July first in Minnesota.

From the accompanying rainfall charts we are able to locate the regions of *greatest* and of *least* rainfall *during the year*, as well as the more important matter of its *distribution in time*. For the farmer and planter this last is of the greatest importance.

The least rainfall, three inches, occurs in southwestern Arizona. Most of this amount may fall in a single day, or indeed in a few hours, during a single thunderstorm. The greatest annual rainfall in the United States, over 100 inches, occurs in northwest Washington, and while most abundant in winter, is fairly well distributed through the year. The annual rainfall on the Pacific coast decreases southward, in central California being but half of the maximum in Washington.

On the Atlantic coast the maximum rainfall is near Cape Hatteras, decreasing northward and southward.

A rainfall of two to four inches a month during the growing season is desirable for agriculture. Occasionally many times this amount falls, as much as ten inches being recorded in a single day. Such torrential downpours are injurious alike to growing crops and to cultivated lands. The soil is washed away, streams are flooded and overflow their banks, causing destruction of property and life. These heavy downpours are popularly known as *cloud-bursts*.

The recorded rainfall includes snowfall, ten inches of snowfall being estimated, when melted, as the equivalent of one inch of rain.
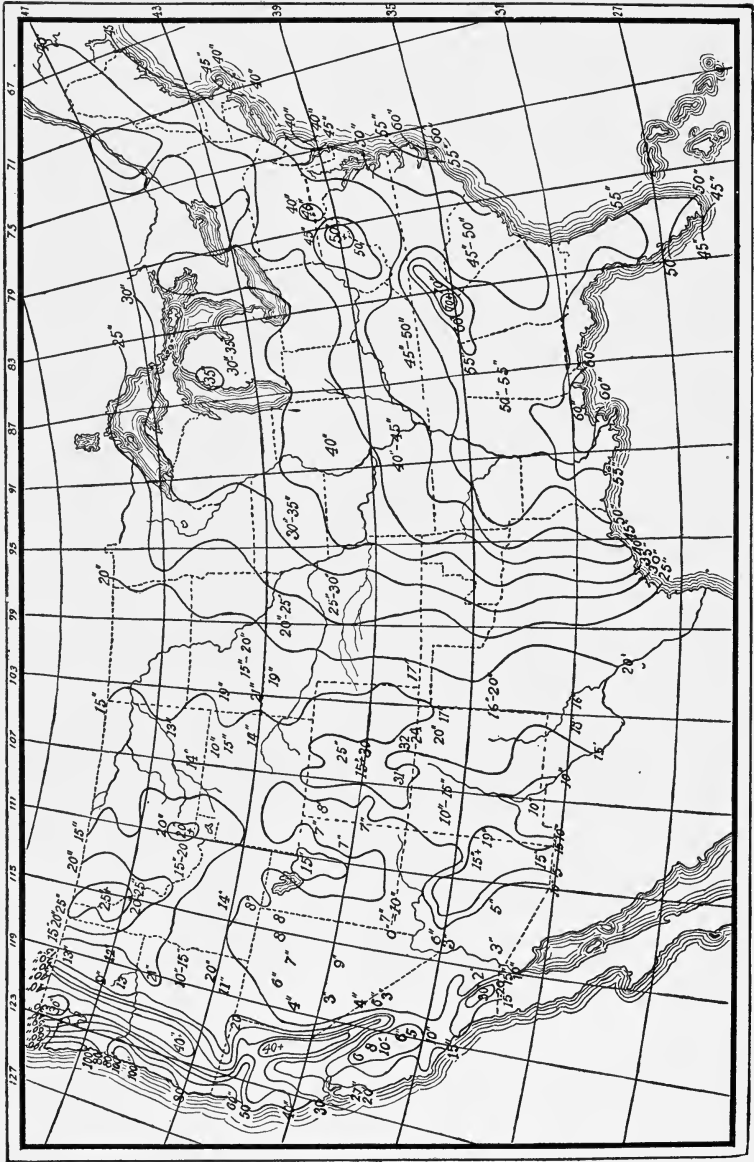
FIG. 79.—AVERAGE RAINFALL OF UNITED STATES.   (U. S. WEATHER BUREAU)

Distribution of Snow.—Every part of the United States, excepting southern Florida and southern California, receives some snowfall. It is least at the south, and increases with latitude and altitude. It is more than 40 inches in the region of the Great Lakes and in the Rocky Mountains, and occasional heavy snowfalls occur in the extreme south. A fall of 13 inches occurred at Baton Rouge, Louisiana, in 1895, during a single storm in February; but such snows usually melt within a day or two after falling.

The greatest annual snowfall in the lowlands of the United States, 130 inches, occurs in the northern peninsula of Michigan, the moisture being supplied from the adjacent lakes. The greatest average annual snowfall of the entire country, not including Alaska, occurs in the Sierra Nevada Mountains. The moist westerlies from the Pacific, compelled to rise in passing over the mountains, precipitate, on an average, 378 inches of snow at Summit, California.

The Rocky Mountain region has a heavy annual snowfall, though less than the Sierra Nevada and Coast ranges. It is mainly to the melting of these snows in the Rockies that the great irrigation projects look for their supply of water. The floods in the Missouri and other eastward flowing streams with sources in these mountains occur in May and June, when the normal rainfall is augmented by the melting snow.

The snowfall in the northern plains and prairie regions is variable; some winters it is excessive, others, light. When abundant in the wheat-growing sections a good crop is expected, since the snow serves as a protection from the cold, and also leaves the soil in good condition.

In the lumbering sections of the north, from Minnesota to Maine, the profits of the season are directly related to the snowfall, which is usually abundant. Little snowfall in these regions means smaller output.

Number of Days with Precipitation.—The number of rainy or snowy days during the year varies widely in different sections of the country. In general, it is least in the interior, and increases toward the coasts; and is greater in the north than in the south. The greatest number, 180, occurs in northwest Washington; then follows the Great Lakes region, with 170 days. In the southwest desert region the number falls to 13. For most of the agricultural sections the number varies from 100 to 140. Forty *consecutive* rainy days are reported in northwestern United States, and 150 days of *consecutive drouth* in the arid region of the southwest. The more equable the distribution of rainfall during the year the less the liability to long-continued rains or drouths.

Humidity.—The *absolute humidity* of the air is greater in southern United States than in northern; is greater in summer than in winter, and greater near the coast than in the interior.

The *relative humidity* is on an average lowest on the Colorado plateau,

where it is about 40%, and highest on the eastern and western coasts, about latitude 40° N., where it is about 80%. In the Gulf region it is about 75%, and approximately the same in the region of the Great Lakes, although, as a rule, continent interiors favor low relative humidities.

The percentage of cloudiness agrees well in winter with the relative humidity, but in summer one of the areas of greatest cloudiness is over the Colorado plateau, where the *average* relative humidity is low. This is probably due to the strong convectional currents set up during the summer season, the air rising to sufficient heights for saturation.

Winds.—As before stated, the winds are stronger upon the coasts, and over the prairie regions than over forests and mountainous regions. For most of the country the season of strongest winds is spring; and the month of weakest winds, August.

Aside from tornadoes and hurricanes, during which, for a few seconds, the velocity of the wind may considerably exceed 100 miles an hour, the strongest winds are about 70 miles an hour inland, and 90 miles an hour on the coasts.

Though the direction of the wind is variable in all parts of the United States, in valleys there is a decided *up* or *down* the valley tendency in wind direction. On the coasts, in winter, there is a predominance of *land* winds. This is especially true of the Gulf and Atlantic coasts. On the Pacific coast the meeting of the land winds and the prevailing westerlies produces " along-shore " winds. In summer the conditions upon the Atlantic and Pacific coasts are reversed. The Pacific now has *strong ocean winds*, while the in-blowing winds upon the Atlantic coast are *met* by the westerlies, producing "along-shore" winds from the southwest.

The winds which bring cloudy weather and precipitation vary with the section. They are generally winds blowing from the nearest great water body. On the Atlantic and Gulf coasts, and over most of the interior of the United States, they are east and southeast winds, while on the Pacific coast they are generally southwest winds. In winter, in the northern section of the United States, snow often accompanies winds from a northerly direction. Winds from southerly directions, in front of the low, bring higher temperatures, and yield rain, while the colder winds in the rear yield snow.

QUESTIONS

1. Why is the rainfall of the Pacific coast so much greater in Washington than in southern California? And why are the rains at the north less distinctly winter rains than those at the south?

2. Why should thunderstorms be practically unknown upon the Pacific coast?

3. Are the Sierra Nevada or the Rocky Mountain ranges more responsible for the arid climate of the Great Basin? Why?

4. Why does the Atlantic coast have so much greater variation in temperature than the Pacific?

5. From what direction do storms in your section usually come?

6. What direction of wind is usually coldest?

7. What direction of wind is most apt to bring snow in winter and rain in summer?

8. How does knowledge of your climate concern your daily life and occupation?

PART III

THE SEA

CHAPTER XV

GENERAL CHARACTERISTICS OF THE SEA

The Relation of the Sea to the Land.—Most of the phenomena connected with the wearing away of the land, with moderating the climate, and even with the existence of life itself, depend in large measure upon the sea. The source of the water supply for the land is the sea; and the streams with their sediments from the land return to it.

The sea is a great international highway, and plays an important part in the commerce of the world. It is no longer a barrier between countries. The great steamships are little affected by storms at sea. Being equipped with wireless telegraph instruments, ships communicate with each other at sea and with land stations, thus removing the isolation that was formerly experienced in crossing the great oceans. Countries are connected by submarine cables so that news is sent and business transacted between nations separated by oceans, almost as easily as between different parts of the same country. The digging of canals across isthmuses tends to change routes of travel and commerce at sea. The Suez Canal has had a far-reaching effect on trade in the Old World, and the Panama Canal will influence trade routes in the New.

The surface of the sea is commonly regarded as having a very nearly uniform level, known as the " level of the sea," from which land elevations and sea depressions are measured. The sea is drawn toward and upon the continents that surround it, especially when large mountain masses are situated near the coast, so that sea level cannot be of uniform curvature. The actual deformation of the ocean level in different parts of the earth due to this cause has been estimated to amount to several hundred feet. On the

coast of India, owing to the attraction of the great Himalaya Mountains, the water stands much higher than water in mid-ocean or water along a lowland coast, such as western Europe or that of the eastern United States.

The extent of the sea has not been constant in ages past and is not now a fixed area. Much of the land furnishes evidence that it has at some time been covered by the sea, and regions now sea-bottom have been land. The great central valley of the United States was once sea floor, there being an unbroken stretch of sea from the Gulf of Mexico to the Arctic Ocean. On the other hand, land along the eastern coast of North America has suffered drowning.

Scientific explorations of the sea, made by different governments, by societies, and by individuals, from time to time, have given us most of our knowledge of the depth of the ocean, its temperature, its movements, its deposits, and its life.

Divisions of the Sea.—The continuous body of salt water called the sea, covering about three-fourths of the earth's surface, has five divisions, called oceans. The polar circles, the continents, and the meridians from their southern points form the boundaries.

The Pacific is the largest ocean, comprising three-eighths of the entire sea area. Its greatest width is about 10,000 miles, in a direction east and west along the equator. It is characterized on its Asiatic shores by numerous border seas, festoons of islands, and many rivers; and on its American shores by high mountain ranges parallel to the shore, and few rivers.

The Atlantic is the second in size, with an area about one-quarter of the whole sea surface. It has an average width of 3,600 miles. The equator divides both the Atlantic and the Pacific Ocean into a northern and southern part. The North Atlantic, both on the American and the European sides, has many seas and bays which give it an irregular shore line. It has a wide continental shelf and many rivers. The South Atlantic has a more even shore line and few good harbors.

The Indian Ocean has an outline that is roughly circular. It has one-eighth of the total sea area and a diameter of about

6,000 miles. The Indian Ocean is bordered by large seas and bays, and a northern and western boundary consisting of very high plateaus and mountains.

The Arctic Ocean is an extension of the Atlantic. It has a width of about 2,500 miles and about one-thirtieth of the sea area. A considerable area of the Arctic is covered most of the year with drifting ice.

The Antarctic Ocean lies within the Antarctic Circle. Within this region there is a continent covered with an ice cap thousands of feet thick. The relative area of land and water in this frozen region is at present unknown.

Distribution of the Ocean Waters.—By holding a globe so that the greatest expanse of water is seen, the island of New Zealand will be found to be near the center of the water hemisphere, or what might be called the water pole of the earth. London, England, will be found to be nearly opposite, and the center or pole of the land hemisphere.

Depth.—The greatest known depth of the ocean is 31,614 feet, in the Pacific, near the Ladrone Islands. This depth is a little greater than the height of the highest mountain above the sea level. Many places in the sea are more than four miles deep, and the area of surfaces of the sea floor in deep water greatly exceeds the area of high land. The average depth of the ocean is about 2½ miles, and the average height of land about half a mile. It may be inferred from this that the continental land masses would make a small beginning in filling up the deep sea.

Composition of Sea Water.—The water of the sea is so salt and bitter as to be undrinkable. If 100 pounds of sea water are evaporated, about 3½ pounds of a whitish powder will remain. About three-fourths of this powder is common salt. The bitterness is due to chloride of magnesia, Epsom salts, gypsum, and small quantities of almost every soluble substance known. Sea water contains in addition to mineral matter dissolved atmospheric gases. Oxygen is more abundant in the water near the surface, and the proportion of carbon dioxide increases toward the bottom.

The oxygen dissolved in the water is being consumed by marine life and its supply is furnished by the atmosphere. The amount of saltness of the sea varies slightly in different parts of the earth. Where evaporation is more rapid, as in the trade wind belts, the saltness of the water is greater, since salts are left behind when sea water evaporates. When rainfall is abundant, as in the doldrum belt, the sea water becomes less salt and of less density. Rivers bring to the sea fresh water which mixes with the salt water and makes it of less density.

Temperature.—The *surface* waters of the sea are warmest, as the water is heated by the sun's rays; and the warmer water being lighter than the colder water, remains at or near the surface. The temperature varies from about 80 degrees near the equator to about 29 degrees near the poles. The decrease of temperature with increase of latitude is far from being regular, the irregularity being largely due to ocean currents which vary in temperature from that of the surrounding water.

The surface waters of the sea are alternately warmed and cooled in both hemispheres, depending upon the season of the year. At the equator and the poles the seasonal change is slight, but in middle latitudes it amounts to several degrees. In the latitude of New York the winter temperatures are usually between 50 and 60 degrees, and the summer between 60 and 70 degrees.

The temperature of water *below the surface* falls rapidly with increase of depth. Even near the equator the temperature at a depth of less than half a mile is usually below 40 degrees. At the bottom of the deep sea the temperature is generally below 35 degrees.

The decrease of temperature with increase of depth is not uniform because of the deep circulation of the ocean water. Because of currents beneath the surface sometimes warmer and sometimes colder, slight irregularities in temperature occur. Sea water, when cooled either by cold air or by melting ice, tends to sink. The great supply of cold water from the polar regions *creeps along the bottom* of the sea and is the cause of the low tem-

perature in the equatorial as well as in the temperate and polar regions. The temperature of the deep water in enclosed portions of the sea, such as the Mediterranean, in low latitudes, never falls to the low temperature of the deep open sea because of the raised sea bottom in the straits, which acts as a barrier and keeps out the creep of cold water.

Sounding and Dredging.—The depth of the ocean water and the nature of its bottom are studied both for economic and scientific reasons. Before submarine cables are laid, suitable routes must be determined.

Soundings of the deep sea are made by means of a weighted wire. The weight, called the sounding lead, surrounds a metal tube and is attached in such a way that when the tube strikes bottom the weight is released and remains on the bottom. The tube has a device for bringing up specimens of material found on the sea bottom. At intervals along the sounding wire specially devised minimum thermometers are attached, which record the temperature at the various depths reached. It will be seen that by a single sounding, not only are depths measured, but temperatures at different depths and a sample of deep sea deposit are obtained.

By dredging, specimens of deep sea life are obtained. A basket of large dimensions and with a flaring opening is dragged along the ocean bottom, and various remains and forms of animal life brought to the surface.

The ocean floor has its mountain ranges, its plateaus and its plains. There are great volcanic peaks in many places, some of which rise higher above the sea bottom than any mountain of the land rises above the platform on which it rests. Dolphin Ridge is a broad area in mid-Atlantic over which the depth varies from 5,000 to 12,000 feet, and is bordered on either side by the relatively steep slopes of great troughs in which the water is from 15,000 to 25,000 feet deep. Chains of islands like Cuba and its neighbors are believed to be the peaks of submerged mountain ranges. In these major features the ocean floor resembles the land.

The most striking characteristics of the ocean bottom are the *smoothness and the absence of the steep slopes* so familiar on land. Below sea level the slopes of volcanoes and the "abrupt" slope at the outer margin of the continental masses are rarely steeper than a rise of one foot in twenty.

There are very few slopes on the ocean floor that would be considered difficult for an automobile to climb, or that are steeper than some of the grades on our trunk line railways.

The *smoothness* of the ocean floor is due largely to the absence of those agents of erosion, which sculpture the land into hills and valleys, and also to the accumulation of deposits in depressions. Between the shore line and the seaward limit of wave action, waves and shore currents are spreading out land sediments, forming a smooth and nearly level area. Beyond this area deposits of several kinds are constantly accumulating, and as the deep water here is practically at rest, the sediments settle, filling depressions and maintaining a nearly level surface.

It is interesting to study the way chalk settles from a mixture of prepared chalk and water. This mixture is somewhat similar to some of the oozes which settle on the ocean floor. We notice that the surface of the sediments is more nearly horizontal and more regular than that of the bottom of the vessel. This sort of action is continually, though slowly, in progress on the ocean floor, which is gradually approaching a level surface.

The Continental Shelf.—Near the borders of the continents the sediments brought down by streams, and materials worn from the land by the waves, are spread out by the waves and currents, forming a gently sloping smooth floor which is called the *Continental Shelf*. The continental shelf is, strictly speaking, a portion of the continental mass rather than a portion of the ocean basin. It extends seaward to the 100-fathom line, where the slope, becoming steeper, descends to the bottom of the ocean basin proper.

The continental shelf is well developed along the eastern coast of North and of South America, and in places is more than 100 miles wide. On the western coast it is in most places much narrower.

FIG. 80.—THE CONTINENTAL SHELF OF NORTH AMERICA
After model by Howell.

The British Isles are on the continental shelf that borders Northern
Europe.

There is evidence that much of the area of the continental
shelf has been above sea level. Several of the valleys of large
rivers flowing into the Atlantic may be traced seaward across
the continental shelf by valleys or canyons which were cor-
raded by the river when the continental shelf was a part of the
dry land.

Materials of the Ocean Floor.—The ocean is the great settling basin of the world. The rivers are constantly bringing in vast quantities of sediment and lesser quantities of dissolved mineral. Waves cut into the land and add much to the contribution of the streams, and a considerable quantity is added by the winds. The solid matter thus received is assorted, transported, and deposited in beds, which may ultimately become sedimentary rocks. A large part of the dissolved carbonates is taken up by plants and animals, which change it to some such solid form as coral or shell, which is eventually added to the deposits of the ocean floor.

Deposits of the Continental Shelf.—These consist of sand and gravel beds, and mud beds. Gravel beds are usually found near the mouths of rivers or in localities where the wave action is particularly violent. Sand beds sometimes extend many miles from the shore. The mud beds are made up of the finest particles and are located beyond the sand in the open sea or in the quiet water of bays. Pure limestones are formed in clear water beyond the mud beds. The deposits on the continental shelf grade into each other.

Deposits of the Deeper Ocean.—Beyond the mud deposits the only material derived directly from the land, which accumulates on the ocean bed, is the dust from the air, and this is so small in amount that it is overshadowed by the organic remains. The waste materials of the land extend some distance beyond a depth of 100 fathoms, but they gradually disappear and are replaced by *oozes* which cover the bottom of the deeper ocean where the depth is less than two and one-half or three miles. The oozes consist of microscopic shells of animals that live in the surface waters even in mid-ocean. When the animals die their shells sink to the bottom, forming the soft and grayish deposit, known as ooze.

Deposits of the Deepest Ocean.—As the depth of the ocean increases, the percentage of calcareous matter in the deposits decreases, and at a depth of about three miles the deposit is chiefly *red clay*. It seems that at these great depths the minute shells and other matter of similar composition which form the

oozes are dissolved before they reach the bottom.   The red clay consists of the less soluble matter which settles from the air as volcanic ash, and dust from meteors, several millions of which enter our atmosphere every day.   Fragments of pumice and particles of meteoric iron occur in the red clay, and the insoluble parts of the bodies of animals living on the surface are relatively abundant. More than 100 shark teeth and between 30 and 40 ear bones of the whale have been brought to the surface at a single haul of the dredge.   Since there are but two ear bones in a whale, this proves that the deposit must accumulate very slowly indeed.

Life of the Ocean.—All of the great classes of animal life are represented in the ocean.   Several of the mammals, an order whose natural habitat is on land, live in the sea, though it is necessary for them to come to the surface to breathe.   Among them are the whale, porpoise, walrus, seal, and sea lion.   No birds make their permanent home on the sea, but many aquatic species spend much of their time there.   Fish of great variety in size and form are abundant.   Thousands of species of invertebrates of nearly every order, from the microscopic protozoan to the gigantic squid, are found in great abundance.   Among these are the lobster, crab, shrimp, oyster, clam, star-fish, and the coral.

Various species of plants occur almost everywhere along the shore.   A few of them, like the mangrove and certain grasses, are land plants which have adapted themselves to conditions of life on the beach; but the majority of the plants are unlike those on the land.   Some species of seaweed reach great size, larger than our tallest trees; but their structure is unlike that of the trees, and the weight of the solid matter which they contain is only a small fraction of that of our common trees.

Distribution of Plant and Animal Life.—The distribution of the life of the sea is controlled just as is that of the land, largely by the climatic conditions of the various parts.   The walrus, fur seal, and narwhal are found in cold, and the corals only in warm waters. The corals and certain allied species are also limited to the regions where the water is clear and normally salt; other species, like the

oyster, prefer brackish water and do not require absolute clearness.

The depth of water controls the distribution of life as effectively as any other varying condition. *Light* does not penetrate to depths much greater than 100 fathoms, and animals and plants requiring light must develop above this depth.

The *temperature* of the deep ocean is near the freezing point, hence some forms of life are excluded. The *pressure* in the deeps is so great that other forms are excluded. And finally the *motion of the water* is so slight that fixed forms of life, whose food must be brought to them, are excluded.

For these reasons the great depths of the sea are like the desert regions of the land in the comparative sparseness of both animal and plant life. Such animals as there are have strange forms; some of them have eyes, but others are blind. Some of the forms probably emit phosphorescent light which enables them to see and to be seen. There are no plants in the very deep sea.

It has been claimed that the life of the sea, as a whole, exceeds that of the land, equal areas being compared. It is doubtful, however, if life is as abundant in any portion of the sea as it is on the more fertile portions of the land. The surface waters everywhere abound in life. Many species and many individuals of each species occur; but both the number of species and the number of individuals is greater between the 100 fathom line and the shore line than elsewhere.

Ice in the Sea.—Sea water ordinarily freezes at a temperature between 26° and 28° F., depending upon the saltness of the water. In the higher latitudes ice forms along the shores and also on the deep sea, often to a thickness of eight or ten feet.

The ice formed in winter is usually broken in pieces in the summer. These floating pieces, called *field* or *floe-ice*, are often crowded and jammed together into an *ice-pack*, which, because of the lateral pressure, is raised considerably above the water. The sea ice may be driven upon the land by waves and tides and become twenty feet or more thick by accumulations of snow. Rock fragments from overhanging cliffs and from the imbedding of rocks along the shore, gather upon and in this ice of the shore known as an *ice foot*. In winter the grinding of the ice foot up and down the shores smooths and rounds the rocks of these coasts. In the

summer it breaks up and scatters the rocky material, often long distances.

Glaciers entering the sea from the land in both polar regions break at the shore and send off larger masses of ice, known as *icebergs*. Some icebergs are a mile or more in length, and have been known to rise 500
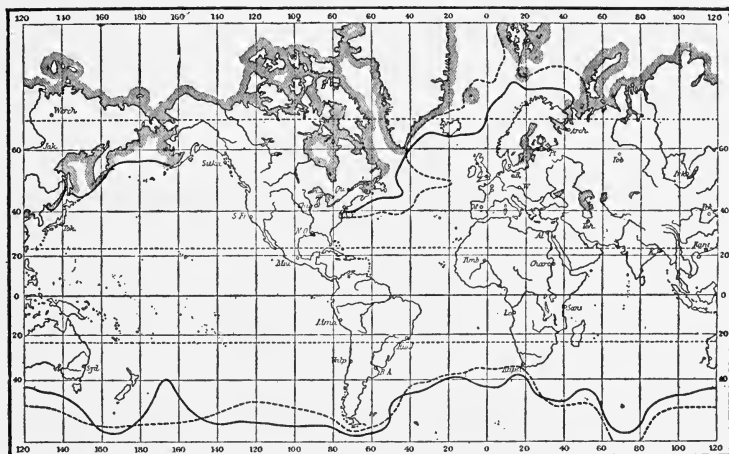
FIG. 81. — ICE-BOUND SHORES (SHADED), AND LIMITS OF DRIFTING ICE IN NORTHERN WINTER (BLACK LINES). DOTTED LINES, LIMITS OF DRIFTING ICE, NORTHERN SUMMER

feet above the water. As ice is nearly as heavy as water, the greater part of the floating iceberg is below the surface of the water. The relative heights above and below are on the average about 1 to 8. The chief work of an iceberg is to transport material in the form of bowlders and glacial pebbles, dropping them on the sea bottom in the warmer and more open seas.

QUESTIONS

1. Where is the great water supply for watering the land? What other advantages does the land receive from the sea?

2. Name the boundaries of the different oceans. Compare the Arctic and Antarctic oceans in respect to area.

3. Calculate roughly the number of cubic miles of water in the Atlantic ocean. How does this compare with the volume of the land mass of North America?

4. What mineral substances and gases are dissolved in sea water? How much common salt in a hundred pounds of sea water? What causes the sea water to change in density in different localities?

5. Describe the distribution of the surface temperature of the sea in different latitudes. Compare the temperature at the surface with that at the bottom of the sea, both in the higher and lower latitudes. Account for the striking difference in the equatorial regions.

6. How are temperatures of the deep sea determined? How are soundings made? What is the object of dredging?

7. Compare the ocean floor with that of the land. Account for differences. What is a continental shelf? About how wide are continental shelves, how deep is the water upon them, and what purpose do they serve? What causes tend to change the area of continental shelves?

8. What is the character and source of ocean bottom materials? How do the deposits differ in different localities? What conditions determine the distribution of animal and plant life in the sea. Point out specific examples.

9. Locate the two ice caps of the earth. Under what conditions and how is the ice formed? What is the difference between floe ice and icebergs? What effect does ice in the polar region have upon the land?

CHAPTER XVI

MOVEMENTS OF THE SEA

The most important movements of the ocean are: (1) **waves;** (2) tides; and (3) currents.

WAVES

A gentle breeze causes ripples to form on the surface of water over which it blows; a strong wind changes these ripples into great waves. During the passage of a wave each particle of water affected rises and falls and moves forward and backward, describing a curved path in a vertical plane. The forward motion of the
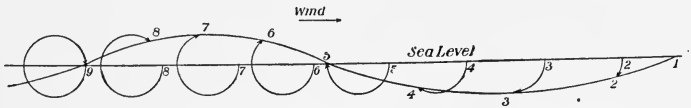
FIG. 82.—DIAGRAM OF WAVE, SHOWING MOVEMENT OF WATER PARTICLES

Particle 3 is going backward, 7 forward, 5 upward, and 9 and 1 downward.
From 1 to 5 the particles of water are going backward in the trough, from 5 to 9 forward on the crest, from 3 to 7 upward on the front, from 7 to 9 and from 1 to 3 downward on the back.
What two motions combined has each of the following: 2, 4, 6, and 8?
How long and how high is this wave?
In what direction is the wave form advancing?
If this wave should run ashore, would the water at the shore advance first or recede first?

water is most rapid in the ridge or crest of the wave, and the backward motion is most rapid in the furrow or trough. The forward motion is slightly in excess of the backward motion. Because of the excess of forward over backward motion of the water particles, when the winds are long continued in the same direction, currents are produced which flow in the same direction in which the wind blows. On the front of the wave the water rises, and on the back of the wave the water falls. As waves move new water enters in front and leaves on the back of the wave.

Height and Length of Waves.—The horizontal distance from the crest of one wave to the crest of the next is the *length,* and the vertical distance between the crest and the bottom of the trough is the *height* of the wave. The height and force of the waves depend upon the force of the wind, the length of time the wind continues to blow, the depth and breadth of the water, and the form and direction of the coast line.

Ground-Swell.—In the open sea during a gale waves are often 30 to 40 feet high, and have a length of a thousand feet or more. High waves often pass out from an area of storm-winds into a region of gentle winds many hundreds of miles away. They become of less height, but keep their velocity and length. These waves that have outrun the storm which started them, and persist after the storm, are known as the *ground-swell.*

Breakers.—When a wave approaches a gently sloping shore the wave length is diminished, and the wave height is increased. The front of the wave, because of a lack of water, becomes steeper than the back; and as the wave continues to move into water of less depth the crest curls and falls forward, forming a line of *breakers.* At the line of breakers on a sandy shore a sand bar is formed. Rocks or bars near the surface of the water may also be located by breakers. Thus breakers are a warning of danger.

Surf and Undertow.—When the waves run into shallow water and break near the shore, *surf* is formed. The water that is then thrown forward in the crest of the waves returns as a current along the bottom. This backward under-current along the bottom of a shallow sea, due to waves and surface currents produced by the wind, is called the *undertow.* When the waves reach the shore obliquely, a current along the shore is produced.

THE WORK OF THE WAVES

Pounding of the Waves.—Waves are agents of erosion; that is, they break and grind the material along the shore and transport it varying distances from the shore.

The work of breaking and grinding is done by the fall of the breakers upon the shores. In summer, in the Atlantic the average blow of breaker is about six hundred pounds on every square foot of surface. In winter the force of the breakers may be as high as 3,000 pounds per square foot. The impact or pounding of the waves on the shores is made effective by the sand, the pebbles and such rock fragments as the waves are able to move. Driven by the force of the waves, they serve as tools for cutting and grinding, and become rounded by acting upon each other.

FIG. 83.—A SEA CAVE

Weak rocks exposed along the shores are broken down and removed. The more resistant rocks are loosened by undercutting, and because of the joints and seams in the rocks fall as angular blocks. These angular blocks in course of time become reduced in size and rounded. Large masses of rock, too large at first to be moved by the waves, are reduced by smaller fragments driven against them until the waves are finally able to use them also as

weapons of attack. Thus huge masses of rock are reduced in turn to cobbles, pebbles and sand, and finally to the finest mud particles, which may be carried away by the undertow.

Sea-Cliffs and Sea-Caves.—The cutting of the waves at the water level may be compared to a horizontal saw. As the waves cut into the shore the unsupported material often falls, leaving a
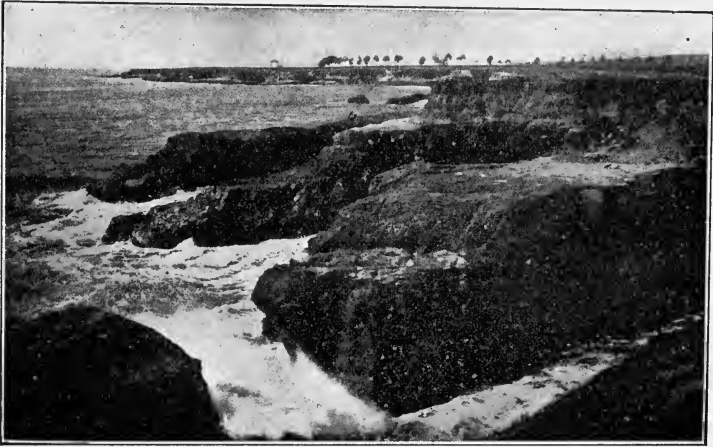
FIG. 84.—THE ACTION OF WAVES, SHOWING TENDENCY TO FOLLOW JOINTS IN THE ROCKS

steep face known as a *sea-cliff*. If the sea-cliff is a wall of rock, and the waves continue undercutting at the base, a *sea-cave* may be formed.

Sea Arches and Chimney Rocks.—If the wearing away of the roof continues, the remaining portion may form an arch or bridge. Sometimes the waves remove block after block of rock along certain joints, so that a column or pillar of rock may be isolated from the shore. These are then known as chimney or pulpit rocks. The "Old Man of Hoy," on the coast of the Orkney Islands, is an example.

Small irregularities in the shore line develop because of differences in the resistance of the rocks, and in their exposure to the attack of the waves; but as a rule the action of waves and shore current

tends to make the shore line more regular; the projecting head-lands are worn away and bay heads are filled.

In certain places waves wear away the land and deposit the material in the sea at a lower level. The rock fragments, pebbles, and sand formed at the shore are ground finer and carried away by the combined action of waves, undertow, and along-shore currents.

Deposition by Waves, Undertow and Shore Currents.—In other localities material is brought in from the sea by the waves and deposited on the shore within the zone of wave action, and forms the *beach*. When the material carried out by the undertow meets that brought in by the waves, an accumulation begins at the place of meeting. A low ridge called a *barrier* is formed, and its position is shown by the line of breakers. Such barriers are often built up to and above the surface of the water, making a sand *reef*.

The free end of a beach or a barrier is called a *spit*. The deposits along the shore depend largely upon the shore currents. The growth westward of Rockaway Beach, on the southern shore of Long Island, is due partly to along-shore currents in that direction.

The growth of shore deposits tends to fill up bay entrances and interfere with navigation. At the entrance to New York harbor dredging is necessary in order to deepen the channels through which the largest boats pass.

TIDES

Tides Defined.—Along the shores of the ocean and its gulfs and bays the water rises slowly for about 6 hours and 13 minutes, and then falls slowly for about the same time, making on an average 12 hours and 26 minutes from high water to next high water, or from low water to next low water. *This periodic rise and fall of the level of the sea twice in every 24 hours and 52 minutes constitutes the tides*.

This makes the hour of high water at any particular place vary from day to day. If it is high water at the ocean shore this after-

noon at 4 o'clock, the next high water will occur again 26 minutes past 4 to-morrow morning, and high water again 52 minutes past 4 to-morrow afternoon, and so on.

Variation in Tidal Range.—The amount of rise and fall is greater along most continental coasts than in mid-ocean, and greatest in bays with broad openings to the sea and narrow toward their heads. The *tidal range* at Key West, Florida, is usually not more than two feet, while in the Bay of Fundy it is often more than 50 feet.

The amount of the rise and fall of the sea at any particular place also varies. The tidal range may increase from day to day for about a week and then decrease for the same period, making a maximum and minimum range twice a month. At Governor's Island in New York Harbor the tidal range may be as small as 3.4 feet, and as great as 5.3 feet during a single week.

Flood and Ebb Tides.—The change of level of the sea is accompanied by tidal currents called the *running of the tides*. When the tide is running from the open ocean into bays, it is *flood* or incoming *tide;* and when the tide runs to the open ocean again, it is the *ebb* or outgoing *tide*. During the few minutes when the flood tide changes to ebb tide or ebb to flood *slack water* occurs.

Tidal Races.—When the tidal currents pass through a strait, such as a narrow inlet into a bay or between an island and the mainland, the currents often run many miles an hour. Such currents are called *tidal races*, and are often so strong as to interfere with navigation. The tidal currents " race " through Hell Gate, the narrow passage from the East River into Long Island Sound, at the rate of five or six miles an hour.

Tides in Rivers.—The tidal wave often runs up rivers to a point many feet above sea level. The tide runs 150 miles up the Hudson River to Troy, five feet above sea level, where the tidal range is more than two feet. The tide is felt 70 miles up the St. John River in New Brunswick, where the elevation is fourteen feet above sea level; and at Montreal, 280 miles up the St. Lawrence River.

The action of tidal currents in narrow rivers is very different from the action of tidal currents on open seacoasts. In rivers, when the water stands above the average level, the tidal current flows up-stream along with the tidal wave, and when the water stands below the average level the tidal current flows down-stream, opposite to the direction of the tidal wave. Since the rate of flow depends upon the difference in level, the flow is most rapid at high and low water instead of being slack water at these times, as on open coasts. Hence the tidal current flows up-stream for some time after high water has passed and the water level is falling; and the tidal current flows down-stream for some time after low water is reached and the water level is rising. In broad, deep mouths of rivers, slack water does not occur at high and low water as on open coasts, nor at average level as in narrow shallow rivers, but at some intermediate level.

Tidal Bore.—In the estuaries of many rivers broad flats of mud or sand are nearly exposed at low water. The tidal wave when entering these rivers often rises so rapidly that it assumes the form of a wall of water. Such a wave is called a *bore*. Tidal bores occur in some of the rivers of China, where in one case the bore travels up the river at every high tide, often reaching a height of twelve feet. After the bore has passed, an after-rush often carries the water up several feet higher.

Bores have been observed on the Severn in England, on the Seine in France, on the Amazon in South America, and on a few other rivers of the world.

Causes of the Tides.—Since Newton announced the law of universal gravitation it has been generally recognized that the tides result from the attraction of the sun and moon. The tide-producing forces of sun and moon can be computed with reasonable certainty, but because of the modified effects due to local conditions an agreement between theoretical and the actually observed tides is not easily secured. Although the moon's mass is only a small fraction of the sun's mass, the moon's nearness to the earth makes it, rather than the sun, the principal cause of the tides.

First Law of Motion.—A body in motion will move in a straight line unless deflected from its straight path by some external force. This law of motion may be illustrated by whirling a stone around the hand by means of a string. The natural tendency of the stone, at each instant, is to move in a straight path. It is deflected and moves in a curved path because of a pull or force, called *centripetal force*, exerted by the string acting inward upon the stone. The stone resists being pulled inward and so tends to move outward, and exerts a pull or force upon the hand called *centrifugal force*. The string being under tension when the stone is whirled, is subject to equal and opposite forces, one acting toward (centripetal), and the other away from (centrifugal), the center of revolution.

Balance between Centripetal and Centrifugal Forces.—The revolution of the moon about the earth is illustrated by this simple experiment. The invisible force called the gravitation which acts between
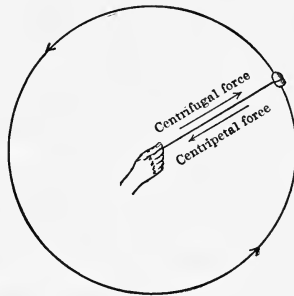
FIG. 85

the moon and the earth replaces the centripetal force exerted by the string that holds the stone to the hand. The moon whirls about the earth with sufficient velocity and at such a distance that her resistance to curved motion, or centrifugal force, just equals and balances the attraction between the earth and moon.

Center of Gravity.—The moon does not revolve about the center of the earth, but about a point 3,000 miles from the center, or 1,000 miles below the surface. This is because the earth is eighty times as heavy as the moon and the centers of the two bodies are 240,000 miles apart.

This may be easily illustrated by balancing two balls, one eighty times the weight of the other and connected by a slender rod. The place where they balance, called the common center of gravity, will be one-eightieth of the distance from the center of the larger ball to the center of the smaller.

Revolution About Common Center of Gravity.—The common center of gravity of the earth and moon is at C. The big and little balls correspond to the earth and the moon, and the stress in the rod represents the
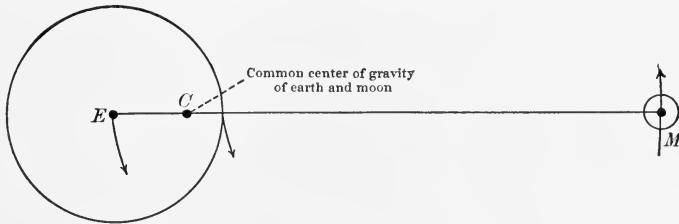
FIG. 86

attraction that holds the earth and moon together. Both the earth and the moon revolve about this common center of gravity, C, in about 28 days, and in so doing the earth's center describes a circle with a radius of 3,000 miles.

The daily rotation of the earth, which is not now being considered, must not be confused with the revolution of the earth, without angular turning, about a point 1,000 miles below the earth's surface. Only the earth-moon revolution about C without rotation of either body is here considered. When a body revolves about another without rotation, *a given side always faces the same direction in space.*

Revolution without Rotation.—It may be stated as a general proposition that whenever an object revolves without rotation, every particle of the object describes a path the size and shape of that described by a particle at the center of the object. The motion of the different particles of a connecting rod attached to the driving wheels of a locomotive illustrates this action.

All parts of the earth then must be subject to equal and parallel centrifugal forces, due to the monthly revolution of the earth and moon about their common center of gravity. These forces act in a direction away from the moon. The total of centrifugal forces acting on the earth is just balanced by the total centripetal force due to the moon's attraction, although it is evident that the two opposite forces acting on any single particle are only equal at the center of the earth.

Unequal Attraction of the Moon in Different Parts of the Earth.—
The moon's attraction for the earth is always toward the moon, but
is not equally distributed, for the attraction on the side of the earth
nearest the moon is stronger than at the center, and on the side of the
earth farthest from the moon weaker than at the center.

Resultant of Two Opposite Forces.—In the figure, A B C D, repre-
senting the equator of the earth, A is a particle farthest from the moon;
C a particle nearest to the moon, and E a particle at the center of the
earth.   The arrows of equal length, extending to the left away from the
moon, represent the equal centrifugal forces; and the arrows of unequal
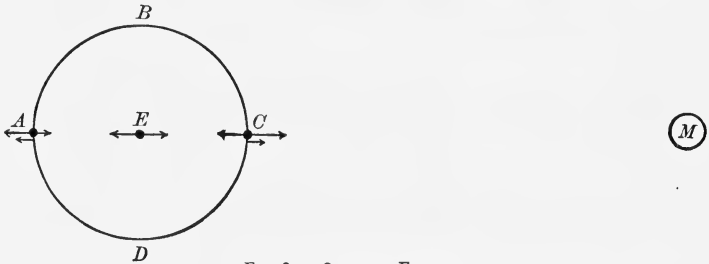
FIG. 87.—OPPOSITE FORCES

lengths, extending to the right toward the moon, represent the unequal
value of the moon's attraction at these points.

When two forces act in opposite directions at the same point, the
effectiveness or resultant of the two forces is found in a force equal to
the difference between the two and acting in the direction of the greater
force.

At C the moon's attraction is greater than the centrifugal force at that
point, so that the *tide-producing force*, which is the difference or resultant
between these forces, acts toward the moon and causes the water on the
side of the earth toward the moon to bulge out toward the moon.

At A the moon's attraction is less than the centrifugal force, and the
tide-producing force consequently acts away from the moon, and causes
the water on the opposite side of the earth to bulge out away from the
moon.

At E the moon's attraction and the centrifugal force are equal and
opposite.   If they were not, the earth and moon would either approach
or recede from each other.

These two bulges of the ocean are the two high tides, and midway
between them is the low tide zone.

The magnitude and direction of the resultant or tide-producing forces
acting at different points on the earth's equator are shown in Figure 87.

Effect of Rotation of the Earth.—The daily rotation of the earth from west to east constantly carries the high and low tide westward around the earth, and brings places alternately to high tide and low tide positions.

The tidal movements are interfered with by the continents which tend to stop or change the direction of the tidal wave. The tidal wave travels faster in the deep ocean than in the shallow water near the continents. The tidal waves are also interfered with by the strong winds and changes of atmospheric pressure. Their advance in different parts of the ocean becomes so irregular that they often interfere with one another. This explains in some measure why the actual local tides in so many places fail to agree with the general theory.

The Establishment of the Port.—The rotation of the earth tends to carry the tidal waves forward in the direction of the rotation. The moon tends to hold the tidal waves back. The result is that the tides are said to lag. The interval of time between the passage of the moon across the meridian and the next high tide, mariners call " the establishment of the port." The establishments of different ports have various values. The port of New York has a value of 8 hours and 13 minutes.

Cause of Solar Tides.—The explanation of solar tides is analogous to that of lunar tides. Since the cause of lunar tides is the difference between the moon's attraction and centrifugal force in different parts of the earth, in like manner solar tides are due to the difference between the sun's attraction and centrifugal force in different parts of the earth, caused by the earth moving about the common center of gravity of the earth and the sun.

Effect of Solar upon Lunar Tides.—The intensity of the tide-producing force due to the sun is about half of that due to the moon. Since the lunar tides are stronger than the solar tides, the solar tides may be said to modify them, that is, to strengthen the tides when sun and moon act together, and to weaken them when they oppose each other.

Twice a month, at times of new and full moon, the lunar and solar tides fall together, producing a higher tide than usual. This condition of greatest range is called *spring tide*. At first and last quarters of the moon the solar high tide falls at lunar low tide, and solar low tide falls at lunar high tide. The effect of this is to lessen the tidal range, that is, the high tides are not so high and the low tides are not so low as usual. This condition of least range is called *neap tide*.

The relative ranges of spring and neap tides may be shown graphically by the construction of tide curves for any station. The data for these tide curves may be found in tide tables published by the Government.

The tides in any latitude vary with the changing angular distance of the moon and sun north or south of the equator, as well as with their changing distances from the earth.

Inequality of Tides.—The two successive high tides of a given place are usually of unequal height. They are of equal height only when the moon is over the equator, and as this occurs on only two days of the month two weeks apart, the two successive high tides are usually unequal. The maximum inequality of successive high tides occurs when the moon is farthest north or south of the equator. This variation at some places amounts to several feet.

Maximum Yearly Tide.—The conditions that favor the greatest tidal range in any particular harbor are: (1) new or full moon; (2) moon and sun nearest to the earth; (3) moon and sun's zenith distances approximating the latitude of the place affected; (4) wind direction favorable to direction of tidal movement.

Effect of Tides.—The erosion caused by tidal currents is known as *tidal scour*. The tidal scour of the flow and ebb of the tide maintains inlets in barrier reefs along many shores. An example of this may be seen in the sand reefs along the shore of New Jersey. Tidal scour also often maintains deep waterways in some bays to the advantage of navigation; whereas at the entrance to other bays the tidal currents tend to fill, making the water shallow, and because of shifting of deposits are dangerous to naviga-
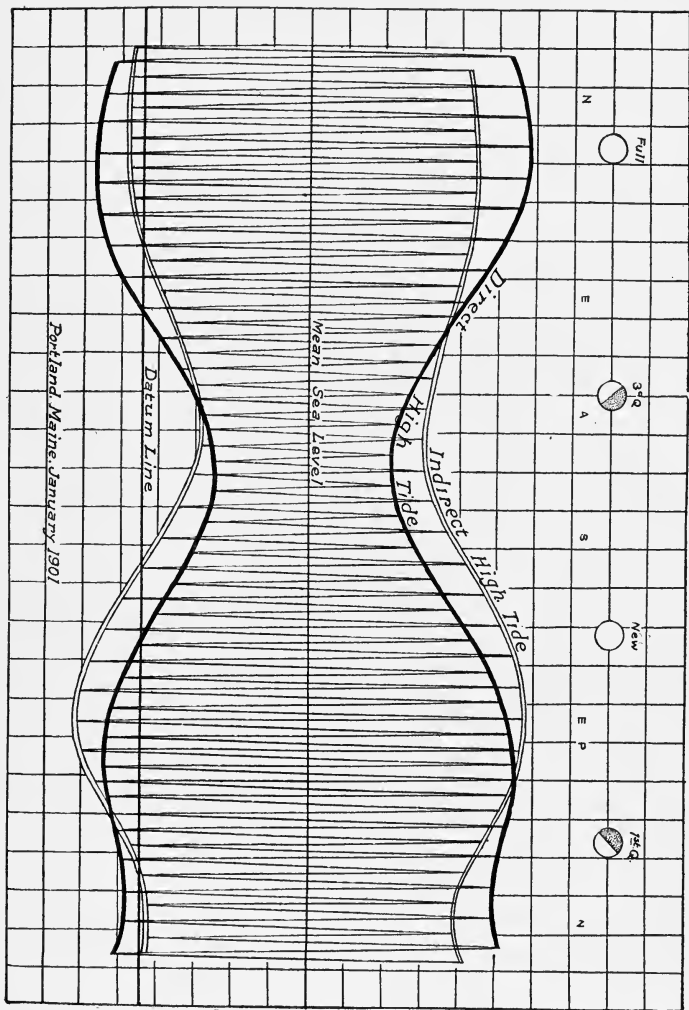
Fig. 88.—Diagram of Tidal Curve

tion. Strong tides hinder the formation of beaches across the entrance of some bays.

The tidal currents cause a circulation of water in bays and harbors which prevents stagnation and helps to remove the sewage that is drained into them near cities. This circulation of water aids or hinders boats, according to their direction, and sometimes drifts vessels out of their course and subjects them to danger of rocks and shoals, especially in times of dense fogs.

Tidal currents transport material along shore from more exposed positions, such as headlands, to the less exposed position at the heads of bays. This filling of bay heads tends to straighten the shore line.

CURRENTS

Every continent is washed by ocean currents, and every ocean has its distinct circulation. Currents from equatorial regions carry warm water into polar regions, and other currents carry the cold polar waters into lower latitudes.

While each ocean has its separate circulation, yet the separate schemes of circulation fit into the general scheme as cog-wheels in a vast machine.

The Pacific Ocean, which for most purposes is considered as one ocean, is by reason of its circulation divided into two distinct parts, the North Pacific and the South Pacific. The Atlantic and Indian oceans lying, like the Pacific, on both sides of the equator, are also divided into northern and southern oceans by reason of their distinct circulation.

Systematic Movement.—Ocean currents, like air currents, obey Ferrel's Law, in that they turn to the right of a straight course in the northern hemisphere, and to the left in the southern. This results in a distinct eastward drift about the margin of the south polar ocean, and a less distinct eastward movement about the Arctic Ocean. In other oceans the northern divisions have a clockwise circulation, whereas the southern divisions have their circulation counter-clockwise.

The movement of the waters in all oceans is chiefly about the

OCEAN CURRENTS
Warm Currents ▭ Cold Currents ▭
The direction of the Currents is shown by the arrows ⟶

O   C   E   A   N

90°

Spitzbergen   Franz Josef Ld

onland

Zemlia

Iceland   Arctic   Circle   60°

EUROPE   Caucasus   A   S   I   A   Stanovoi

Alps   Gobi

Himalaya   Hondo   30°

Sahara   Arabia   Tropic of Cancer

S   u   d   a   n   Philippines

AFRICA   Ceylon   Sumatra   Borneo   0°

Equator   Celebes

Indian Counter Current   New Guinea

INDIAN

Equatorial Current

Madagascar   Tropic of Capricorn

OCEAN   AUSTRALIA

OCEAN   30°

Tasmania

West Wind Drift   West Wind Drift   60°

Antarctic Circle

E WORLD

SHOWING

AN CURRENTS

NOTE
In the Indian Ocean, the China Sea and the West Coast of Mexico
and Central America, the Currents change with the Monsoons   90°

margins, leaving the great central areas undisturbed. In these areas of quiet water seaweed and other floating matter accumulates, thus producing what are known as Sargasso Seas. These seas are avoided by masters of sailing vessels, who find it difficult to get out of these drift-covered waters when driven into them by storms. Columbus thought, when he came to the Sargasso Sea in the Atlantic, that he had come upon land.

Causes of Currents.—Anything that produces a disturbance of the *level* of the ocean surface will, at that place, cause currents.

In the trade wind belts the hot dry winds cause a slight lowering of the surface by evaporation, and there is a natural tendency for the waters to flow in both from the north and the south.

In the doldrum belt, the excessive rainfall slightly raises the surface of the sea, and the water flows out to north and to south.

Great storms, as at Galveston, pile the water up against the land, often with great destruction, and the return of the sea to its normal level produces local currents.

Differences of temperature, while effective in producing *vertical* currents when the heavier water is at the top, can produce *horizontal* movement only when by reason of these differences of temperature the *surface of the sea is raised or lowered*. This may cause a *slight raising of the surface* at the equator or a *slight lowering of the surface at the poles*.

While these various causes may produce local currents, they do not account for the systematic circulation of the oceans. There remains to be considered the all-sufficient cause, the *winds*.

Origin of Ocean Currents in the Trades.—All winds, however fitful, brush the surface water along with them. If they constantly vary in direction, no systematic or continuous currents can result. When the same direction is held for several days, a distinct drift with the wind is observed.

Continued east winds over Lake Erie have at times so heaped up the water toward the west end that Niagara Falls have practically run dry. We are told, too, that strong east winds some-

times drive the waters back from one of the northern arms of the Red Sea, and make it possible to cross this basin " dry-shod."

It is only in the trade wind belts that we find winds blowing continuously from the same direction; and we are disposed to look upon these belts as the *birthplace* of ocean currents. Here the direction of the ocean currents agrees with that of the trades, and neither difference of density nor difference of temperature can have any part in producing this westward movement of the ocean waters. These are the *north* and *south* equatorial currents.

Poleward Currents.—The equatorial currents are barred in their westward movement by islands and continents across their paths. They are thus forced to turn poleward along the western shores of the oceans. Whether they turn northward or southward is determined by the outline of the coast.

While the currents are moving along and near the equator, the earth's rotation has but slight deflecting influence; and it is probable that, if not interrupted by land barriers, the equatorial currents would continue their westward course around the earth.

As soon, however, as they begin to flow into other latitudes, the rotation of the earth is effective in turning them from a straight course to the right in the northern hemisphere and the left in the southern.

These poleward currents are *warm* currents, and carry the warm water from the equatorial regions into colder latitudes. At the same time they spread out, lose their velocity, and are then known as *drifts,* which move to the margins of the polar oceans, then eastward to the eastern shore of the ocean in which they have their origin.

Equatorward Currents.—By continued deflection, these eastward moving currents, now cooled from loitering in high latitudes, are turned toward the equator along the western coasts of the continents. Returning thus to the trade wind belts, in which they assume their westward direction, the circulation about the ocean is complete.

The equatorward currents are *cold* or *cool* currents, and bring

lower temperatures toward or even to the equator, causing the eastern sides of *equatorial* oceans to be cooler than the western sides.

The movement of currents about the Arctic Ocean is less systematic than about the Antarctic, because of the numerous islands in the north that interrupt. Branches from the circumpolar movement in the north are sent off southward into the Pacific and the Atlantic. These *cold* currents deflected to the right, follow closely the eastern coasts of Asia and North America, until they sink beneath the warm currents between the parallels of 40° and 50° N.

Creep.—Their further journeying toward the equator is known as *creep*. In this way the cold polar waters are carried even to the equator, and the low temperatures of deep equatorial seas are accounted for. We cannot *observe* the creep, but as *more surface water* is *carried into polar regions than returns as surface currents*, the excess must be equalized by under-surface return currents.

Monsoon Currents.—If any doubt existed as to the sufficiency of the winds to produce ocean currents, that doubt would be removed by a study of those currents which change their direction with the change of direction of the monsoons.

While there are monsoons at the Horse Latitudes, the winds there are of neither sufficient strength nor constancy to be effective in producing ocean currents. It is in the monsoon belt over which the heat equator migrates that we find conditions favorable for the production of ocean currents.

About the northern Indian Ocean, when the southwest monsoon blows, the water is set drifting in a clockwise direction. As these winds weaken, this drift slackens; and soon after the northeast monsoon begins, the direction of the drift is reversed. It continues as a counter-clockwise circulation while the northeast monsoon continues, changing again to the clockwise direction with the return of the southwest monsoon. These changes of direction of the ocean currents can be accounted for only by the reversal of the winds.

In the Pacific Ocean, where the heat equator lies prevailingly north of the terrestrial equator, the southeast trades, changed to southwest winds north of the equator, *set up an ocean drift to eastward*. This is the *Equatorial Counter Current*. It is fairly distinct throughout the year, though better developed during the northern summer. Its explanation is the same as that of the clockwise movement about the northern Indian Ocean during the southwest monsoon.

Because of the narrowness of the Atlantic Ocean at the equator, the counter-current is not so well developed as in the Pacific.

Currents and Navigation.—Sailing vessels lay their courses to suit the winds and ocean currents; and even steamships do not scorn to take advantage of the great ocean circulation.

Sailing vessels from New York to English ports take advantage of the northeast Atlantic drift; on their return they use the trades. Those bound from New York to Rio Janeiro must lay their courses far to eastward of the eastern cape of South America, lest the equatorial currents carry them northward again while in the doldrums, where winds are apt to fail.

Ships sailing from Atlantic ports for Australia sail eastward around the Cape of Good Hope, to take advantage of the Antarctic drift; while those returning also sail eastward past Cape Horn, to have the advantage of the same drift.

Vessels bound from Honolulu to San Francisco sail northward beyond the trades and equatorial current, then east; returning, they take a more southerly route.

Currents and Life.—The distribution of many marine forms is determined by the temperature of the water, which in turn is in part determined by ocean currents. Corals serve well to illustrate. The waters about the Galapagos Islands are too cold for corals, although these islands are situated upon the equator. The cold Peruvian current makes these waters cold. Contrasted with these are the Bermudas, in latitude about 35° N., which are largely composed of coral rock and bordered by coral reefs. The warm waters are brought to these islands by the Gulf Stream.

The seeds of many plants are distributed by means of ocean currents; and insects and the smaller animals are carried upon drifting materials in these currents.

Currents and Climate.—The *direct* climatic influence of ocean currents is confined to the ocean and immediately bordering lands. Indirectly their influence may be felt hundreds of miles inland. This is markedly true of lands lying to leeward of currents that are abnormally cold or warm.

The North Atlantic Drift, the continuation of the Gulf Stream, is perhaps the most pronounced and far-reaching of all ocean currents in its climatic influence. The winds from over this broad sheet of warm water not only bring abundant rainfall to the British Isles and Norway, but so temper the cold of these high latitudes as to make them comparable in temperature to our own eastern coasts, twenty degrees farther south.

The North Pacific Drift, the continuation of the Japan Current, tempers the climate of Alaska and British Columbia in like fashion.

These great drifts, in both oceans, continue or send branches southward along the western coasts of the continent; and when they reach the latitude of northern Mexico and Africa, their effect is to *temper the heat of these coasts*.

The cold currents that follow closely the eastern coasts of North America and Asia, being to leeward of those continents, do not affect the climate so far inland. However, the bleakness of Labrador and Kamchatka is in some degree traceable to these currents.

In the southern hemisphere the *western* coasts are *cooled* and the *eastern* coasts *warmed* by the ocean currents; but their influence is less pronounced than in the northern hemisphere.

Currents and Harbors.—The harbor of Hammerfest, at the north of Norway and well within the Arctic Circle, is about as free from ice as that of Boston, 30° farther south. In the one case we see the effect of the warm North Atlantic Drift; in the other, of the cold Labrador Current.

In the Pacific Ocean the barrier of the Aleutian Islands, together with the narrowness of Bering Strait, prevents the North Pacific Drift from entering the Arctic Ocean. As a result, the bays on the north coast of Alaska, in the same latitude as Hammerfest, are practically closed by ice throughout the year.

The Russian-Japanese War had for one of its objects the securing for Russia of the open harbor of Port Arthur. The harbor of Vladivostock, Russia's chief port on the Pacific, in about the latitude of New York, is for a long time every year closed by ice, owing to the cold current coming down through Bering Strait.

The Gulf Stream.—This greatest and most important of all ocean currents derives its name from the Gulf of Mexico, from which it issues. It is in fact a continuation of the combined equatorial currents.

The North Equatorial Current in the Atlantic is turned by the land masses in its path wholly into the northern division of this ocean. Much of its waters pass among the islands of the West Indian group, while the remainder passes to the eastward.

The eastern cape of South America is so situated that it divides the South Equatorial Current in two, part of it turning southwest along the coast of Brazil as the Brazilian Current, while the other part enters the Gulf of Mexico between the West Indies and the mainland of South America. This water issues through the Strait of Florida as the *Gulf Stream*. It is truly a *stream*, flowing between banks of water. It is there deep and narrow, scouring the bottom of the strait, and flows with a velocity greater than that of the lower Mississippi River.

Joined by the waters that come through the West Indian group of islands, and that which passes outside, the Gulf Stream is greatly increased in volume. It passes parallel to and near enough to the Carolina coasts to send off return eddies, which build the Carolina capes. Spreading and decreasing in velocity, the Gulf Stream becomes the North Atlantic Drift.

The frequent and dense fogs off Newfoundland are produced by warm winds from the North Atlantic Drift, blowing over the cold

Labrador Current. The line of meeting of the cold and warm waters is known as the *cold wall*.

QUESTIONS

1. Tides resemble waves in many respects. High and low tides correspond to what parts of the wind wave? Tidal currents correspond to what phenomenon of the wind wave? The change in tidal range, the velocity and form of the tidal wave as it advances in shallow water on the continental shelf and into bays may be compared to what changes in the wind wave as it moves toward the shore? Compare the height and length of wind waves with that of tidal waves.

2. Is sea-sickness more likely to occur on large or small boats? Why? What is the difference between surf and a breaker? What work is done by breakers and the undertow? Why are breakers a warning of danger?

3. Explain how the waves act as a horizontal saw cutting into the land. What are some of the shore features resulting from wave action? What effect has these features upon the value of harbors and shore property?

4. How would a thoughtful person living at the shore for any length of time naturally connect the cause of the rise and fall of the sea with the moon?

5. Explain how navigation is affected by (a) Tidal range; (b) Flood tide; (c) Ebb tide; (d) Tidal races; (e) Tidal bores. How do you think the state of the tide affects fishing?

6. How can one moon cause two daily tides, or in other words, what is the cause of a high tide on the side of the earth opposite to that of the moon?

7. Which has a lower low water, a spring or a neap tide? Explain. How often does the moon cross the equator? What effect has this on the height of the two daily tides?

8. What effect has tidal scour upon waterways, inlets, and tidal streams? What is the general effect of tides upon the water and shores in and about bays and harbors?

9. What is an ocean current? How fast do they flow? How deep are they? Describe a particular current in detail.

10. What is meant by the cog-wheel scheme of circulation? What is a Sargossa Sea?

11. What is the general cause of ocean currents? Point out definite evidence. Name and locate several ocean currents. What is a "creep"?

12. What is the effect of ocean currents upon climate? Point out specific examples. What is the effect of ocean currents upon navigation? Point out specific examples.

PART IV

THE LAND

CHAPTER XVII

THE MANTLE ROCK

Structure of the Solid Earth.—Everyone is familiar with the fact that solid rock appears on the surface of the land in but few places, and that this surface nearly everywhere consists of loose or unconsolidated earthy matter. This is the *mantle rock*. In some places it reaches a thickness of several hundred feet, but as a rule, the full thickness is revealed in stream valleys, and one can find such sections as that shown in Fig. 89 in nearly all ravines.

The solid rock which underlies the mantle rock is called the *bed rock*. In the ordinary sense the term rock does not include loose, fragmental deposits, but natural formations of the same origin show all degrees of consolidation from that of sand to the hardest sandstone. We therefore define rock as *a natural deposit of earthy matter, whether consolidated or not.*

Economic Importance of the Mantle Rock.—The mantle rock is of the greatest economic importance. Without it the surface of the land would be solid rock, and agriculture would be impossible.

All the mantle rock, except the layers of pure clay, permits water to pass readily through it, thus acting as a *distributer of water.* A portion of the rainfall sinks into it, and through the action of gravity is slowly distributed to all parts below the *water table* (p. 270). Above the water table, water is diffused by capillary action.

The mantle rock acts as *a great reservoir* which receives and temporarily stores a large portion of the rainfall, thus tending to *prevent floods* which would otherwise occur after every heavy rainstorm. The quantity thus conserved is much greater than that conserved by the forests, important as is this latter amount. The water in this reservoir supplies wells and springs, keeps plants alive in dry weather, and much of it gradually makes its

way into the streams, furnishing a supply of water even in dry seasons, thus making the larger *streams permanent* and fairly uniform in size.   A large portion of the water supply of Brooklyn, N. Y., is obtained from wells that do not reach the bed rock and from which several million gallons per day are pumped.

The mantle rock is a *natural filter*.   Rain washes the air, beating down dust particles and removing disease germs.   On the surface
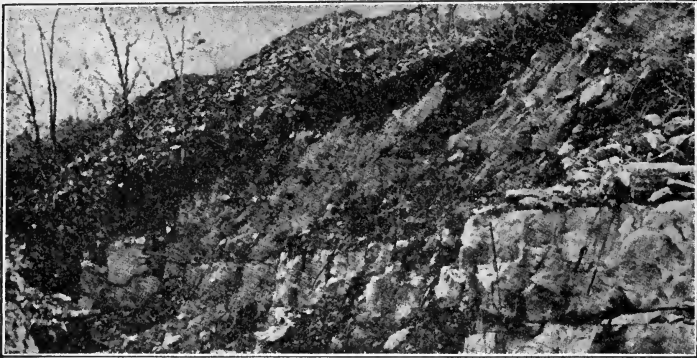
FIG. 89.—NATURAL SECTION SHOWING MANTLE ROCK AND BED ROCK
Lockport, New York. Geological Survey of New York.

of the earth it becomes muddy and is contaminated in many ways, making the surface water unsafe for household use. The water of wells and springs is clear because the mantle rock has filtered it, and if wells are not too shallow the water is generally pure and safe to use.

The mantle rock is a great *storehouse of plant food*. As it is a poorer conductor of heat than the solid rock it acts as a blanket, diminishing the earth's loss of heat by radiation.

Origin of the Mantle Rock.—The mantle rock consists of fragments of bed rock in various stages of disintegration and decay, that have been loosened and changed through the action of a number of natural agents which accomplish the result in different ways.

The quiet action of the atmosphere, with its moisture and its changes in temperature, slowly disintegrates solid rock, and in this manner has formed much of the mantle rock and is of great im-

portance. This process is known as *weathering*. *Glaciers* and *running water* wear away the surface of the rock over which they move and add the loosened particles to the mantle rock.

An appreciable addition to the mantle rock results from the action of wind-blown sand and the waves on solid rock. Figs.
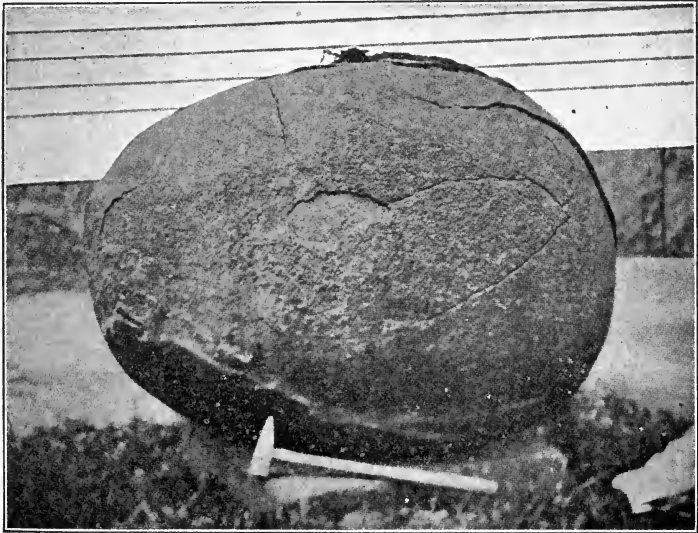
FIG. 90.—OVOIDAL BLOCK OF GRANITE
Produced by weathering. Redstone Quarry, Westerly, R. I.
From U. S. Geological Survey.

94 and 97 show rock that has been much worn by wind-blown sand and Fig. 83 by wave action.

The most important source of mantle rock is weathering.

Weathering.—Every boy has learned that the stones found in the fields differ greatly in hardness and strength. Sometimes one finds a stone that will crumble in one's hands or that will scale off on the outside and is well preserved and hard in the center. Such specimens illustrate weathering.

The difference in the appearance and the solidity of freshly quarried rock, and that of the same rock which has been exposed long to the action of the elements, is due to weathering. The

stones of many buildings less than a quarter of a century old show
the effect of weathering, and some of the stones that are used
extensively for building in the United States, weather to such an
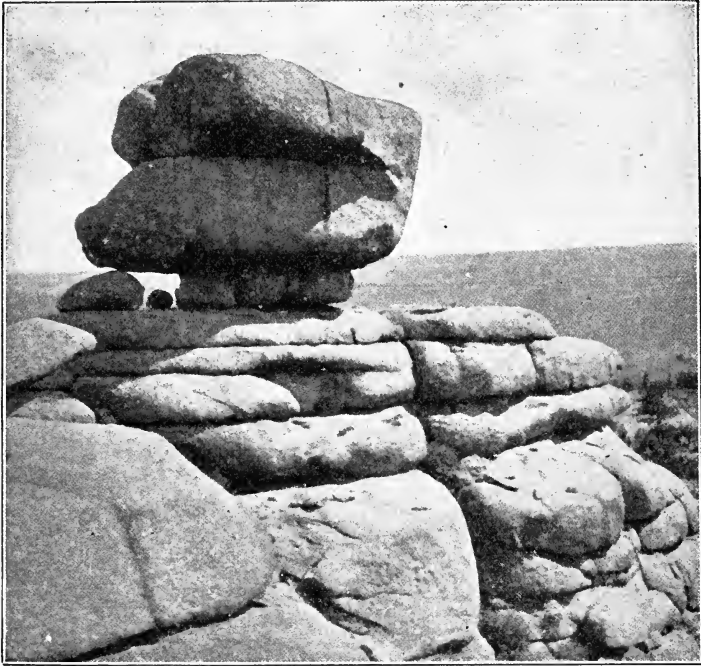
FIG. 91.—GRANITE BROKEN BY INTERNAL STRESS AND AFTERWARD WEATHERED
The rounded forms and apparent stratification were caused by rapid weathering along the
lines of fracture.

extent in a few years that it is necessary to protect them in some
manner to prevent their entire destruction.

*Weathering is the term applied to the various natural processes of
softening and disintegrating the surface layers of rock exposed to the
atmosphere.*

Chemical Weathering.—Certain agents of weathering attack
rock in practically the same way that articles made of iron are
attacked when they rust. These agents produce chemical changes
iu the rock and the products of their action are new substances
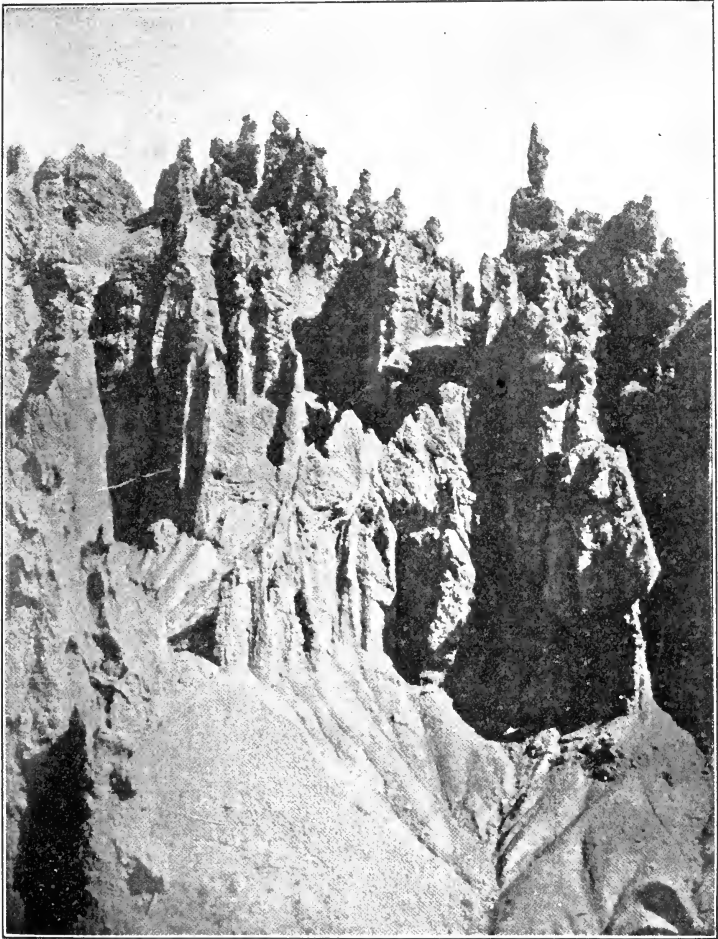
FIG. 92.—HOODOO BASIN, AHOARAKA RANGE, YELLOWSTONE PARK
Showing fantastic torms carved from igneous rock by rain and weathering.

entirely unlike the original, just as iron rust is unlike the iron from
which it was formed. These are the *chemical agents* of weathering.
The most important chemical agents concerned in weathering are
oxygen, carbon dioxide, and water.

Oxygen.—This is the most active of the elements in the air. In the presence of moisture it not only combines with iron and a number of other metals but it also attacks many compounds found in the rocks, uniting with them and forming new compounds. A ledge of rock is often easily crumbled and of a brownish or yellowish color on the outside, and firmer within. Such changes are due to the action of oxygen, and the changed substance is said to be oxidized.

Carbon Dioxide.—This is another constituent of the air which *corrodes* rock. It is most active when dissolved in water. The igneous rocks are largely composed of complex minerals and are decomposed by water containing carbon dioxide. When the constituent minerals contain calcium, one of the products of this action is calcium carbonate. Being soluble the calcium carbonate thus formed is carried to the sea by streams, where much of it reappears in solid form as limestone.

Water.—Water often combines with some of the constituents of rocks, with an increase in volume which causes the remainder of the rock to crumble. Certain micas illustrate this action, and this probably accounts for the rapid weathering of micaceous sandstones.

Other Chemicals.—Nitric acid formed in the air by lightning, certain sulphurous gases erupted by volcanoes, and acids formed by decaying vegetation also produce chemical changes in rocks which result in their disintegration.

Mechanical Weathering.—Certain agents *abrade* rocks in the same way that a file wears away iron. This is a mechanical process and the products remain the same material as the original substance, just as iron filings are the same material as the piece of iron from which they were separated. Other agents disintegrate rocks by blows like those of particles of flying sand. All of the agents which disintegrate without changing the identity of the material are *mechanical agents*.

Changes in Temperature.—When stone is heated or cooled it expands or contracts. If the heating or cooling is slow enough to change the temperature uniformly throughout the mass the effect

is slight. If, however, the rock is unequally heated or cooled it produces the same sort of stress in the rock that is produced in a glass jar when hot fruit is poured into a cold jar. This stress caused by unequal expansion of different parts frequently breaks the rock just as it does the fruit jar. Both glass and rock are poor conductors of heat, and, therefore, when the surface of either substance is heated the temperature of the surface rises more rapidly than that of the interior, thus establishing the condition of stress which tends to disrupt the substance. Every ledge of rock upon which the sun shines is subjected to this action to a greater or less degree, and when the daily range of temperature of the rocks is large, as it is in high altitudes, expansion and contraction is sometimes the most effective agent concerned in local weathering.

When a layer of rock has been uncovered so as to receive the sun's rays, as at the bottom of a stone quarry, the resulting rise in temperature expands the rock, producing tremendous lateral pressure which sometimes causes the rock to buckle and break. This pressure is increased in the daytime and diminished at night. These daily fluctuations in stress are effective in weakening the cohesion of the rock, thus assisting in weathering it, and the varying lateral pressure may materially aid in displacing the adjoining rock.

In New York City a cement sidewalk 700 feet long and 15 feet wide was completed in February. One warm day the following June the lateral pressure due to the high temperature caused the sidewalk to buckle in three places, raising three miniature mountain ranges nearly a foot high across the walk. The stone was much broken at these places. It was repaired in July and has not since repeated the phenomenon. Why?

When the Chicago and Northwestern Railroad was in process of construction a portion of its line along the shore of Devil's Lake, Wisconsin, passed over a large mass of very hard rock, quartzite, occupying a narrow space between a nearly vertical cliff of the same substance and the shore. After expending large sums of money experimenting with various kinds of drills, including the diamond drill, in an effort to remove the rock by blasting, they

FIG. 93.—TOP OF PIKE'S PEAK, SHOWING ROCK BROKEN BY FREEZING AND THAWING

were about to abandon the work when someone suggested that wood fires be built upon the rock and that when the rock was well heated a stream of cold water be thrown upon it. The plan was a
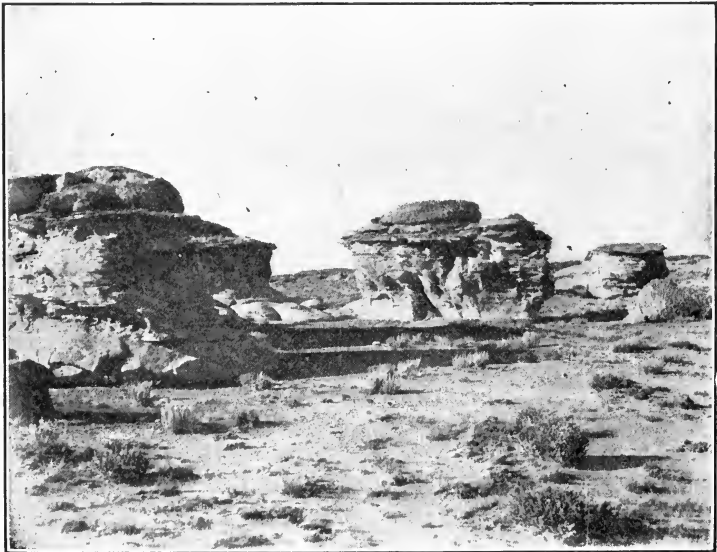
FIG. 94.—EFFECTS OF WIND-BLOWN SAND (ARIZONA)
By permission of Oliver Lippincott.

success and the quartzite was removed in this way. Farmers sometimes remove bowlders by this process.

Frost (*Freezing and Thawing*).—Water is usually found in crevices and the minute spaces between the particles which compose the rock. When this water freezes it expands and breaks the rock just as water freezing in water pipes breaks the pipes. The
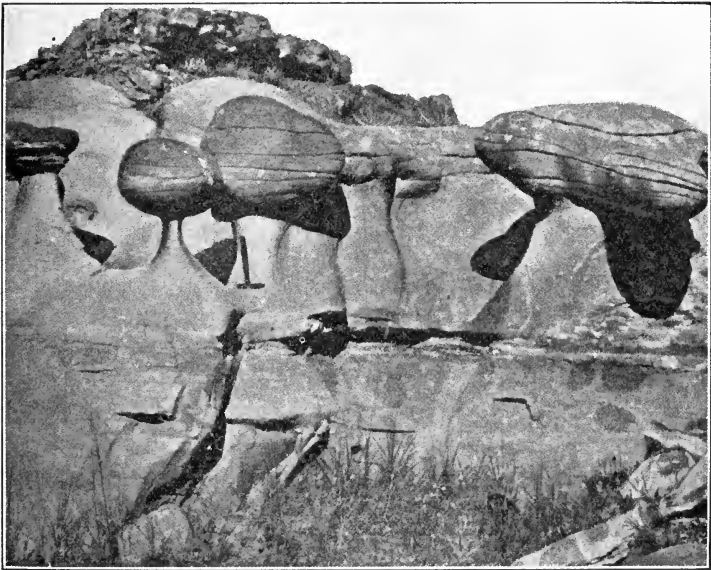
FIG. 95.—OVAL CONCRETIONS
Exposed by weathering of the weaker sandstone surrounding them. Near New Castle, Wyoming.

effect upon the rock is the same as would be produced by driving minute wedges into each space containing water. This action is sometimes called the "wedge work" of ice.

The process of freezing and thawing is more effective in weathering porous rocks, particularly those composed of large crystals, than compact rocks. In a dry though cold climate this action is of much less importance than in a moist, cold climate.

The obelisk now in Central Park, New York City, stood for

FIG. 96.—RIPPLE MARKS, FORMED BY WIND (VOLTS TRADING POST, NEW MEXICO)
By permission of Oliver Lippincott.

3,000 years near the mouth of the Nile in Egypt, yet when it arrived in the city the inscriptions on it were finely preserved. In a short time freezing and thawing had weathered it to such an extent that it became necessary to treat the surface of the obelisk with paraffine to fill the pores and keep the water out. Fig. 93 shows the extent to which the rock forming the top of Pike's Peak has been broken by this action.

Wind.—The sand blast, a device which blows a stream of sand against objects, is widely used as a means of cleaning the outside of stone buildings, removing rust from metals, etching glass, and similar processes. Wind-blown sand is a natural sand blast; it loosens particles from exposed surfaces of rock, and adds them to the mantle rock.

Window panes in houses, in certain localities on Cape Cod, are abraded by wind-blown sand and their transparency destroyed; and in regions of strong winds pebbles are worn into triangular shapes and even perforated.

Plants and Animals.—The roots of plants find their way into cracks in rocks and as they grow larger exert great pressure on the rock, often

breaking off large pieces.   Roots of trees growing near a city sidewalk frequently illustrate this action by raising or breaking the walk.   The decay of vegetable matter supplies acids which act vigorously on certain minerals.

Earth worms, moles, ants, and other animals living in the ground bring much soil to the surface, exposing it to the air, and thus play an important part in changing insoluble minerals into the soluble form suitable for plant food.   They also aid in the distribution of air and ground water through the tunnels and holes which they make.

Gravity assists in weathering rock by removing loosened fragments from steep rock walls, thus exposing fresh surfaces to the air.

Weathering Below the Surface.—Certain kinds of weathering take place below the surface, but it is in general much less rapid than on the surface; indeed, one foot of impervious soil has frequently been found to have quite perfectly preserved the polish and the scratches given the bed rock by continental glaciers.   In porous mantle rock weathering certainly takes place at considerable depths.   This is proved by the thick deposit of residual mantle rock which overlies some deposits of granite and other durable rocks.
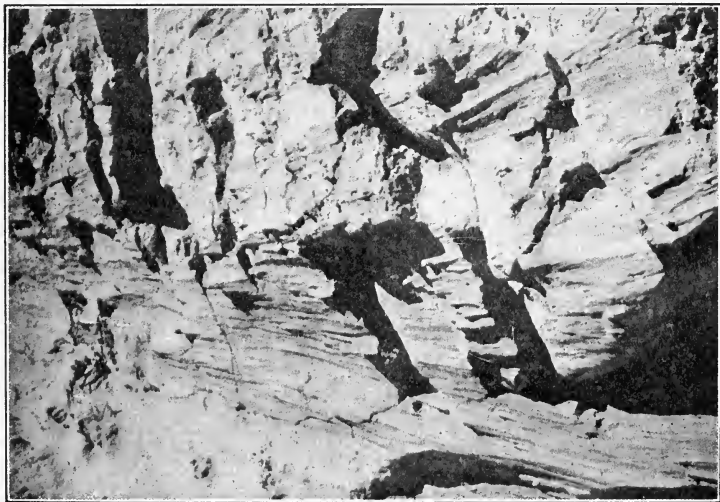
FIG. 97.—SANDSTONE UNDERCUT BY WIND-BLOWN SAND (BANNER COUNTY, NEBRASKA)

Residual Mantle Rock.—Some portions of the mantle rock remain in the position in which they were formed and such deposits are called *residual mantle rock*. All residual mantle rock is a product of the weathering of the bed rock below it, and consists only of such materials as can be formed from the bed rock by the processes of weathering. The gravel and stones scattered through the deposit are all like the bed rock except as they show various stages of decomposition. The upper layers of residual

FIG. 98.—DIAGRAM OF RESIDUAL MANTLE ROCK

mantle rock consist of smaller and more perfectly decomposed particles than the layers below them, because these upper layers protect to some extent those below them. There is usually a gradual increase in size and angularity of the fragments as we descend, as indicated in Fig. 98.

A change in the character of the bed rock is at once indicated by a change in the nature of the mantle rock, and it is not usual to find large areas having the same kind of residual mantle rock.

Deposits of Vegetable Matter.—During the last stages of the destruction of a pond or a lake vegetable matter accumulates more rapidly than the other materials which fill them, and the swamp thus formed is often a bed of plant fibre that is quite free from earthy matter and that burns well when dried. *Peat* is formed in this way. It consists chiefly of the remains of mosses

and marsh grasses which are but slightly decomposed. Many
ponds and marshes illustrate a stage in the formation of peat,
and many peat bogs are found in the New England States, in
New York, and in many other parts of the United States. The
peat bogs of Ireland are well known and very extensive, one of
them having an area of more than 600 square miles.
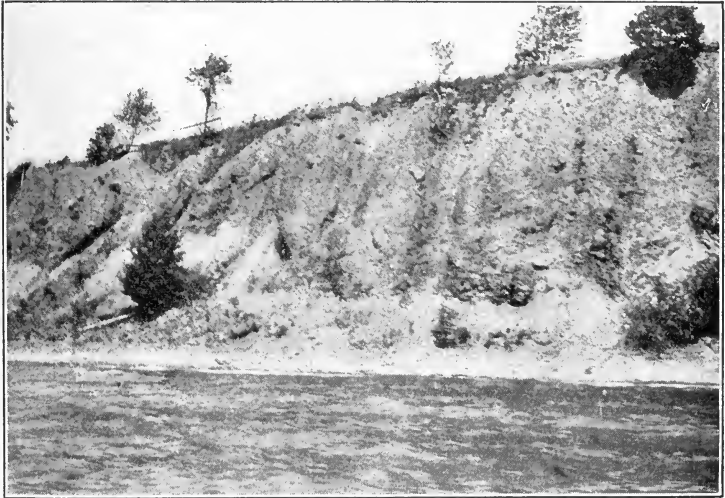
FIG. 99.—TRANSPORTED MANTLE ROCK
Bluff Point, N. Y.

The Dismal Swamp of Virginia, and the million acre swamp of
the Kissimmee Valley of Florida, are examples of large deposits
of a similar nature in the United States.   These deposits of partly
decomposed vegetable matter are a part of the mantle rock and
are like the residual mantle rock in that they have not been re-
moved from the locality where they were formed.

When exposed to the air vegetable matter decays and its con-
stituents pass into the air, but when under water it loses its volatile
constituents and gradually approaches more and more nearly a
pure form of carbon.

The mosses that form these deposits grow on the surface and die

beneath, thus raising the surface so that it sometimes rises above the surrounding land or even climbs an adjoining hillside as in the "climbing peat bogs."

Transported Mantle Rock is that which has been carried to the location where it is found by some natural agency. Its composition, as a rule, bears no relation to that of the underlying bed rock, and is a mixture of fragments of many kinds of bed rock. Since certain agents which transport rock-waste act over large areas, we sometimes find deposits of transported mantle rock of quite uniform composition and structure extending over thousands of square miles. The deposits of all large rivers illustrate this fact.

Transportation of Mantle Rock.—Five agents are chiefly responsible for the transported mantle rock.

1. *Rivers.*—Every muddy stream is actively engaged in the work of transporting mantle rock, and each stream has a burden in progress toward its mouth that is measured by the extent of the bottom lands along its valley and the depth of the transported mantle rock that forms the bottom lands. Mantle rock that has been transported by streams is called *alluvial mantle rock.*

2. *Glaciers.*—The glaciers carry mantle rock slowly, but the size of the particle carried is not limited by the velocity, as it is in the case of rivers, and the total load that a glacier can carry is limited only by the amount that it can get. The greater part of the transported mantle rock in the northern United States and in northern Europe is *glacial mantle rock.*

3. *Wind.*—The presence of dust in the air is a familiar fact in every household; it settles on everything that air reaches. No building is so tall that the upper story rooms never need dusting, and no mountain is so high that its snows are free from dust.

Dust and sand grains are supported in the air by irregular currents, both convectional and forced.

In the Missouri Valley during low water great clouds of sand and dust are picked up by the winds and carried many miles. In the arid regions of the Southwest it is claimed that the dust storms are as dangerous as the blizzards of the Northwest.

Volcanic eruptions sometimes project great quantities of ash or volcanic dust (finely divided lava) into the air. The finer particles of this dust are carried great distances; indeed, it is believed that the dust projected into the air during the great eruption of Krakatoa in 1883 was carried several times around the earth and that some of it remained in the air for three years. This is probably the only way in which material from the land adds to the deposits forming in mid-ocean.

4. *Gravity.*—Avalanches and landslides are well-known illustrations of transportation through the action of gravity which occasionally moves great masses of mantle rock. A recent landslide in British Columbia removed a large section of a mountain, buried a town located in an adjoining valley, and portions of the mountain were carried some distance up the opposite side of the valley.

A disastrous avalanche occurred February 27th, 1910, in northern Idaho. It buried the mining towns of Mace and Burke, with great loss of life and destruction of property. On March 1st, 1910, a train on the Great Northern Railroad was swept from the tracks by an avalanche which buried the track beneath a mixture of snow and earth. The accident occurred at Wellington, Wash., near the summit of the Cascade Mountains.

In connection with the ground water gravity moves the mantle rock slowly down slopes, sometimes breaking off pieces of inclined strata over which it passes, and opening the layers so that air and water may circulate more freely. This action is known as *creep*.

Mantle rock that has been transported by gravity is called *colluvial mantle rock*.

5. *Waves.*—Between the breakers and the shore line water dashes up the beach from every incoming wave and carries so much of the beach sand with it that the water usually looks muddy. If the sand is white and free from clay, the water becomes clear at the instant that the shoreward motion ceases, to become muddy again as it gains velocity during its return. This latter motion follows the laws which govern motion down an inclined plane; it moves in the direction of the slope of the plane and increases its velocity at a rate which depends upon the slope of the beach. This return motion, the *undertow*, carries the finer particles of the beach deposit with it.

When the wave is oblique to the shore line the to and fro motion of the water between the breakers and the shore is not along the same line as it is when the waves are parallel to the shore. This backward and forward motion transports the beach materials slowly along the shore. The amount of material transported in this way increases as the waves become more oblique and reaches a maximum when the wind is parallel to the shore.

Deposition.—The agents that transport mantle rock deposit it as they lose carrying power and form physical features that differ so widely in shape and structure that, in most cases, the agent that transported a given deposit may be readily determined.

1. *Alluvial Deposits.*—The sediments carried by streams are quite perfectly assorted, giving us layers of mud, silt, sand or gravel in the various deposits, but the stratification is very irregular. A layer of clay may be found a given distance below the surface at one point, and 100 feet away gravel may take its place. Such changes are due to the fluctuations in volume which vary the transporting power of the stream and which often wear away portions of a deposit, afterward filling the depression thus formed with material that differs from that removed, and breaking the continuity of the layers. The gravel of the deposits consists largely of rounded pebbles of the more durable rocks. The physical features thus formed have a nearly level surface.

Flood plains, as the valley *flats* which border many streams are called, have the characteristic irregular stratification mentioned. They are usually somewhat higher along the margin of the stream than farther away and often slope gently down stream, following the river profile.

Deltas.—The upper and lower beds of a delta consist of nearly horizontal layers of fine material and the middle portion of diagonal layers of coarser particles. The middle layers are formed by the material rolled along the bottom of the stream.

Fans and Cones.—These are ordinarily semi-circular deposits with very imperfect stratification. They occur where a stream leaves a gorge or ravine having a steep slope and flows over a low-land of more gentle slope. The coarsest material is found where

the most abrupt change in slope occurs, that is, at the mouth of the gorge.

2. *Glacial Deposits.*—The deposits formed by a glacier are always unassorted and unstratified, and they consist of many kinds of rock. Fragments of weak rocks, like shale, are found in them. The pebbles are angular instead of rounded and their surfaces are rough like freshly broken stone, except where one has been smoothed and flattened by contact with the rock over which the glacier passed. Unlike the river sediments, glacial deposits contain little decomposed rock; even the smallest particles are ground rock rather than decomposed rock.

Among the more important features formed by glaciers is the terminal moraine described on page 337. Its surface is irregular, with mounds and hummocks associated with irregular depressions. Level sky lines are conspicuous by their absence.

The drumlin described on page 344 is an oval hill of bowlder clay and was deposited under the ice. Deposits formed under the ice are sometimes composed of rock fragments and bowlders imbedded in a tough clay. This is called bowlder clay.

3. *Aeolian Deposits.*—Inasmuch as the wind holds the fine particles in suspension longer than the coarse, moving air deposits the coarse and fine particles in different places. This results in layers made up of particles which within certain limits are uniform in size and weight. The assorting is much less perfect than that of water, and the conditions causing deposition of a stratum of a given character are generally less permanent. The velocity of the wind is proverbially inconstant and every change alters the size of particle deposited; but deposits formed by wind show distinct and characteristic stratification.

Obstructions are effective in determining the location of the coarser particles to a somewhat greater extent even than they are in determining the location of snowdrifts, because the greater part of the sand is carried in the lower layers of the air. A rather larger proportion of such deposits, therefore, will be found about obstructions. The deposit itself becomes an obstruction of increasing importance. Such hills of wind-deposited sand are called *sand dunes*.
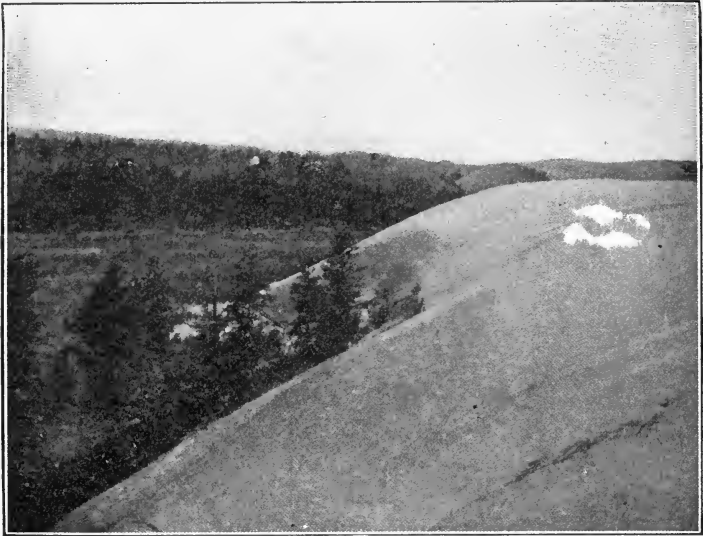
FIG. 100.—SAND DUNE ADVANCING OVER TREES (DUNE PARK, INDIANA)
Note the steep slope of the lee side.

Sand Dunes.—The typical sand dune has a much more gentle slope on the windward side than on the leeward. This is true of even the smallest deposit, such as that formed about a chip; the sand grains carried by the air strike the chip, lose velocity and drop or bound back, piling up on the windward side until the pile forms an inclined plane up which the wind can roll grains of sand.

Standing beside a small dune when a strong wind is blowing one sees the sand moving up the windward slope, streaming over the crest, and falling upon the leeward slope, which from time to time adjusts itself to the proper angle by miniature landslides formed where it has become too steep. The angle at which such a slope will come to rest is called the " angle of repose," and varies with the size and shape of the particles.
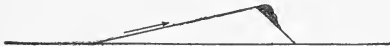
FIG. 101.—DIAGRAM OF SAND DUNE
Arrow shows wind direction.

Dunes are numerous along coasts, because sand is com-

monly found there.   They are more likely to be formed by on-shore
than by off-shore winds (why?); and they are more common on the
east side of bodies of water in the prevailing westerlies and on the
west side of similar bodies in the trade wind belt, than on the oppo-
site sides.   For example, dunes of great height occur on the east
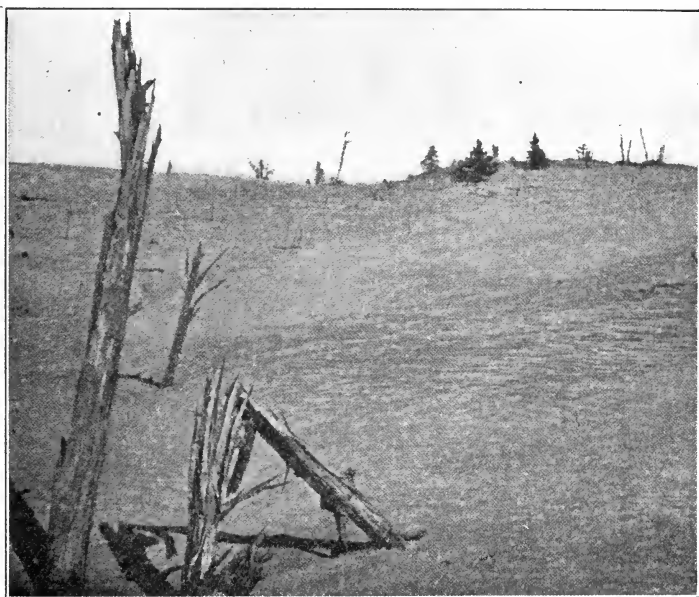
FIG. 102.—TREE STUMPS UNCOVERED AS A SAND DUNE MIGRATED (DUNE PARK, IND.)
Note the gentle slope of the windward side.

side of Lake Michigan, as at Grand Haven, Mich., and very
few are found on the west side of the lake.

Dunes also abound in deserts and in the semi-arid regions of the
United States, sometimes reaching the height of several hundred
feet.   In regions subject to nearly constant winds the removal
of sand from the windward side and its deposition on the leeward
side causes the dunes to migrate slowly in the direction of the
prevailing wind, sometimes burying buildings and forests.

The damage caused by the migration of sand dunes may be post-
poned for a time by building fences across the path of the dune.   The
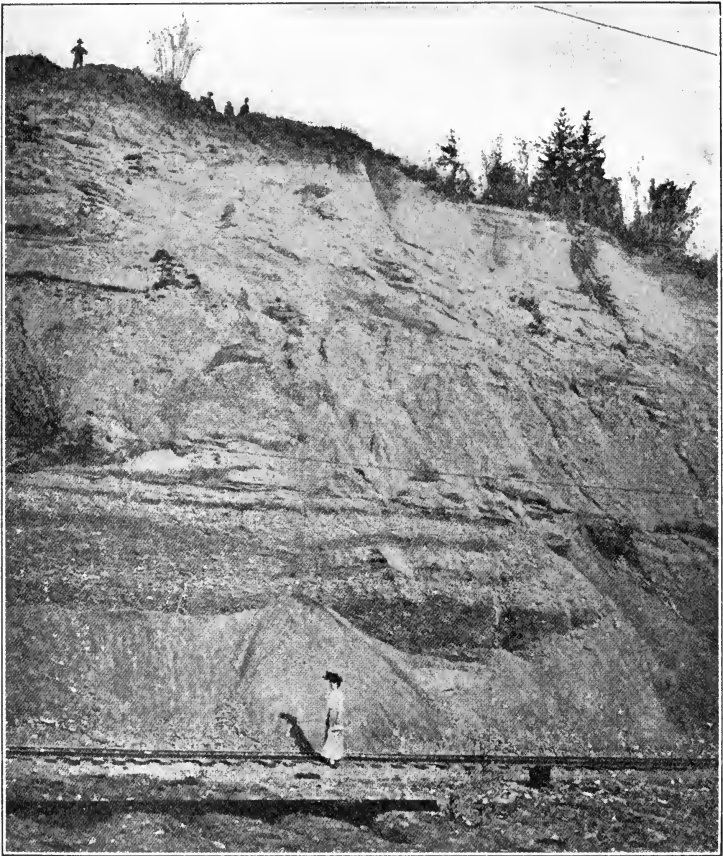
FIG. 103.—SOIL ABOVE MANTLE ROCK (PORTLAND, OREGON)
The mantle rock consists of sand above and gravel below.

best way to prevent the progress is to plant such grasses and shrubs as will grow in sand on the windward slope of the dune. If once started vegetation will check the migration quite satisfactorily.

The Loess.—In Kansas and other western States, in Europe, and notably in China, there are deposits called *loess*, consisting of particles larger than those of clay but smaller than those of sand. Their origin is in dispute, but there seems to be good evidence that a part of it, at least, is a wind deposit. It is without the distinct horizontal stratifica-

tion of aqueous deposits and approaches consolidated rock in its ability to stand with a nearly vertical face. Some deposits of loess are 1,000 feet in thickness.

Volcanic Dust.—In Kansas and Nebraska there are beds of volcanic dust three feet thick which cover large areas and which are hundreds of miles from either active or extinct volcanoes. Pompeii was buried to a depth of about 20 feet by such a deposit.

FIG. 104.—STRATIFIED CLAY (HAVERSTRAW, N. Y.)
Used chiefly for bricks.

4. *Colluvial Deposits.*—The most numerous of these deposits is the talus slope that forms at the foot of ledges of bare rock and that eventually covers the ledge with mantle rock.

5. *Shore Deposits.*—The assorting action of the waves deposits layers of clay composed of particles of remarkable uniformity in size. Only the harder and more durable minerals remain on the beach, and as these grow smaller they are carried out to deeper water. This is why beach sand is chiefly quartz fragments. Quite sizable pebbles may be mixed with the sand grains, but vigorous wave action completely removes the fine particles and often leaves the sand white. Beach pebbles are generally quartz pebbles and are smoothed and rounded.

Useful Materials from the Mantle Rock.—In addition to the economic importance of the mantle rock as a whole, it is of much importance as a source of supply of clay, sand, gravel, marl, peat, and many materials used in the arts.

Clay occurs in very large quantities, is widely distributed, is of various degrees of purity, and is suitable for many uses. The purest clay, kaolin, is used in manufacturing the better class of

FIG. 105.—CLAY PIT (NEAR VANCOUVER, WASH.)
B, gray brick loam.   P, blue clay used for terra cotta.

porcelain. The less pure varieties are used in making chinaware, pottery, terra cotta, tiles, drain tiles, and bricks. Fire clay, used in the manufacture of furnace and stove linings, owes its ability to withstand high temperatures to the absence of lime and such alkaline substances as act as a flux.

The clay products manufactured in the United States are valued at about $160,000,000 a year.

Sand is used in making glass, mortar, and cement. It is also used in molding metals and as an abrasive. The sand used for these purposes yearly is valued at about $15,000,000.

Gravel is used in roofing, in concrete, and in road building.

Marl is used as a fertilizer, in making certain kinds of bricks, and in making Portland cement.

We obtain from the mantle rock of the United States more than half a million dollars worth of these necessary materials every working day of the year.

THE SOIL

Economic Importance.—The upper and fertile portion of the mantle rock is called *soil*. It differs from that below it, which is called sub-soil, chiefly in the greater quantity of decaying animal and vegetable matter called *humus* and in the large number of bacteria which it contains.

Agriculture has been the most important means of support from the earliest times, and the progress of the early nations depended in a more marked degree even than that of modern nations upon the fertility of their soil and their skill in cultivating it. In the United States the yearly value of the direct and indirect products of the soil exceeds $7,000,000,000, or more than three times the total value of all the mineral products.

Fertility.—Soils differ greatly in fertility from place to place, because of unlike *composition* and unlike *texture*.

Composition.—All plants require nitrogen, potash, and phosphorus, and these elements of plant food must be natural constituents of the soil or must be supplied artificially to make the soil fertile. The soils of residual mantle rock contain only such of these elements as were in the rock from which they were formed. Granite and kindred rocks are usually rich in potash and deficient in phosphorus, though some of them contain the latter. A pure limestone usually contains an abundance of phosphorus, derived from shells, but is deficient in potash, and soil formed by its decomposition would be similarly deficient. A shaly limestone, like that at Trenton, N. Y., contains both phosphorus and potash. The famous " Blue Grass Region " of Kentucky has a soil formed by the decay of such a limestone. A pure sandstone contains neither phosphorus nor potash, and would form an unproductive soil; but

sandstones containing many fossils produce a soil containing phosphorus. The unproductiveness of the sandstone soils in Kentucky is in marked contrast with the fertility of the " Blue Grass Region." Transported soils are likely to be more fertile than residual soils because the processes of transportation tend to grind them finer, to mix the soils of different localities, and to increase the amount of organic matter in them. Such soils necessarily differ among themselves as the agents by which they were transported and deposited differ.

Texture.—The physical condition of the soil is fully as important to its fertility as is the chemical composition. If the particles composing it are very small the amount of water retained in the fine capillary passages between them will be large, and because of the high specific heat of water the soil will warm slowly. Such soils are ''cold'' and ''late.''

Fine grained soils do not absorb so much of the rainfall as coarse grained soils, and the run-off on the former is greater in proportion than on the latter type. The size of the particles composing the soil also determines the nature of the plant's water supply, and hence the ability of the crop to withstand drought. If they are too large, water is not lifted a great distance by capillary action, and plants die when the water table is too far below the surface. If they are too small water rises too slowly, with the same result.

The *situation* of soil controls the accumulation or loss of humus and the finer particles of the soil, as well as the available plant food. On steep slopes the swift flow of the run-off above the surface and of the ground water below causes them to wash away the smaller and more perfectly decomposed particles, and to dissolve and remove the soluble parts of the soil from which plants derive their food. Soils on such slopes are always less fertile than soils of the same origin on more gentle grades.

Fertility of soil requires something more than plant food. It requires water in the right amount and at the right time; it requires heat; it requires air, which must be distributed through the soil and must be renewed as it is exhausted; and finally, it requires

tillage, which contributes mellowness, facilitates the renewal of the air supply, and conserves the supply of moisture.

Origin.—The flood plain of the Mississippi and the valley of the Sacramento in California have *alluvial* soils of great fertility. The valley of the Red River of the North in North Dakota has *lacustrine* soil, deposited on the bottom of a former lake, and is one of our great wheat growing regions. The region covered by the continental glacier has a *glacial soil.* It is less uniform in its character than either alluvial or lacustrine soils. On Long Island and Cape Cod it is sandy, whereas the New England States have many clay soils which are parts of the ground moraine. The large deposit of *till* in northwestern Ohio provides a soil that is more fertile than the residual soil of the southeastern part of the State, but is less fertile than the alluvial soils bordering the Ohio River.

Types of Soil.—The common classification of soils as *sands, loams,* and *clays* is based upon the physical structure or texture of the soil rather than upon its chemical composition. It is true that coarse sands are usually composed chiefly of quartz grains, and that clays contain a larger percentage of kaolin than either sand or loam; but the distinguishing characteristics such as *plasticity* and *ability to hold moisture* depend chiefly upon the size of the particles composing the soil.

Sands are composed of particles between 1 mm. and .05 mm. in size. Their distinguishing characteristic is their want of coherence when dry, and this characteristic is possessed equally by the sand composed of quartz fragments, with which we are all familiar, and by the sand found about coral islands, which is made up of fragments of coral and shells.

Sandy soils are porous and well drained; they permit free circulation of the air, but are likely to suffer from drought. They are classed as " early " and " warm " soils, and if they are not too coarse yield excellent crops of garden truck and potatoes.

Clay is composed of particles less than .005 mm. in size. It is plastic when wet, shrinks on drying, but retains the form given it

when plastic. It becomes impervious to water when puddled (worked with water to a thick paste).

Clay soils permit very little circulation of the air. They are usually poorly drained and are therefore likely to be " drowned " in a wet season. They are less likely to suffer from drought than gravel or sand, but do not stand dry weather as well as loam. They are "cold" and "late" soils, but make good meadows.

Loam.—This is a mixture of sand and clay containing enough coarse particles to make the soil mellow and to permit free circulation of air. It also contains enough fine particles to facilitate capillary circulation, but not enough to make the soil sticky in wet weather. Loams are well drained and therefore stand wet weather well. They also stand dry weather well.

Silt is the term applied to deposits of river-borne sediments composed of particles between .05 and .005 mm. in size.

Muck is a black soil formed in swamps and contains a large quantity of humus; hence it is rich in nitrogen.

The following table shows the percentage of particles of various sizes to be found in some of the types of soil:

Size Particles	Barren Sand	Coarse Sandy Loam	Clay Loam	Clay
Sand, 1–.05 mm.	83.6	75.6	48.1	7.6
Silt, .05–.005 mm.	5.4	7.2	24.3	32.2
Clay, .005 mm.	1.8	11.7	18.5	42.2

The sandy loam described in the table is an early and warm soil that is well drained and stands drought well. The clay contains so large a percentage of the finest particles that it is very wet during a rainy season, and supplies water to plants so slowly that they would be parched during a drought.

The Department of Agriculture at Washington publishes the following table of the percentage of each size of particles in typical soils for certain crops:

	Truck	Corn	Wheat	Grass	Bright Tobacco	Heavy Tobacco	Barren Clay
Gravel, 2–1 mm. ..	..	..	..	..	3.09	1.12	..
Sand, 1–.25 mm...	6.34	2.80	1.95	.21	28.90	3.19	.29
Fine Sand, .25–.05 mm.....	81.92	43.06	42.90	11.47	49.68	5.73	10.20
Silt, .05–.005 mm..	8.17	40.90	32.13	23.69	21.41	44.98	36.98
Clay, .005–.0001 mm..	2.80	10.10	23.78	51.75	4.80	35.24	50.02

The typical soil for vegetables or garden truck seems to be warm, sandy, and well drained; that for corn a sandy loam, and that for wheat a clay loam.

QUESTIONS

1. Is all rock properly called stone? Why?

2. What two forces distribute water through the mantle rock?

3. Show that the mantle rock tends to keep the flow of streams uniform.

4. Why is spring water better for drinking purposes than surface water?

5. How does the action of the chemical agents of weathering differ from that of the mechanical agents?

6. Under what climatic conditions is the action of freezing and thawing most effective in disintegrating rock?

7. What kind of soil retards weathering below the surface?

8. Dust is always present in the air, yet it is always settling. How is it supported in the air?

9. Compare residual soils formed from granite with those formed from a pure limestone.

10. What should result when rain falls on heated rock? In what two ways may igneous rocks become surface rocks?

CHAPTER XVIII

THE BED ROCK

Rock-making Minerals.—The consolidated rock of the lithosphere was formed in various ways and is of many kinds, but with the exception of coal and a few similar deposits of animal or of vegetable origin it is all composed of mineral matter. Much of it consists of minerals in crystalline form, and the rest, with the exception of coal, consists either of fragments or decomposition-products of minerals, or is a fused mass of mineral matter.

The term *mineral* was originally used to designate a substance found in a mine, hence something found in the rocks as distinguished from animal and vegetable products.

A mineral is a natural substance not of obvious organic origin and having definite chemical and physical properties.

The durability and economic value of building stones depends to a large extent upon the physical properties of the minerals from which they were formed. The following are the rock-making minerals of most frequent occurrence:

Quartz.—This is the hardest of the common minerals. It is harder than glass, is almost infusible, and is not affected by common acids. It is quite brittle and the broken surface is curved like the surface of a shell. It has no cleavage, is of glassy luster, and occurs in many colors. When in crystals it forms six-sided prisms, terminated at one or both ends by six-sided pyramids.

The gems, amethyst, carnelian, opal, onyx, and bloodstone, belong to the group of minerals of which quartz is the type and have almost identical properties. Flint, another similar mineral, was of great importance to prehistoric man because of the sharp cutting edge of broken pieces. From this substance he fashioned his cutting implements such as knives, awls, spearheads, and arrow points.

Later the flint-lock musket was used in the American Revolution, and it is reported that many of the guns used during the Civil War were altered to "flint locks," and sold to the savage tribes in Africa.

Feldspar is first in importance as a rock-making mineral. It occurs in a variety of colors, commonly pale pink, yellow, or white, but sometimes gray, blue or iridescent. It is nearly as hard as quartz but cleaves easily in two directions, giving flat reflecting surfaces. When exposed to moist air containing carbon dioxide, or to infiltrating water containing carbon dioxide or other acids, its luster is quickly lost and it soon crumbles into a soft clay, called "kaolin." Because of its ready cleavage and its lack of permanence under natural conditions, feldspar is not a durable mineral, and most of the clay and the mud rocks of the earth are chiefly products of its decomposition. Feldspar and kaolin are used in making porcelain and china, and feldspar is valuable as a fertilizer.

Mica is familiar to everyone in the misnamed isinglass used in stoves. Its most important properties are its perfect cleavage into very thin, elastic leaves which have a pearly luster, its ability to withstand high temperature, and the resistance it offers to the passage of currents of electricity. It usually occurs in rocks in rather small sheets or scales, but sometimes large masses are found which furnish large sheets. White and black are the common colors. Mica is very soft, and rocks containing an excess of it are easily broken. It is used as an insulator in electrical apparatus, also in stove doors, lamp chimneys, and wall papers.

Calcite.—When pure and crystallized, calcite is a transparent, colorless crystal which cleaves in three directions, making oblique angles with each other. It is much softer than quartz and is easily scratched with a knife. Its effervescence with dilute acid and its double refraction distinguish it from other common minerals.

Calcite is one of the most abundant minerals, for it forms the basis of limestone, one of the commonest rocks. It is dissolved by water containing carbon dioxide in solution; therefore, limestone and other rocks containing much calcite are worn away by rain water.

Structure of the Bed Rock.—When one visits a stone quarry or a rocky ledge he often finds that the rocks are arranged in parallel layers like those shown in Fig. 106. The layers may differ in color and in kind of rock, or there may be many layers of the same kind; some of the layers may be less than an eighth of an inch in

FIG. 106.—STRATIFIED ROCK
Near Engineer Mountain, Cal. Beds of hard sandstone or limestone alternate with shale. The pass of Coal-Bank Hill is shown on the right.

thickness and others many feet thick. The layers are commonly horizontal, though sometimes upturned like those shown in Fig. 114. These are the "bedded" or *stratified rocks*. They are chiefly sandstones, limestones, and shales, but sometimes layers of coal, conglomerate, or iron ore are found.

In exceptional localities, particularly in mountainous regions, we sometimes find massive rocks, as shown in Fig. 108. These are the "crystalline" or *unstratified rocks*. They are more apt to appear on the surface in mountains, but are found everywhere below the stratified rocks when we dig deep enough. The bed rock consists, we must conclude, of a great mass of unstratified rock which
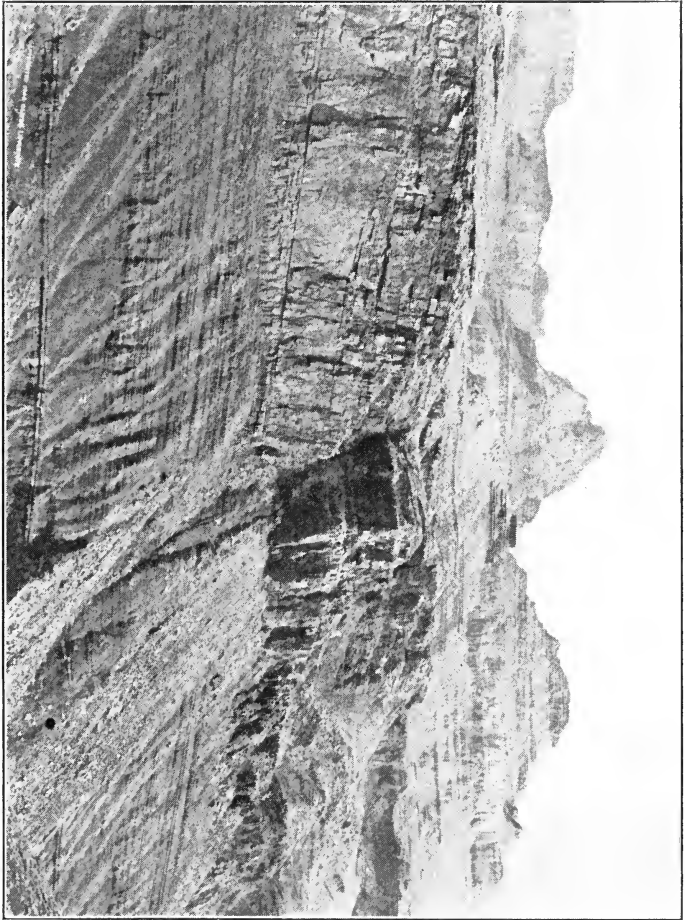
FIG. 107.—SEVERAL THOUSAND FEET OF STRATIFIED ROCK (GRAND CAÑON OF COLORADO) The upper layers are not parallel to the lower ones, showing that the lower layers were tilted before those forming the buttes were deposited. Copyright, 1908, by Oliver Lippincott.

is covered in most places by the beds of stratified rock. As a rule, the unstratified rock is reached by borings less than a mile deep, but in some places the stratified rocks are much thicker than that. In the Colorado Cañon, more than 8,000 feet of consecutive stratified rocks are exposed at one point, but at the bottom of the cañon unstratified rock is found.
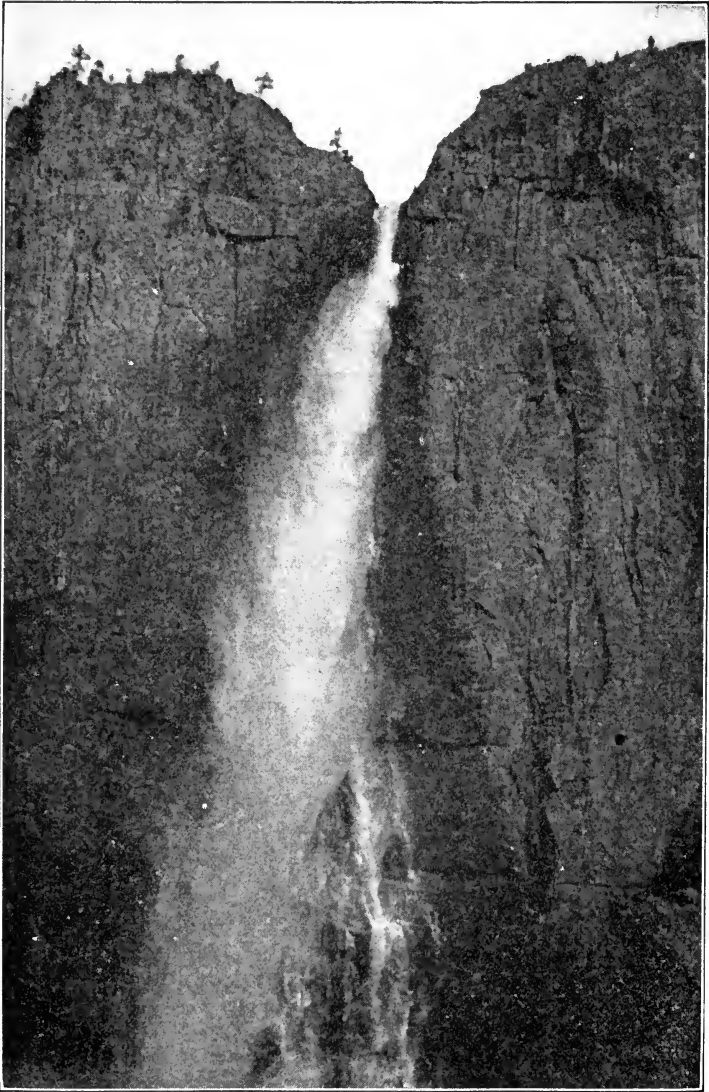
FIG. 108.—UNSTRATIFIED ROCK. YOSEMITE VALLEY
Copyright by Underwood and Underwood.

Origin of the Bed Rock.—Portions of the bed rock show that they assumed their present form *on cooling from a molten state* and are therefore called *igneous rocks*. Modern lavas belong to this class, but form a very small part of it. Much of the unstratified rock which underlies the stratified rock is of igneous origin.

Other portions of the bed rock *accumulated as sediments in some body of water*. These are called *sedimentary rocks*. They are always

FIG. 109.—A LAVA FLOW WITH UNBROKEN SURFACES (HAWAII)

stratified, and so large a portion of all the stratified rock was formed in this way that it is customary to treat those that accumulated on land with the sedimentary rocks. Sedimentary rocks are made up of products of the disintegration and decay of former rocks; in other words, they consist of mantle rock which has been assorted, accumulated in layers and consolidated.

A third portion of the bed rock *has been so changed* through the action of natural agencies as to give the rocks new properties. These are the *metamorphic rocks*. They are usually composed wholly or partly of crystals.

The Igneous Rocks.—Every volcanic eruption contributes to the igneous rock of the surface. Some lavas come to the surface
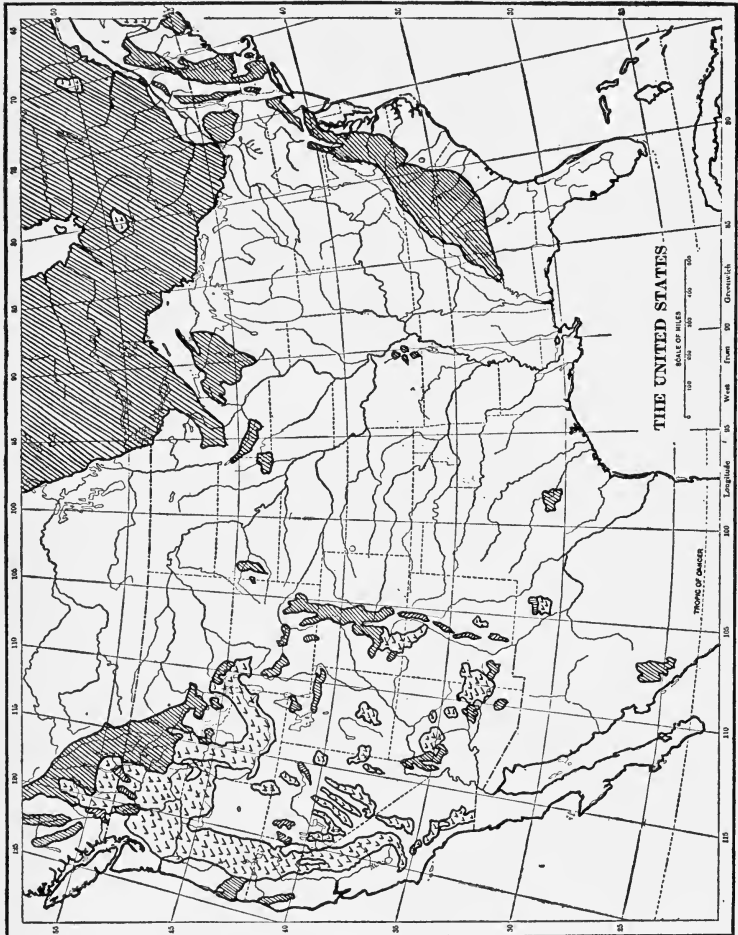
FIG. 110.—DISTRIBUTION OF SEDIMENTARY, METAMORPHIC, AND IGNEOUS ROCKS IN THE UNITED STATES.*

in a very fluid state, and cooling quickly, form a volcanic glass called *obsidian*. Some lavas are mixed with steam so thoroughly as to form a very porous glassy rock called *pumice*. In some cases the explosion of steam and other gases separates the

*Areas in which the top of the bed rock is metamorphic are shaded; those in which it is igneous are marked vv. The white area includes certain minor areas in which the origin of the bed rock is unknown, but with these exceptions it is sedimentary.

lava into fine particles, which fall as *volcanic ash* or dust. These
different forms are due to the conditions of the eruption rather
than to differences in composition of the lava.

Classes.—Certain lavas, particularly at the bottom of a thick lava
flow, show the beginnings of a crystalline structure. Many extinct vol-
canoes have been so worn away that lava, which was covered by thick
beds of rock while it cooled, is now exposed, and these lavas are found
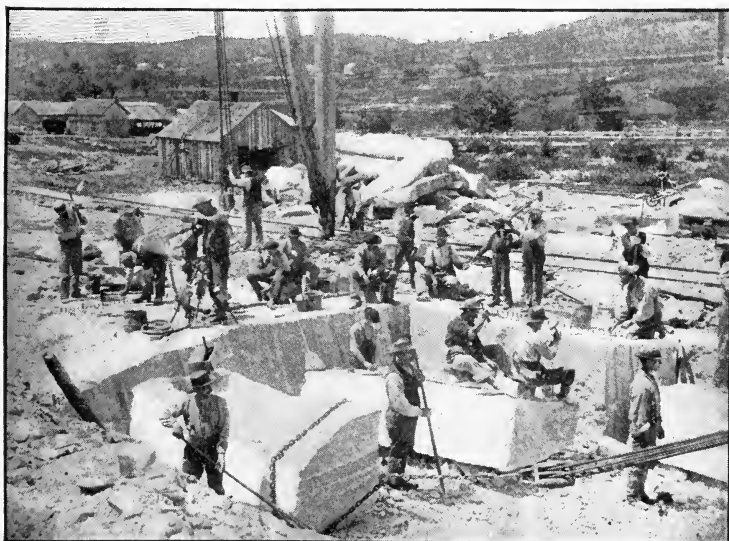
FIG. 111.—A GRANITE QUARRY

to be perfectly crystallized. They differ from the lavas which cooled
at the surface to such an extent that igneous rocks are divided into two
classes: *the eruptive class, or those which cooled rapidly at the surface, and
the plutonic, or those which cooled slowly beneath a thick rock blanket.*

Granite is chiefly composed of quartz and feldspar, though mica
is usually present. The minerals are often in such coarse crystals
that they may be readily recognized without the aid of a lens, and
they are irregularly distributed through the mass. Granite cooled
very slowly and crystallized beneath a thick blanket of rock, which
in many cases has been worn away. Granite is extensively used

in buildings, in monuments, and in pavements. It is one of the
more durable rocks.

Sedimentary Rocks.—The beds of assorted mantle rock such
as clay, sand, and gravel, when consolidated, form sedimentary
rocks known as shale, sandstone, and conglomerate respectively.
They were deposited in horizontal or nearly horizontal layers in
some body of water, generally the ocean. Other sedimentary
rocks were formed from material dissolved from the mantle or
bed rock, carried to the ocean in solution, and recovered from the
solution by plants and animals which absorbed the material from
the sea water to form shells and skeletons. The most important
rock formed in this way is limestone.

Sandstone.—Quartz is the most durable of the common rock-
making minerals, and fragments of quartz should therefore pre-
ponderate in the coarser deposits of rock-waste formed in the sea.
The sands of most shores are chiefly quartz fragments. Sandstone
is a sand bed held together by some natural cement and may be
recognized by its hardness, its rough *feel*, and the fact that it is
composed of quartz grains. It is usually quite porous.*

Conglomerate is a consolidated gravel bed composed of rounded
pebbles, usually embedded in finer material. The mass is bound
together by some mineral substance which forms the cement.

Shale.—Decomposed fragments of feldspar and other minerals
less durable than quartz reach the ocean in very small particles
and settle to the bottom in quiet water, farther from the shore than
the sand deposits. When consolidated, the beds thus formed are
called mud stones or shales.

Shale is so soft that it may be scratched with the finger nail.
It splits readily into thin layers parallel to the planes of stratifi-
cation, and it weathers quickly. It is not affected by acid, and when
moistened has an odor of wet clay. Shale is useless for building
purposes, but is used in manufacturing cement, terra cotta, and

---

*Sandstone has a variety of colors. Perhaps the various shades of red and yellow are
most frequently seen, but some specimens are nearly white, and impure sandstones often
are blue or gray. It is used for grindstones, scythe stones, and in building. Shaly sandstones
make excellent sidewalks.

bricks. Some of the black shales contain valuable oils like petroleum which are recovered by distillation.

Limestone.—The deposits of the calcareous parts of animals and plants which gather in the sea form limestone when consolidated. Some of these deposits are shell beds, like those that form *coquina* off the coast of Florida; others are beds of coral sand such

FIG. 112.—A LIMESTONE QUARRY

as form the beaches of coral islands; and still others are made up of the harder parts of minute animals that inhabit the upper part of the sea even in mid-ocean. The latter deposits form *chalk*.

Limestones formed near the continents are usually rendered impure by sand or mud brought by waves and shore currents. Pure limestone can only be formed in a region which does not receive such deposits. It may be formed in the deep sea, beyond the muds; or in shallow water, about coral islands; and in exceptional localities about continents where sediment from the land is not being deposited.

Some small deposits of limestone are formed on land by direct deposit from spring water which has lost its dissolved carbon dioxide, and can, therefore, no longer hold the limestone in solution. *Calcareous tuff* is thus formed. In some other cases limestone has been deposited in the beds of salt lakes through the evaporation of the concentrated sea water, but it is not believed that any of the important limestone deposits of the world have been formed in this way.
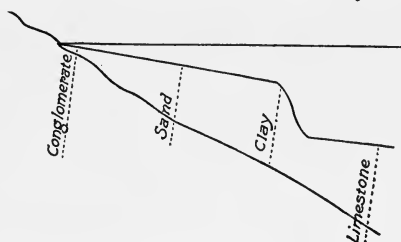
FIG. 113.—DIAGRAM SHOWING RELATIVE LOCATION OF SEDI-MENTARY DEPOSITS

Limestone effervesces when treated with a weak acid, and has about the same hardness as calcite. It is slowly dissolved by water containing carbon dioxide or acids derived from the decomposition of vegetable matter, and is therefore one of the less durable rocks.

About one quarter of the limestone quarried is used in making quick-lime and cement. The remainder is used in buildings and as a flux in smelting ores.

Location.—Wave action assorts the sediments deposited in the sea and we find the coarsest material, the gravels which form conglomerates, nearest the shore; next beyond them come the sands which form sandstones; and next come the muds and clays which form shales. Beyond the muds are the calcareous deposits which form limestone. The diagram (Fig. 113) indicates the order in which these deposits would occur in a region where all of them were forming at the same time.

Bituminous Coal.— When peat is buried beneath deposits which exclude the air it becomes more compact and gradually loses some of the constituents of woody fibre, approaching more and more nearly to a form of pure carbon. This is the way in which *bituminous coal* was formed, but the deposits from which it was formed contained the remains of ferns which grew to be large trees as well as palms and other forms of tropical plant life, in addition to the mosses and grasses which commonly form peat.

Bituminous coal burns with much smoke and flame. This is due to the large amount of volatile matter which it contains and which makes it valuable in the manufacture of artificial gas. It has a dull black color and usually breaks along bedding planes parallel to the coal seam.

Chemical Deposits: Rock Salt and Gypsum Beds.—When a salt lake dries up, or a body of water that has been isolated from the sea evaporates, all of the dissolved mineral matter is deposited, and an interesting assorting action of great importance to mankind accompanies the deposition. This assorting is due to the varying solubilities of minerals. In the case of sea water, gypsum, a very difficultly soluble mineral, begins to be deposited when 37% of the water is evaporated; common salt, a very soluble mineral, is not deposited until 93% is evaporated. About 10,000 square miles of New York state, in the southwestern part, are underlaid by a deposit of rock salt formed as described. It is mined at Livonia, Piffard, Warsaw, and at several other points. In some of the mines the deposit is 80 feet thick. Other important deposits are found in Michigan, Kansas, and Utah. The most important European deposit is at Stassfurt in Saxony.

Metamorphic Rocks.—Some of the metamorphic rocks are known to have been slowly formed from sedimentary rocks, others have been formed from igneous or other metamorphic rocks. The chief agents by which rocks are metamorphosed are *heat, moisture,* and *pressure.*

Rocks have sometimes been metamorphosed by heat from a lava flow or a dike, and we may find layers of sedimentary rocks passing gradually into metamorphic rocks as we approach the lava, thus showing what kind of rock was metamorphosed and the cause of the change. Sandstones have been changed into quartzite under such conditions; shales and clays into slate and then into mica schist. Pure limestone has been changed into white marble, and shaly limestone into a marble containing such minerals as mica and garnet; and in several States along the

Appalachian Mountains bituminous coal has been changed into a natural coke or into an anthracite. When large areas have been metamorphosed it is not always possible to determine the original form of the metamorphic rock. The changes produced by pressure are of fully as much importance as are those due to heat. Pressure has caused the characteristic cleavage of slate, Fig. 114, and the foliated structure of gneisses and schists.

Quartzite is a metamorphosed sandstone. The separate grains can easily be distinguished by the aid of a lens, but they are much more firmly cemented together than are those of sandstone, and the rock is less porous. The cement is silica, like the grains, and it has a shell-like fracture. Metamorphism seems to be destroying its granular structure and restoring the properties of the quartz crystal.

Marble is a metamorphosed limestone which in its typical form is quite perfectly crystallized. Pure limestone becomes white marble. Colored marbles are due to impurities, such as iron. Marble is used for statuary, in the ornamentation of buildings, and was formerly much used for tombstones.

Slate is metamorphosed shale. It is somewhat harder and more durable than shale, and it cleaves into thin layers having smoother surfaces than those of shale and quite independent of the original bedding of the mud deposit. Fig. 114 shows the cleavage lines of the slate across the bedding. The principal use of slate is for roofing. Small quantities are used for school slates and blackboards. It is also used in making imitation marble and as a support for electrical fixtures.

Gneiss is composed of crystals of quartz, feldspar, and mica arranged in parallel layers. *Mica schist* is composed chiefly of quartz and mica. Gneiss and mica schist may be of either igneous or sedimentary origin. They are widely distributed and of great extent in northern North America and in the central portion of mountain ranges.

Anthracite Coal, seen in thin sections under the microscope, shows cellular structure, indicating that it is of vegetable origin; but it differs from bituminous coal in that it contains very little

FIG. 114.—A SLATE QUARRY
Slatington, Pa.

volatile matter and burns without the large amount of smoke and flame characteristic of bituminous coal. It is a hard, lustrous, dense substance which does not break along bedding planes as does soft coal, but has a shell-like fracture.

Anthracite is found only in regions of disturbed and folded strata.

Table.—The relation between the deposits of the mantle rock and the sedimentary and metamorphic rocks which they form when consolidated and metamorphosed is shown in the following table:

MANTLE ROCK	SEDIMENTARY ROCK	METAMORPHIC ROCK
Clay...............	Shale...............	Slate—schist
Sand...............	Sandstone...........	Quartzite
Gravel..............	Conglomerate	
Marl } Shell Beds }	Limestone...........	Marble
Peat...............	Bituminous coal.......	Anthracite coal (Graphite)

ECONOMIC IMPORTANCE OF THE BED ROCK

Metals.—Several metals occur in their pure state in the rocks and are called native metals. They are occasionally found in large masses but more frequently are scattered through the rock in small particles. Gold, silver, platinum, mercury, and copper are the *principal native metals.*

Much of the metal of commerce is obtained from minerals in which the metal is combined with other elements. Such minerals are called *ores* if they yield a metal in profitable quantities. The yearly output of our iron mines exceeds the total value of all the other metals together, and the value of our output of copper exceeds that of gold and silver together.

The principal ores of iron are compounds of iron and oxygen, from which the iron is obtained in a pure state by heating the ore with coke and limestone in a blast furnace. Most of the iron ore used in the United States comes from the Lake Superior region, but important mines are located in Alabama, New York, and Pennsylvania.

The principal ores of zinc, lead, copper, and silver are compounds in which sulphur is combined with the given metal. Each of them must be treated by a more or less complicated chemical process to secure the pure metal.

Coal.—About 300,000 square miles of land in the United States are underlaid with coalbeds. Not all of this is workable, because of its impurity or of the thinness of the layers, and the area at present producing coal is but a small fraction of the total. Very large areas in Alaska are also coal lands, but they are at present undeveloped. All varieties of coal are found in the United States, from the graphitic anthracite of Rhode Island, which burns with great difficulty, to the lignite of Texas, which retains much of its woody structure.

The amount of coal mined in the United States last year exceeded that of any other nation, reaching the total of more than 500,000,000 tons.

The map, Fig. 115, shows the regions in this country in which

coal is found. The coal is not all high grade, but recent progress in the construction of furnaces for low-grade coals and in the development of the " producer gas " process has made it possible to use low grade coals for heating purposes and also to produce a gas which is suitable for use in a gas engine and which works well under a Welsbach mantle. Now that we have learned to handle
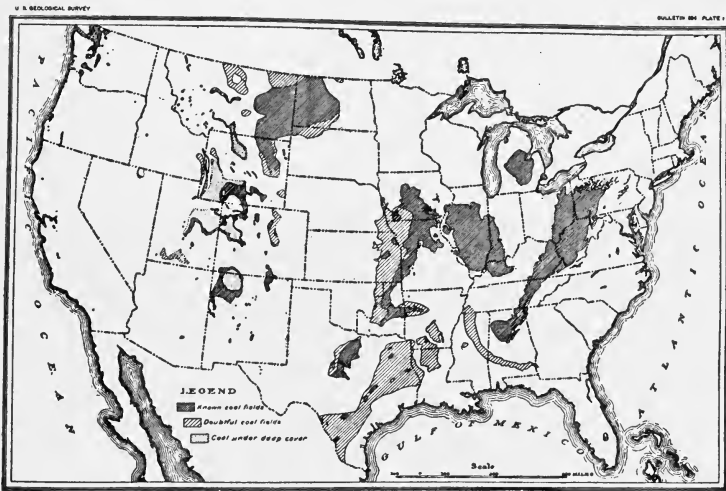
FIG. 115.—COAL BEDS OF THE UNITED STATES

these coals, they have become immensely valuable. They usually have at least 60% of the fuel value of the high grade coals, and occur in regions where other grades of coal are expensive because of heavy freight charges.

Petroleum and Natural Gas.—For the past fifty years we have been taking from the bed rock great quantities of petroleum and natural gas, which have accumulated during the ages.

The value of these products secured during 1907 was about $173,000,000.

In all of the oil fields old wells have ceased to produce or have diminished their output, showing that petroleum is an accumulation and that the supply is not renewed as fast as it is removed. We are rapidly using up the great store, and unless new fields are
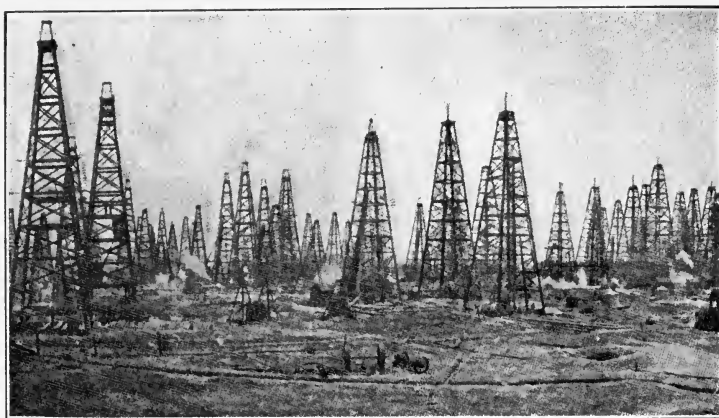
Fig. 116.—A Group of Oil Wells

discovered men will have to learn before many generations to
do without petroleum and natural gas.   The most important oil
fields are in western Pennsylvania and in Ohio.   The Oklahoma
field has recently come into prominence, and Kansas, Illinois,
Texas, California, Colorado, and West Virginia each produces oil.
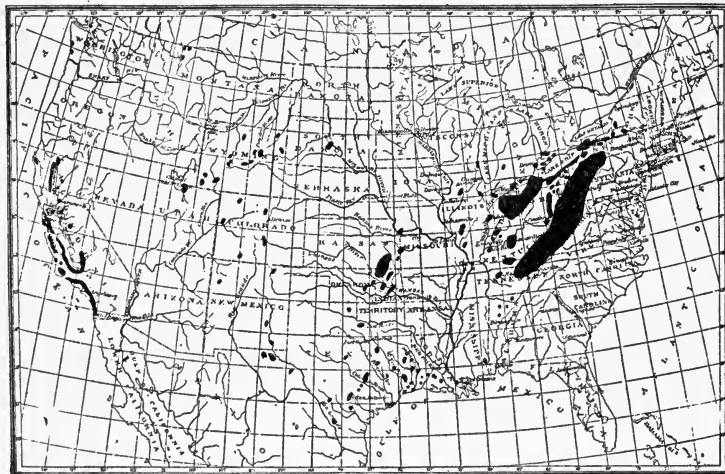
Fig. 117.—Distribution of Petroleum and Natural Gas Fields in the United States

Cement.—The manufacture of Portland cement has become an important industry in the United States. In 1885 the yearly output was valued at about $3,500,000; at the present time it exceeds $50,000,000. It is made by burning certain proportions of limestone or marl with clay or pulverized shale. A hard and durable artificial stone is made by adding water to a mixture of cement and sand. It is now being used extensively in sidewalks, buildings, and other structures.

Stone.—Building stones are so widely distributed that almost every locality in the United States supplies its own demands. It is only when some unusual requirement, such as a particularly large-sized piece or a certain shade of color, is made that stone is shipped long distances. This condition is due to the willingness of most builders to use the stone at hand without regard to its durability, rather than to the universal distribution of good building stone.

Hundreds of " brown-stone " buildings of New York City show the lack of durability of this sandstone. Many of them have been treated with various solutions to fill the pores and protect the stone, but no satisfactory process of protecting poor stone has yet been devised. Probably the best known process is to saturate the exposed portion of the stone with a solution of water-glass, several applications being necessary. When this is dried a solution of calcium chloride is applied.

The following estimate of the "life" of different kinds of building stone in the climate of New York City is given in one of the volumes of the Tenth Census of the United States. By life of a stone is meant the period after which the decay becomes so offensive to the eye as to demand repair or removal:

Life in years.

Brownstone—coarse.............	5 to 15
Brownstone—fine, compact.......	100 to 200
Sandstone—best, silicious cement..	100 to many centuries
Limestone—coarse..............	20 to 40
Marble—coarse.................	40
Marble—fine...................	50 to 200
Granite.......................	75 to 200
Gneiss........................	50 to many centuries

In value of stone quarried the largest yearly return is obtained from limestone. This is doubtless due to the many uses to which it is adapted.

Mineral Fertilizers.—The most important mineral fertilizers found in this country are the rock phosphates of Tennessee, South Carolina, and Florida. These rocks owe their value chiefly to the great number of bones of mastodons and other animals of which they are largely composed. They are efficient fertilizers of lands needing phosphorus. Sodium nitrate (Chile saltpeter) occurs in beds several feet in thickness in the northern part of Chile, and is also found in Humboldt County, Nevada, and in California. It supplies about 15 per cent of its weight of nitrogen. One of the most valuable mineral fertilizers used to supply potash is saltpeter. Saltpeter is formed abundantly in certain soils in Spain, Egypt, and Persia, and is formed in considerable quantities in the soil of many caves in the Mississippi Valley. It yields about 45 per cent of its weight of potash, and 13 or 14 per cent of nitrogen.

Minerals.—Only a few of the many minerals found in the bed rock can be discussed here. For descriptions of others and for more complete accounts of those mentioned below, the student must be referred to works on Mineralogy and to such works as the " Mineral Resources of the United States," published annually by the United States Government.

Graphite, commonly called " black lead," is pure carbon, being identical in composition with the diamond. Extensive graphite mines are located at Ticonderoga, N. Y., and in several Western States, but the quality of American graphite is not equal to that found on the Island of Ceylon and in Siberia. Graphite is a soft mineral with a metallic luster, and derives its name from its property of leaving a mark on substances. It is used in making lead-pencils, crucibles in which to fuse metals, stove polish, electric light carbons, and as a lubricant.

Sulphur occurs uncombined about extinct as well as active volcanoes. In the United States it is mined in Nevada, Utah, California, and Louisiana. Large quantities come from Vesuvius and other active volcanoes. It is extensively used in manufacturing

gunpowder, fireworks, matches, and sulphuric acid. It is also burned to produce bleaching and disinfecting agents.

Gypsum.—Like calcite and common salt, gypsum is one of the minerals brought down to the sea in solution, but it is not absorbed from the sea water by plants and animals, as calcite is. For this reason it is found chiefly in beds formed by the evaporation of salt water, and is usually associated with salt. Important mines are located in western New York, at Alabaster and Grand Rapids, Michigan, and in several of the Western States. It is not affected by acid, is softer than calcite, and has not the glassy luster of calcite. It is used as a fertilizer and as a substitute for marble in buildings, and also in the manufacture of plaster of Paris and Portland cement.

Rock Salt is widely distributed, and some of its deposits are of great thickness. It is used as the basis of many chemical manufacturing processes, *e.g.* making washing soda, soda ash, and hydrochloric acid; also in preserving meats and fish.

Mineral Resources of the United States.—The following table shows that we are extracting from the lithosphere material valued at about $7,000,000 every working day of the year:

SUMMARY FOR 1907.

Metallic.

Pig Iron	$529,958,000
Copper	173,799,300
Gold	90,435,700
Silver	37,299,700
All other metals	71,531,305
	$903,024,005

Non-Metallic.

Coal	$614,798,898
Petroleum and Natural Gas	172,973,524
Cement	85,903,831
Building Stone	71,105,805
Abrasives	1,680,737
Fertilizers	10,661,987
Clay and Sand	173,435,358
Lime, Slate, etc.	19,885,501
Mineral Paints	2,979,158
Unspecified	42,840,312
	$1,166,265,191
	$2,069,289,196
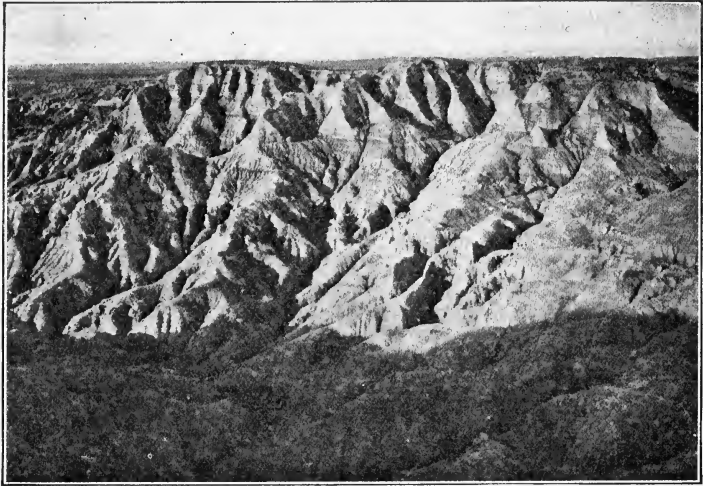
Fig. 118.—The Effects of Erosion on a Hard, Sandy Clay
Foot of Scott's Bluff, Neb.

Destruction of the Bed Rock.—The great mass of the mantle rock impresses us with the fact that the present surface of the bed rock must formerly have been covered with many feet of bed rock that has now disappeared. But the mantle rock of the land tells only a small part of the story. The sedimentary rocks were all of them made of material from former bed rock, and the loose material on the ocean floor, with the exception of that found in the deepest places, was derived from the same source.

To produce this great mass, a quantity of solid rock much greater than the sum of the masses of the mantle rock, the sedimentary rock, and the material on the ocean floor, must have been worn away; for sea water contains millions of tons of matter dissolved from both bed rock and mantle rock, and portions of the bed rock have been deposited and worn away again more than once.

If all this material came from the land at present known, it is evident that the total is equivalent to the removal of thousands of feet of bed rock from all the land of the earth. This great quantity of material has not been removed with equal rapidity in all parts. The rocks have been worn away more rapidly where

FIG. 119.—EROSION IN THE COLORADO CAÑON

Showing the Kaibas Plateau in the middle distance, nine miles away. The peaks in the center are as high as Mt. Washington.
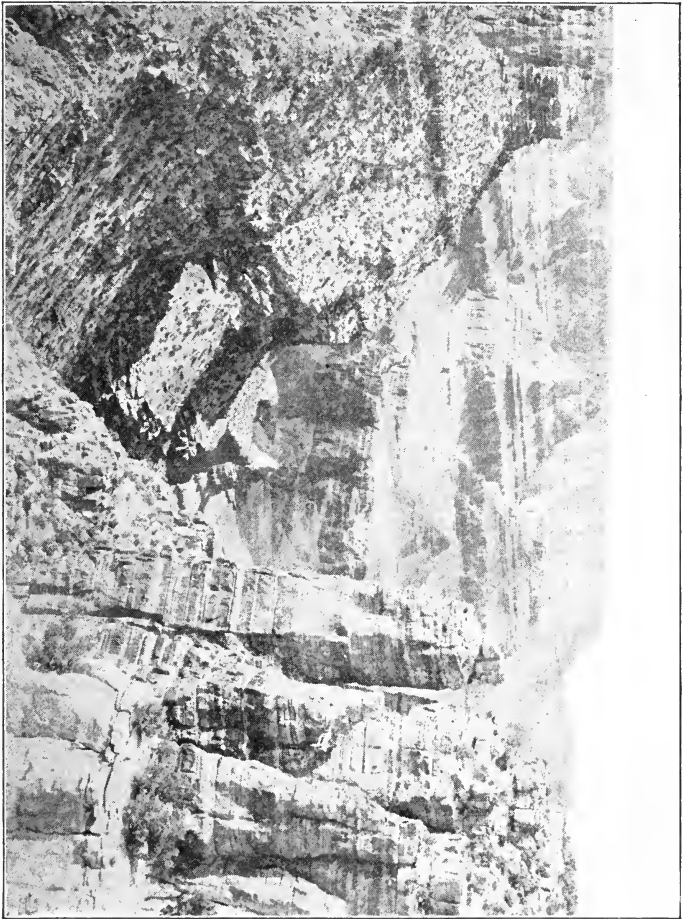
they were weak or where the agents were particularly active, making the land uneven, developing valleys, cañons, gorges, and fiords; and leaving mountain peaks and ridges, or mesas and buttes.

We use the general term *erosion* to designate *the act of wearing away the land*. The principal sub-processes of erosion are weathering, corrosion, and transportation. Weathering differs from the

other processes in that it disintegrates rock but does not transport the rock waste, whereas each of the other processes disintegrates the rock, transports the rock waste, and deposits it elsewhere. Each of these processes has been discussed in other chapters, and we have seen that each of them wears away rock in a characteristic manner and forms physical features both by erosion and by deposition which are easily distinguished.

FIG. 120.—YOUNG MOUNTAINS, SHOWING SLIGHT EFFECTS OF EROSION

The Story Recorded in the Bed Rock.—As one walks along the seashore he notes that the beach is strewn with shells and sea weed, and that many living species make their homes in the sands. Occasionally one sees a fish that has been washed ashore, or finds relics from the plant and animal life of the land, such as leaves blown by the wind or bones brought by some predatory animal.

If such a beach should be consolidated the sandstone formed would preserve many of the modern kinds of life and from them students of the distant future could learn much about our forms of animals and plants. The great series of sedimentary rocks contains just such a record of the forms of plant and animal life of the past, and since each layer is older than all of those deposited above it, we are able to determine the order in which the various types of life occupied the earth's surface. The various layers may be likened to the leaves of a book, each one of which bears a record of the kinds of life which dwelt upon the earth at a given time.

A study of this record reveals some very interesting facts. The lowest layers of the sedimentary rocks rest upon igneous or metamorphic rocks containing few indications that there was any form of life on the earth while they were being formed. In the lowest layers of the sedimentary rocks, however, we find many shells and the remains of animals resembling in some respects the horseshoe crab, but no remains of any higher form. As we examine the layers above the lowest we find that these simple forms are replaced by more and more complex species of the same families, and then fish appear. As we ascend, layers are reached con-

taining the remains of reptiles, small at first, but finally specimens of gigantic size are reached. In succeeding layers reptiles decrease in importance and are replaced by mammals related to the elephant and the dog. In the upper layers the remains of modern animals are found, but the remains of man and his implements and works are confined almost entirely to the mantle rock. This record of the rocks tells us that animal life began with very simple forms which gradually increased in complexity of structure and brain power and that by slow steps, through long ages, the present forms of life have been developed.

QUESTIONS

1. Mention six gems that belong to the quartz group of minerals.

2. State two properties common to both quartz and feldspar. State two properties, either one of which would distinguish quartz from feldspar.

3. Find five illustrations in this book showing stratified rock, and three showing unstratified.

4. State four properties in which calcite differs from feldspar.

5. State two points of resemblance and two of difference between sandstone and shale.

6. Which is the more common surface rock in the United States, sedimentary, igneous or metamorphic? Which least common?

7. What States yield coal? See Fig. 117.

8. How could you determine whether a given specimen was sandstone or limestone, if you had no acid?

9. Why is rock forming near the shore of some coral islands a pure limestone?

10. How may slate be distinguished from shale?

11. Coarse-grained granite is now on the surface in New England; what does this prove concerning the elevation of the surface in these localities at the time when the granite was forming?

CHAPTER XIX

THE GROUND WATER

What Becomes of the Rain.—We all know that rain either dries up, or runs off in streams, or sinks into the ground. In Arizona, for example, where the air is dry and warm, a large percentage is *evaporated*. On steep hillsides a large percentage becomes *run-off* into streams. The streams receive a large portion of spring rains because the air, being cold and moist, evaporates but little, and the ground, being frozen, cannot absorb it. But when rain falls on loose soil, especially where it is level or gently sloping, a large percentage enters the ground and is called *ground water*.
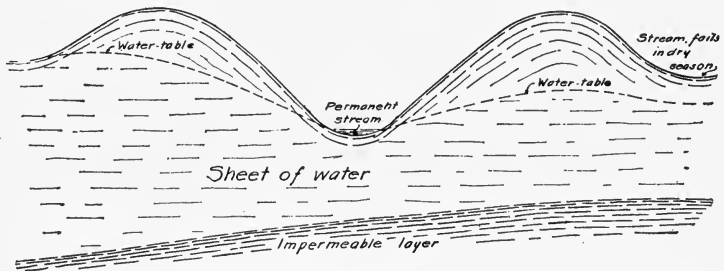
FIG. 121.—WATER TABLE WITH ITS HILLS AND VALLEYS

Importance of Ground Water.—This water that enters the ground supplies our wells and springs, keeps our rivers from running dry between rains, and deposits valuable ores and metals; but its most important work is to dissolve rocks and minerals and to furnish liquid food to plants, thus making agriculture possible.

Water Table.—Surface water tends to sink into the ground until it reaches the saturated portion. This saturated portion extends deep into the earth, perhaps into the heated interior, for

steam forms a considerable part of the product of volcanoes. The *water table* is the upper surface of the saturated portion of the soil and rocks. The level of water in wells indicates the height of the water table. In general, the water table has its hills and valleys corresponding to those of the surface, but with
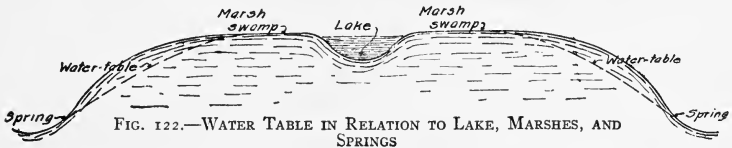
FIG. 122.—WATER TABLE IN RELATION TO LAKE, MARSHES, AND SPRINGS

less difference in elevation, for it is nearer the surface in valleys than under hills. In fact, it frequently *comes to the surface* in valleys, forming springs, swamps, and lakes. The beds of permanent streams reach below the dry-weather level of the water table; streams whose beds are above the water table tend to sink into the ground and disappear. The same is true of lakes and swamps.
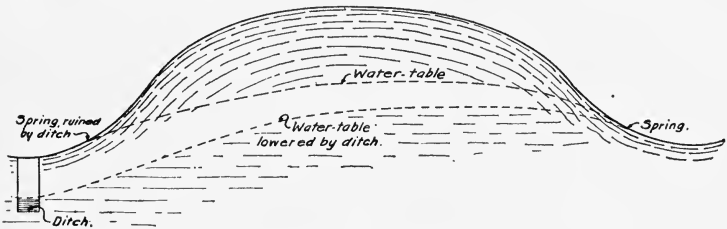
FIG. 123.—WATER TABLE LOWERED BY DITCH

The water table rises after a heavy rainfall and sinks during a dry season. Wherever its surface is inclined there is a constant movement of the water toward the lower portions, causing a *renewal* or change of water, not only in springs, but also in wells.

The water in a well sunk in coarse sand and gravel, in Madison, Wisconsin, stands 52 feet above that of a lake 1,250 feet distant, showing a slope of 1 foot in 24, while in Long Island a slope of 1 in 440 has been found. When water is pumped rapidly from a well, the slope of the surrounding water table becomes steep, and there is a more rapid movement of water toward the well.

Wells.—*Wells* are holes dug or bored for the purpose of supplying water. To be permanent they must sink below the dry-weather level of the water table. They should be so situated and so protected that surface filth and impurities cannot drain into them. Clear, tasteless, odorless water may yet be dangerous.
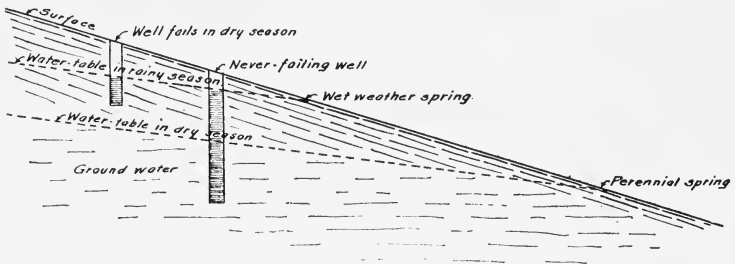
FIG. 124.—WATER TABLE, WELLS, AND SPRINGS

When water comes from great depths it is well filtered and freer from surface impurities, such as typhoid fever germs.

Many small communities depend upon wells for their water supply, but most large cities have abandoned them, using instead the water from lakes and rivers.
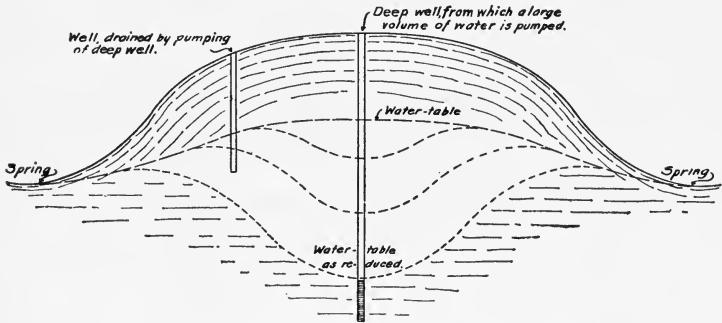
FIG. 125.—EFFECTS OF PUMPING ON WATER TABLE AND WELL

Artesian Wells.—In ordinary wells the water level coincides with the local water table; but this is not the case in artesian wells. *Artesian wells are wells in which the water level is independent of the local water table and dependent upon pressure transmitted from some*

distant water table. The first artesian wells, in Artois, near Paris, overflowed, forming what are called flowing wells.

The *conditions* necessary for an artesian well are an *impervious layer overlying* a *porous layer*, such as sand or gravel, that receives *water from some level higher* than that of the bottom of the well. There may be an *underlying impervious layer*, but this is not necessary. The water in the well tends to rise to the level of the water in the porous layer, and it may overflow.
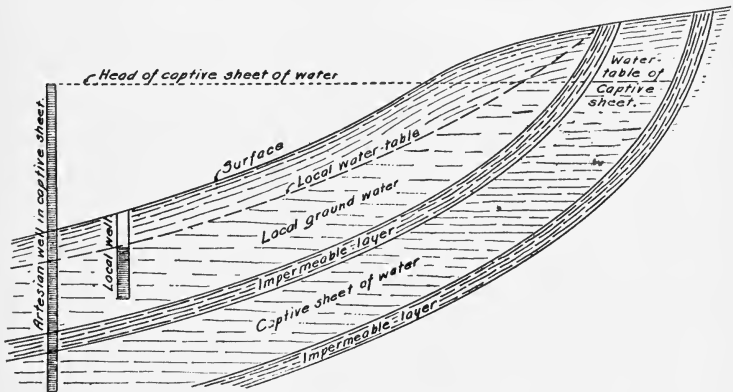
FIG. 126.—DIAGRAM OF AN ARTESIAN WELL

These necessary conditions are frequently found on plains sloping gently from higher land, such as the Great Plains sloping eastward from the Rocky Mountains, and in the Atlantic and Gulf plains in southeastern United States. At Atlantic City, artesian wells 800 feet deep furnish water that fell miles away on the mainland, and flowed under the salt water of the marshes off the coast of New Jersey. Some of the water in the artesian wells of the eastern shore of Maryland has passed beneath Chesapeake Bay; in Calais, northern France, water is drunk that fell as rain on the English side of the Strait of Dover.

To Illustrate the Action of an Artesian Well.—Take a basin, representing the lower impervious layer, and partly fill it with a mixture of sand and water. Force down into the mixture a second (tin) basin with a hole in it. How high will the water spout?

Springs.—When ground water forms a small stream, it tends to follow joints and cracks and the tops of impervious layers. When the stream comes naturally to the surface it is a *spring*. Sometimes there is a *line of springs* along a hillside, just above an impervious layer. A spring rising through sand may form a dangerous or troublesome *quicksand*. In regions with plentiful rainfall springs are numerous. A permanent spring is a valuable
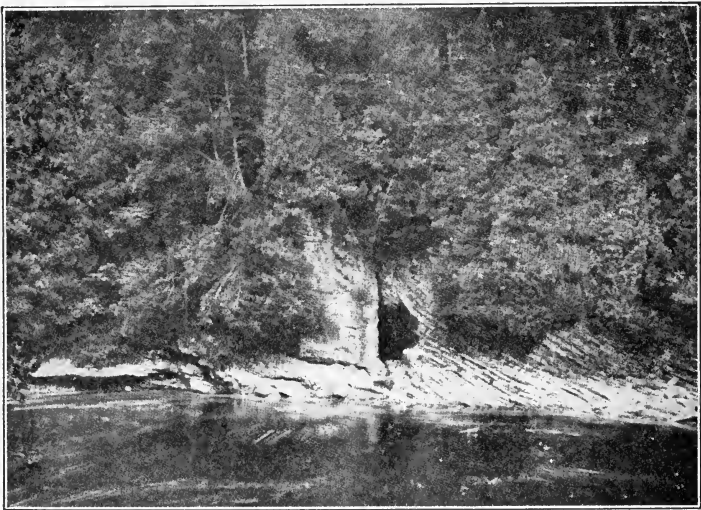
FIG. 127.—SPRING FROM CAVE FORMED BY STREAM FOLLOWING A FAULT

asset on any farm. In arid regions they are especially valuable, for around them is found the only productive land. *Oases* in the desert owe their fertility to springs and wells.

Hot Springs.—Hot springs are formed when their waters come from great depths or from near hot lava. Such springs are generally *mineral springs* also, for warm water is a better solvent than cold water. Many mineral springs have medicinal properties and become health and pleasure resorts. Well-known examples are Saratoga Springs, New York; White Sulphur Springs, Virginia; Hot Springs, Arkansas; Bath, England; Vichy, France, and Karlsbad, Bohemia.

Geysers.—*Geysers are explosive springs of boiling water whose eruptions occur at rather regular intervals.* They are found in the volcanic regions

of Yellowstone Park, Iceland, and New Zealand. The water is boiling hot because it comes in contact with highly heated rock. The boiling point is above 212° Fahrenheit, owing to the pressure of the column of water above. The irregularities of the tube probably make convectional interchanges of water difficult and slow. When, in spite of the great pressure, the boiling point is reached and steam is formed below, causing some of the surface waters to overflow, the diminished pressure lowers the boiling point of the water and enables great quantities much above its boiling temperature to flash into steam. The explosion of the steam expels the overlying water with great force, often sending the column 200 feet above the crater. The operation is repeated at intervals. Beautiful white deposits are formed around geysers.
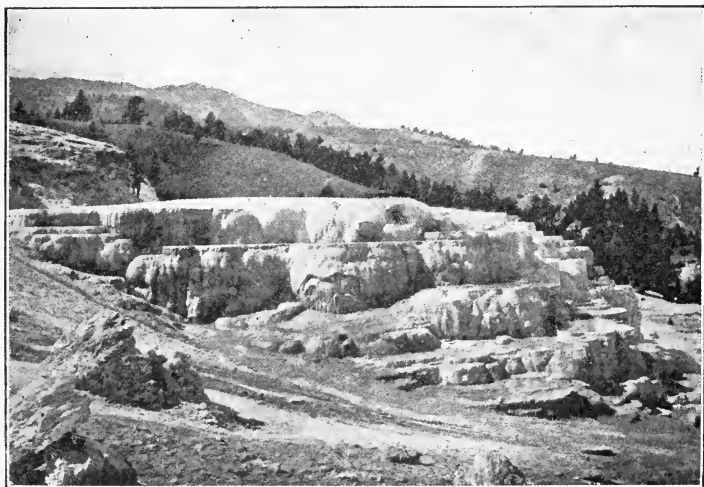
FIG. 128.—DEPOSITS FROM HOT SPRINGS, YELLOWSTONE NATIONAL PARK

Destructive Action of Ground Water.—Ground water absorbs carbon dioxide from the air and acids from decaying plants and animals so that it becomes a *weak acid*. When it passes through the rocks it tends to weather and to dissolve it, weathering it to mantle rock. By weathering the mantle rock it assists in the formation of soil. This is the most important destructive work of ground water. A more spectacular work is seen as it passes through limestone. It slowly dissolves the limestone and forms passages, and in some regions large *caves*.

Mammoth Cave.—The largest known cave in the world is Mammoth Cave, Kentucky. It is over nine miles from entrance to farthest recess. It has a network of numerous galleries and passages which cross and recross one another, with a total length of over two hundred miles. It has its own rivers and lakes, in which are found sightless crayfish. Countless bats cling to its walls. Its blind rats have very long sensitive

FIG. 129.—DIAGRAM SHOWING CAVE AND NATURAL BRIDGE
AA, Layers of limestone; BB, sink holes; CC, vertical shafts or domes; and DD, horizontal galleries with stalactites, stalagmites, and pillars.

whiskers for feelers. The many blind forms of animal life are probably the descendants of normal animals that entered the cave long ago. Skeletons of men have been found there.

The best preserved skeletons of prehistoric man and the best samples of his hand work have been obtained from the limestone caves of France, Belgium, and Spain.

In limestone regions the surface streams sometimes fall into *sink holes*, that lead to underground passages. Where sink holes are numerous there may be no surface streams, as in the *Karst* region east of the Adriatic Sea. Occasionally, too, portions of the roof of a cave fall in, leaving a portion that forms a *natural bridge*. Natural bridges are also formed in other ways.

Underground streams do the same kinds of work that the surface streams do. In addition to this, some of them, where they are closely confined, wear away the roof above them.

Constructive Work of Ground Water.—When water is evaporated it deposits its dissolved mineral matter. An example of this is the scale on the inside of a tea-kettle, or of a steam boiler, in which hard water (from limestone regions) has been boiled. In regions of limited rainfall the evaporation of the ground water leaves on the surface deposits that render the soil unfit for agriculture. In certain portions of New Mexico, where irrigation has been introduced, these alkali deposits are removed by flooding.
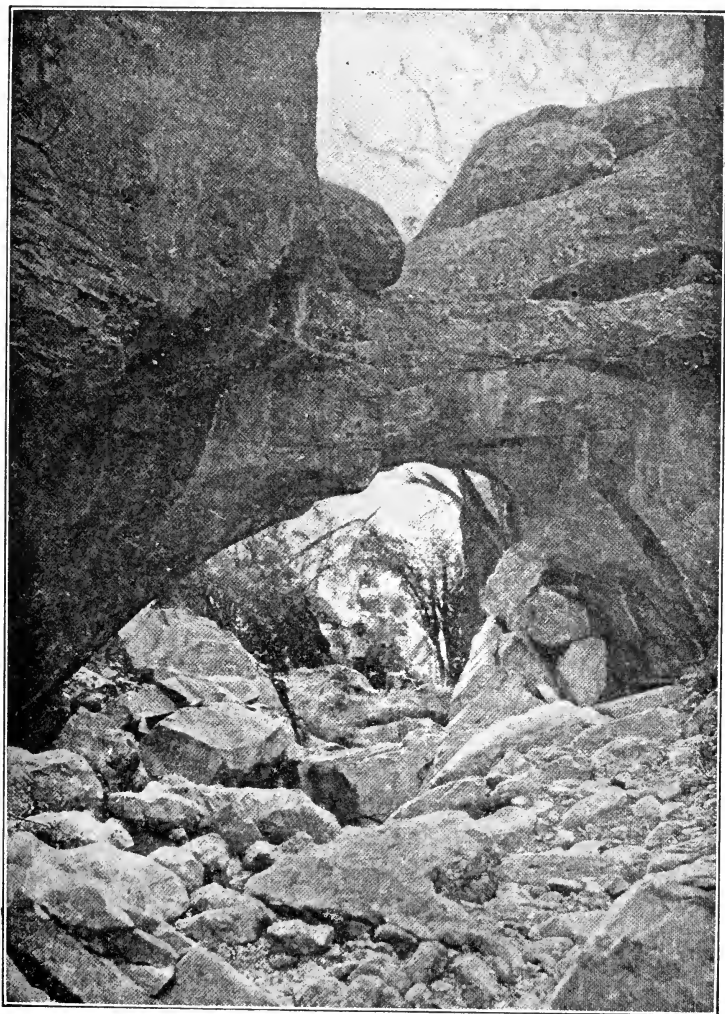
FIG. 130.—NATURAL BRIDGE IN SANDSTONE
Near Buffalo Gap, South Dakota.

In some regions the matter deposited underground acts as a cement, consolidating the mantle rock. Sometimes crevices in the rocks are filled with minerals, from solutions, forming *veins*. They are to be distinguished from *dikes*, in which the crevices are filled with what was once molten matter. Hot water is, as a rule, a better solvent than cold water. Water from deep in the
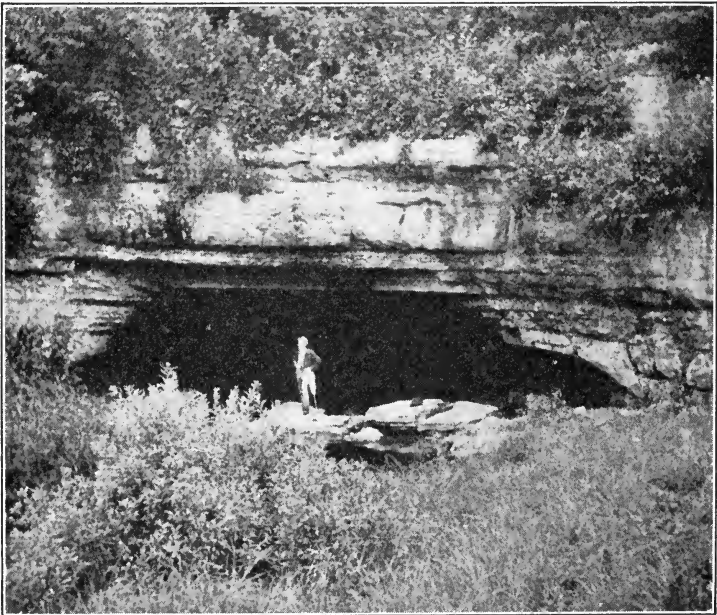
FIG. 131.—THE SIDE OF A "SINK" AND ENTRANCE TO A CAVE IN WEST VIRGINIA
The stream that enters here reappears three-quarters of a mile away. (Photo by Johnson.)

ground is hot. When such water approaches the surface it cools and deposits are formed. Many veins of ore originated in this way.

Where water containing dissolved limestone slowly drips from the ceiling of a cave, the evaporation of the water and the loss of the dissolved carbon dioxide cause the deposition of limestone, both as *stalactites*, hanging like icicles of stone from the ceiling, and as *stalagmites*, on the floor of the cave. A stalagmite may unite with a stalactite to form a *pillar*.

Precipitation.—Sulphur springs are very common in some regions. If the water from such a spring should mingle with water containing dissolved compounds of silver, gold, copper, lead, or zinc, these metals would be *precipitated* in combination with the sulphur as *sulphides*, and would fill the channels through which the mingled streams passed. Other deposits are due to the diminished pressure as the water approaches the surface. This permits the escape of some of the dissolved gases which, like carbon dioxide, are necessary to hold the mineral in solution. Still other deposits from solution are caused by certain minute plants called algæ. A compact limestone is deposited about hot springs in Yellowstone National Park. The white deposits about geysers are believed to be due to the same action.

Petrifaction.—Petrifaction consists in the slow solution of certain organic substances in the earth, and the replacement of the dissolved molecules with deposits of mineral. Many fossils, originally in limestone, have been exactly reproduced in quartz or in iron pyrites.

Capillary Water.—If the corner of a lump of sugar touches a liquid, like coffee or water, the liquid quickly spreads through the whole lump. In a similar way water spreads through soil, covering each soil particle with a thin film called *capillary water*. This capillary water makes the soil moist, and even in a dry season supplies water to the roots of plants above the water table. It also transports water from the water table to the surface, where it is evaporated.

Capillary Action.—As the result of the attraction of water particles for one another and of glass for water particles, water is attracted a short distance up the side of a glass of water. Water rises about $\frac{3}{8}$ of an inch in a glass tube with a bore of $\frac{1}{10}$ of an inch; but it rises 6 inches when the bore is $\frac{1}{100}$ of an inch. This shows that water rises higher in tubes of smaller bore.

In the soil, the small spaces practically form slender tubes or passages through which water moves. If the passages are diminished in size, capillary action is *facilitated*, and the water tends to collect there. Advantage is sometimes taken of this when a person steps upon the place where seeds have just been planted. The weight of the body presses the soil around the seeds, capillary action is assisted, water collects, and the seed germinates more quickly.

On the other hand, if the spaces are increased, as for example when soil is plowed or cultivated, capillary action is *interfered with*. The ground water does not rise so rapidly and evaporation is retarded, leaving more water in the ground to nourish the crop. The loosened soil particles resulting from cultivation constitute what is called a *dust mulch*.

Although the loss of ground water through evaporation is very great, yet in the eastern part of the United States this is in large part counterbalanced by plentiful rainfall. But even here many a farmer has learned by experience the value of cultivating his corn in a dry season, though there are no weeds to be killed.

Dry Farming.—The value of the dust mulch is greatest where rainfall is scanty. In the Great Plains, just east of the Rockies, the rainfall is under 20 inches, not enough for agriculture under old methods. But dust mulching after every rain has made parts of this region, formerly called the Great American Desert, blossom as the rose.

In portions of both the Great Plains and the Plateau Region the rainfall is too scanty, even with careful dust mulching, to raise a good crop every year. So the farmers not only cultivate after every rain, but they also refrain for a season from planting any crop. This cultivating without planting (called summer fallow) stores the rainfall until there is sufficient ground water for a bountiful crop.

The practice of alternate cropping and summer fallowing is, according to the Year Book of the Department of Agriculture for 1907, a common one in the semi-arid region. But the practice of allowing the soil to remain bare during the entire season is questionable, for it must necessarily result in an almost complete destruction of the organic matter in the soil. A much better practice is to raise some kind of leguminous crop which can be turned under while there is still a sufficient amount of moisture in the plants and in the soil to cause rapid decomposition.

Not satisfied with preventing evaporation and conserving the rain of two or more seasons, some farmers cause the ground water to collect near the roots of the plants, where it will do the most

good. This is done by *sub-surface packing*. The sub-surface packer forces the soil particles a little below the surface nearer together. This facilitates capillary action so that the ground water tends to rise and to collect in the packed earth. The dust mulch is used to prevent its escape by evaporation.

Dry farming is the method by which crops are raised in regions of deficient rainfall. It applies the principles of *dust mulching*,

SHADED AREAS
HAVE ENOUGH
RAIN FOR FARMING
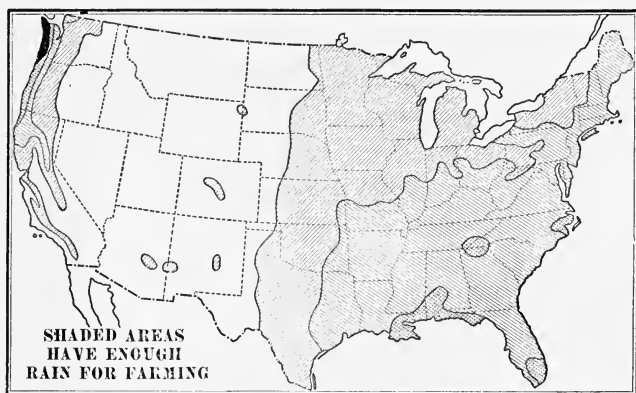
Fig. 132.—Dry Farming is Successful in the Areas Unshaded in the Map

summer fallowing, sub-surface packing, and the selection of *drought-resisting crops*.

Forests.—Regions with sufficient rainfall, well distributed throughout the growing season, are usually forested. A *forest* is a growth of trees sufficiently dense to form a fairly unbroken canopy of trees. Most of our trees are *deciduous*, that is, they shed their leaves in winter. The accumulation and decay of these leaves give to a forest a peculiarly rich *soil* of its own making and covered with leaves that tend to prevent evaporation of soil moisture.

Value of Forests.—Trees furnish us all of our wood and *lumber*. They furnish the *fuel* of the country, much of it directly, but part of it indirectly through coal. They furnish *food*—fruits, nuts, maple sugar, etc. They furnish many valuable *raw materials* used in manufacturing—paper, tanning materials, wood alcohol, tar, pitch, turpentine, resin, fibres. They improve the *climate* by setting oxygen free in the process of making starch; as windbreaks they check the destructiveness of the winds; the

evaporation of their moisture and their shade cool the air, making it moister and subject to changes that are less and slower than in the neighboring open country. They affect *drainage;* by retarding the melting of the snow they prevent spring freshets; the leaves and loose soil retain the rain that would otherwise flow off rapidly in floods; the water so retained is doled out, so that the streams and their water power are maintained during dry weather.

The removal of forests causes floods that destroy property and life, remove the humus and fertile soils, and fill the streams with soil and rock waste. The coarse rock waste of the freshets is spread over the low
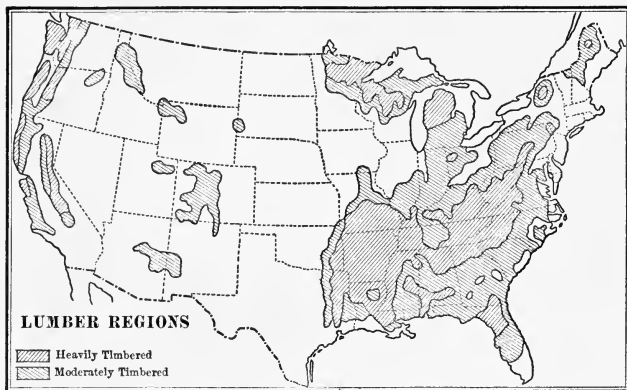
FIG. 133.—THE LUMBER REGIONS

ground, thus destroying what has been valuable farming land. The water power is lessened or destroyed during dry seasons and may be too great to be utilized during floods.

"*Forestry* is the preservation of forests by wise use."—Roosevelt. Our 300,000 square miles of national forest are protected by the United States Forest Service, which administers public property estimated to be worth over $2,000,000,000. The Service aims to diffuse information, to prevent the spread of fires, to destroy injurious insects and fungi, to restrict cattle grazing in forests to certain seasons, to insist that each tree cut be replaced by another of the same kind.

Forests cover 550,000,000 acres, about one-fourth of the United States, and Forestry is becoming more and more important, for a timber famine, especially in the hard woods, is upon us. Forestry is very promising as a profession.

QUESTIONS

1. Would a rainy month in the spring cause floods of the same size as an equally rainy month in the fall? Why?

2. Why is the water table not level? Would it be more nearly level in sand, in gravel, or ordinary soil? Why?

3. Illustrate by means of a diagram properly labeled the position of the water table and a spring, a permanent stream, a temporary stream, a marsh, and a lake.

4. With the vertical scale 1 inch equals 100 feet, draw a diagram for an artesian well that sends water 50 feet into the air. Name and label the parts.

5. Show the proper relative positions of a house, barn, well, and out-buildings on a side hill. Give your reasons.

6. Why do cities generally depend for their water supply upon lakes or rivers instead of upon wells?

7. Which would be more apt to be brackish or mineral, water from springs in a desert, or from springs in a well-watered region? Which might seem better? Why?

8. Illustrate relations of stalactite, stalagmite, and pillar.

9. Fill three flower pots of the same size with the same amount of soils of uniform texture. Cover one with straw, another with dust mulch, and "puddle" the top of the other (that is, wet it so that when it dries it will cake as a dried mud pie). When all are prepared weigh them. Set each in a saucer with a weighed amount of water. As the water is absorbed from the bottom receptacle, keep filling it up, being careful to weigh or to measure carefully the amounts supplied. Compare the amounts absorbed and state your generalization therefrom.

10. How would living in a cave without light affect the various senses of animals compelled to live there for many generations?

11. Why are regions which are believed to be the roots of worn down mountains so frequently rich in ores?

12. How may geysers choke themselves until they no longer erupt?

13. How will the evaporation of water, furnished by irrigation, affect the amount of soluble plant food in the soil below the surface and at the surface?

14. "What's the use of cultivating corn when there are no weeds in it?"

CHAPTER XX

THE WORK OF RIVERS

The rivers of the United States furnish power to great manufacturing industries, supply water to cities, and transport every year hundreds of thousands of people and millions of tons of merchandise and farm products. They have figured in the history of our country from the beginning, both in its peaceful settlement and development and in war. The Hudson River was of vital strategic importance during the Revolution, and the Mississippi and the Tennessee during the Civil War.

In the economy of nature streams have many functions, the most obvious of which is the removal of the surplus rainfall. But while doing this, all streams, from the largest river to the tiniest brook, are slowly wearing down the land.

The Formation and Development of a Gully.—To study the principal phenomena of the work of a river in wearing down the land, it is not necessary to go farther than to the nearest bank of soft earth and to note what happens during and immediately after a heavy rain. The water collects in a stream and flows over the edge of the bank and down its slope, quickly forming a *miniature valley* or gully.

If the stream is swift and the bank soft and steep, the valley *deepens* rapidly. The steepest place is at the edge of the bank, and here the stream cuts into the earth and the valley *lengthens headwards.* During a heavy rain the sides of the gully are washed in and the valley *widens* rapidly.

The *materials* washed out of the gully are, in part, *deposited* at the foot of the bank, where the slope becomes gentler. Here the stream is *building up* instead of cutting down. When the rain slackens it may be possible to see the stream diminish in size after

a time, and the stream-deposits extend up the gully, *partially filling* it and making the miniature *valley flat-bottomed.*

Sometimes for several days a small stream, fed by some temporary spring, will flow down this flat-bottomed valley in a *wind*

FIG. 134.—GULLY AND ALLUVIAL CONE, FORMED IN A SINGLE SHOWER
Near Baraboo, Wisconsin.   Note coarse stones in gully.   (Eliot Blackwelder.)

ing course, cutting into its outer or concave bank at every curve. Here the banks are generally *higher* and *steeper* and the stream *deeper.* The convex inner bank is lower and more gently sloping, *with deposits* in front.

If the gully is examined after the stream has disappeared, it will be seen that in places the slope is too steep for any deposits to be made, but where deposits are made *in steep places coarse materials* predominate, whereas deposits made on gentler slopes are not so coarse. The result is an *assorting* of deposited materials. This is noticeable in the deposits at the foot of the slope.

Sometimes a stone in the path of the stream causes a *fall* to form. Just below the fall the water wears out a *hole* deeper than

the average of the other portions of the stream. A short distance below the fall there is frequently a *deposit* in the bed of the stream.

Most of these phenomena of the gully can be seen without much

Fig. 135.—Man Measuring Stream Flow

difficulty along every stream, in some portion of its course. **Gully** and *stream work may be summarized* in a sentence: Streams *drain* away the surplus rainfall, and in so doing *wear down the land*, and *transport*, comminute, and finally *deposit* the waste so formed.

DRAINAGE

Drainage.—Our rivers remove the equivalent of about 10 inches of rainfall per year from the whole United States. The Mississippi annually carries to the sea about one-ninth of the rainfall of the whole country, an estimated total of 44.7 cubic miles. This is enough to make a lake the size of the State of Illinois, and four feet deep.

The economic value of this water is such that the National Government is seeking to determine the best methods of storing and conserving it for irrigation and power purposes. Government officials have estimated that the streams of the Southern Appalachians alone have 1,400,000 undeveloped horse-power, worth, at $20 each, $28,000,000 per year.

By saving and doling out in dry seasons the water of floods, mills can be kept going that otherwise might be compelled to close. If water power, often called *white coal*, could be used

FIG. 136.—SOME INSTRUMENTS USED IN MEASURING STREAM FLOW

instead of coal for power purposes, our diminishing coal deposits would be conserved.

CORRASION

Corrasion.—Streams wear away their beds and banks, forming most of the valleys of the world and obtaining materials that are eventually deposited in the sea. *Stream corrasion is the wearing away of rocks by running water.* Part of this is due to the solvent action of water. Clear water alone is a *poor corrading agent.* Just as paper by itself is a poor abrading agent but becomes an efficient one when covered with sand as sand-paper, so water supplied with *sand and rock fragments as tools* becomes an efficient corrading agent. A load of sand thrown into the clear water of the Niagara River from the bridge just above the American Falls soon scours away the moss that the water alone is not able to remove from the rocks in the bed of the river.

The *rate of corrasion depends upon* the *resistance of the materials* forming the stream bed, the *volume* and *velocity* of the water, and the *kind and amount of material* transported by the stream and used as corrading tools. In 1906 the Colorado River, which supplied water to an irrigating ditch leading to the Imperial Valley region of southern California, got beyond control. In the weak deposits
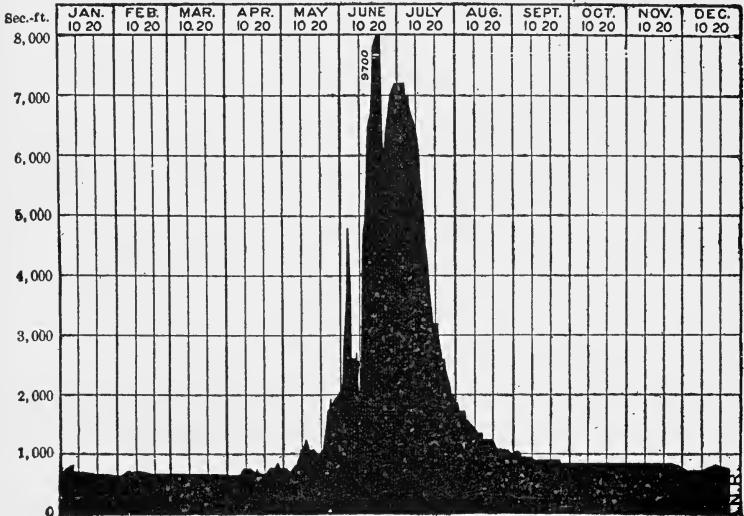
FIG. 137.—STREAM FLOW IN REGION OF LITTLE RAINFALL
Discharge of West Gallatin River at Salesville, Montana, for 1899.
(U. S. Geological Survey.)

of the old delta that the Colorado had built across the Gulf of California, it soon changed a small irrigating ditch to a channel large enough to receive half of the river. In the depression that had once been the head of the Gulf, the Salton Sea was formed, a lake larger at one time than Lake Champlain. A fall over ninety feet high and 1,500 feet wide cut back toward the Colorado at the rate of half a mile a day. After threatening the destruction of $100,000,000 worth of property, the river was, with much difficulty and at great expense, finally brought under control.

(*a*) **Downward Corrasion.**—Every stream is in some part of its course *corrading its bed*, thus *forming or deepening its valley*. The

best example in the world of the work of downward corrasion is the Grand Cañon of the Colorado, 300 miles long and in places over a mile deep, all cut out little by little by the Colorado River.
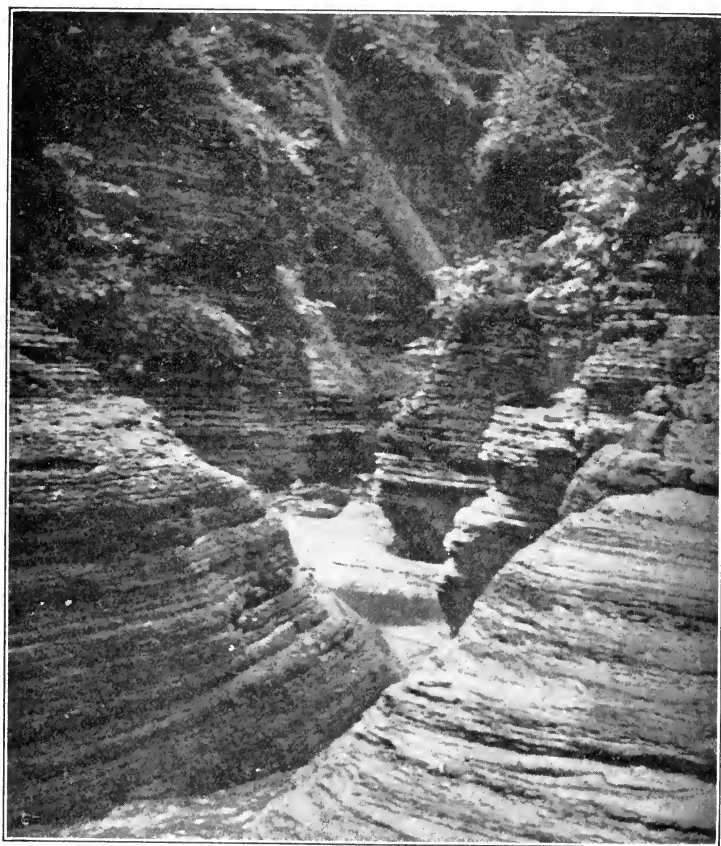
FIG. 135. — GORGE CORRADED IN SHALES, LAKE KEUKA, N. Y.

The *deepening of its valley* is the first work of a river, for the water brings its corrading tools into direct contact with its bed and wears the bed away. The stream tends to cut down vertically and to form narrow, deep valleys with precipitous sides.

called gorges or *cañons*. An overhanging side may be the result either of curving and consequent undercutting by the stream, or it may be due to the rock structure.

The *widening of a river valley* is largely the result of weathering. The side walls are disintegrated and the particles of rock fall and are washed into the stream and carried away. If the materials of the sides of the valley are sand or gravel, the sides cannot be very steep, otherwise the materials would roll down the slope.
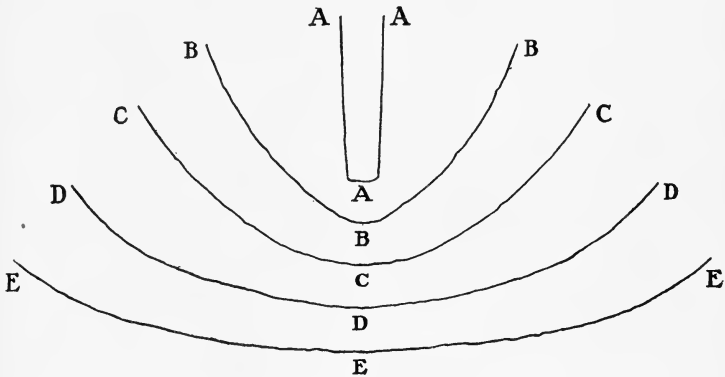
FIG. 139.—DIAGRAM OF GRADUAL WIDENING OF VALLEY

The *rate of widening* determines the *shape of the valley* as seen in cross-section. Torrents may retain for a time valleys with *almost vertical sides*, such as is seen at A A A in Fig. 139; but as down-cutting becomes less rapid, and the weathering agents widen the valley, it becomes *V-shaped* in cross-section, as B B B. As the valley widens more and more, it assumes in turn shapes more like C C C, D D D, and E E E, becoming wider and wider, until its sides have a very gentle slope.

When the valley is cut through rocks of different hardness, the weaker rocks are worn away more rapidly than the more resistant, which may stand out as cliffs, their upper surfaces forming *rock terraces*, as in Fig. 140.

A river valley becomes longer, just as a gully develops, by corrasion at the very head of its valley. This headward corrasion
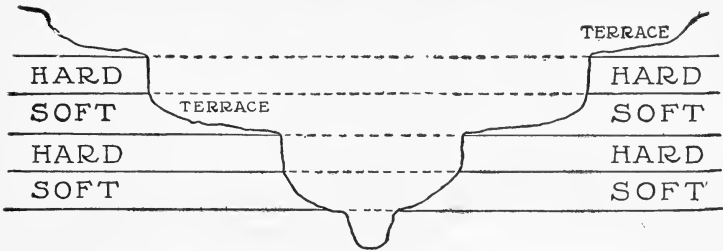
FIG. 140.—ROCK TERRACES

increases the length and decreases the steepness of the stream, as is shown in the series of profiles in Fig. 141. *A river profile is a line showing the slope of the surface of a river from its source to its mouth, according to definite vertical and horizontal scales.* The
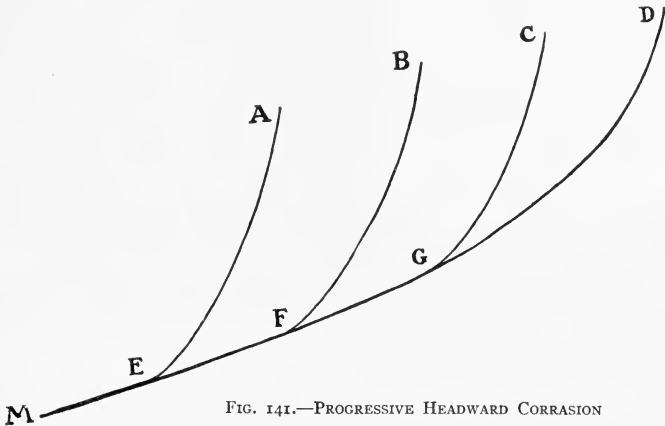
FIG. 141.—PROGRESSIVE HEADWARD CORRASION

profile A E M shows a steep slope near the source, becoming gentler down stream. Profiles B F E M, C G F E M, and D G F E M show progressive headward corrasion.

When a stream encounters in its bed rocks of different hardness, it wears away the weaker rocks more rapidly, producing at the hard rocks *falls and rapids*. At the foot of the falls the water swirls stones and bowlders and tends to wear there a depression called a *pothole*.

Most land surfaces are so uneven that the course to be taken

by rains falling on them is predetermined. In such regions it is easy to locate the water parting or divide. *A divide is the line separating two adjacent river basins.* Sometimes the area between two streams is so nearly level that the course rainfall will take is doubtful. In such a region divides are not well marked. But no
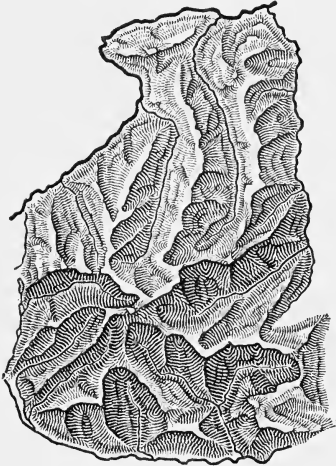
FIG. 142.—DIVIDES AND STREAMS IN AUSTRIAN ALPS. (Hachure Map.)
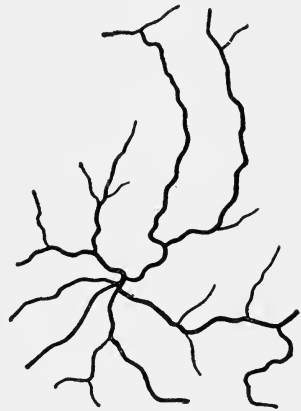
FIG. 143.—DIVIDES IN PRECEDING REGION

matter how level the region, with the headward advance of streams divides must eventually be developed between principal streams, with *subdivides* between tributaries.
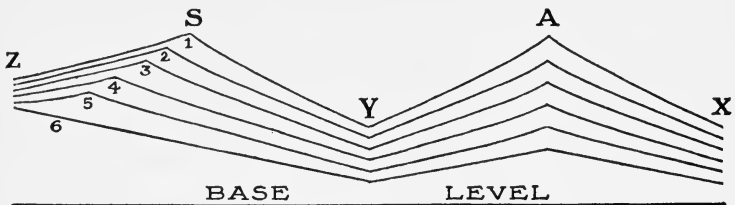
FIG. 144.—DIVIDES, VALLEY, AND STREAMS

Divide A between streams X and Y is adjusted. Divide S between streams Y and Z, shifting from 1 to 5, disappears at 6, causing Z to be captured by a tributary of Y.

If one stream is more actively deepening its valley than a neighboring stream, the divide between them *shifts toward the weaker stream*, as divide S in Fig. 144. But when two streams reach the point of lowering their basins at the same rate, the divide between them is *adjusted*, and instead of shifting sinks vertically as the region is worn down, as divide A in Fig. 144.

Stream Capture.—The effects of shifting of divides are seen in the Shenandoah River Valley, a region of rocks less resistant than those of the Blue Ridge to the east of it. The master stream of
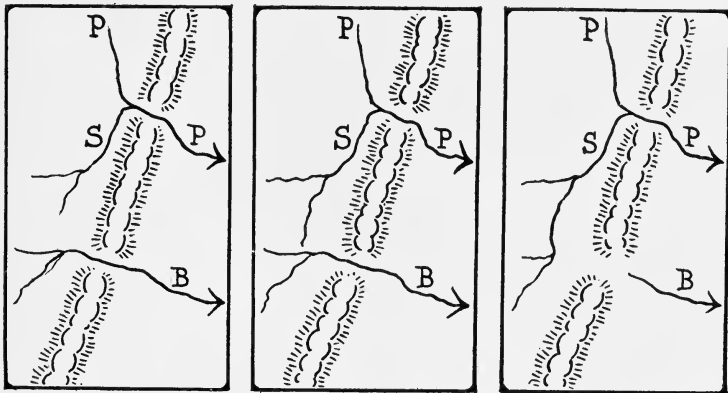
FIG. 145.—STREAM ARRANGEMENT IN WEST VIRGINIA AND VIRGINIA
Three stages in the capture of Beaver Dam Creek, B, by the Shenandoah, S.

the Shenandoah, the Potomac, cuts through the Blue Ridge at Harper's Ferry, forming a *water gap*. Beaver Dam Creek formerly had its course west of the Blue Ridge, as is shown in Fig. 145. It then flowed through the mountain ridge at Snicker's Gap, a battleground of the Civil War.

The Potomac, being larger, corraded its gap deeper than did the Beaver Dam; consequently the Shenandoah, a tributary of the Potomac, was able to corrade more deeply in the weak rocks of its valley than the Beaver Dam through the resistant rocks of the Blue Ridge. The divide between the two shifted nearer and nearer to the Beaver Dam, until finally the Upper Beaver Dam

was captured and became a tributary of the Shenandoah. The present Beaver Dam is a *beheaded stream;* and the abandoned water gap is a *wind gap.* From Snicker's Gap to the Shenandoah the *stream is reversed* in direction. This action by the Shenandoah illustrates one method of *stream capture* or *river piracy.*

Tributaries.—When several streams flowing down the *same general slope* unite, they form a *tree-like system of drainage* in which

FIG. 146.—MEANDERING STREAM IN A NARROW FLOOD PLAIN
Cañon del Muerte, viewed from Mummy Cave.

is illustrated the general rule that *tributaries join their master stream at an acute angle pointing down stream.*

Tributaries, though smaller, are generally steeper and swifter than their master stream, and may be corrading their beds more rapidly; but it is clear that they cannot corrade deeper than their master stream where they join. This tendency of *tributaries* to corrade their beds at such a rate as to *join their master stream at its grade, or level,* is known as *Playfair's Law.*

Stream capture, as we have seen, may result in causing *tributaries to join the capturing* stream at a right angle, or even at an *acute angle pointing up stream.* The Potomac and the Delaware have tributaries joining them at right angles; and Schoharie Creek, N. Y., and the Maumee River, in Ohio, have tributaries that join at acute angles pointing up stream.

(*b*) **Lateral Corrasion.**—Every stream is *cutting into its outer bank at every curve,* because water *obeys the law of motion* that
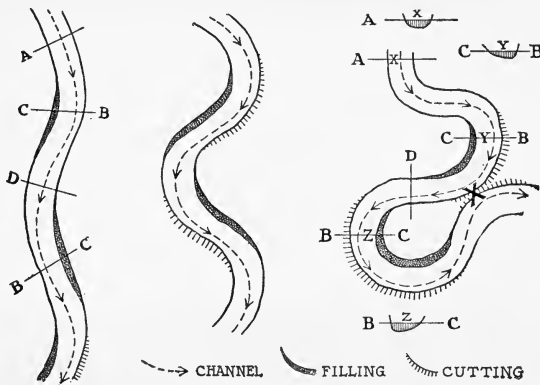
FIG. 147.—DEVELOPMENT OF A MEANDER

bodies in motion continue in motion in a straight line and at a uniform rate unless acted upon by some outside force.

If any curve in any stream is examined, it is found that the main channel and the swiftest current approach the outside of the curve. Let this be indicated in Fig. 147 by a dotted line, and let an arrow indicate the direction of flow. Just above and below the curve, the main channel, at A and D, is in the middle of the stream. But between B and C the water (obeying the law of motion) approaches B, and the swiftest current and deepest water are found nearer B than C. The swift current cuts into the bank at B and tends to undermine it. Soon a portion of the bank at B falls into the stream, and is washed away. This operation continues, and the channel moves more and more toward B.

On the opposite side, at C, on the inside of the curve where the bank is convex, the velocity of the water is less and the stream deposits a part of its load, *building out this side*.

This *cutting and filling* action continues at every curve, and the stream tends to develop a series of *winding curves* called *meanders*.

This tendency to meander is best seen where the materials

FIG. 148.—MEANDERING STREAMS, LARAMIE CREEK, WYOMING
Notice nearest curve bank, high on our right, low on left.

composing the banks of the stream are most easily corraded. These conditions are found in the low " bottom " lands near streams that the water overflows when the streams are in flood. These lands, called *flood plains*, are composed of materials that the stream has brought there and deposited from its muddy waters.

FIG. 149.—HOW CUT-OFF AND OXBOW LAKES ARE FORMED

A river may become so curved, especially where it is meander-
ing over a large flood plain, that two curves approach each other.
At some flood stage the water cuts through the intervening nar-
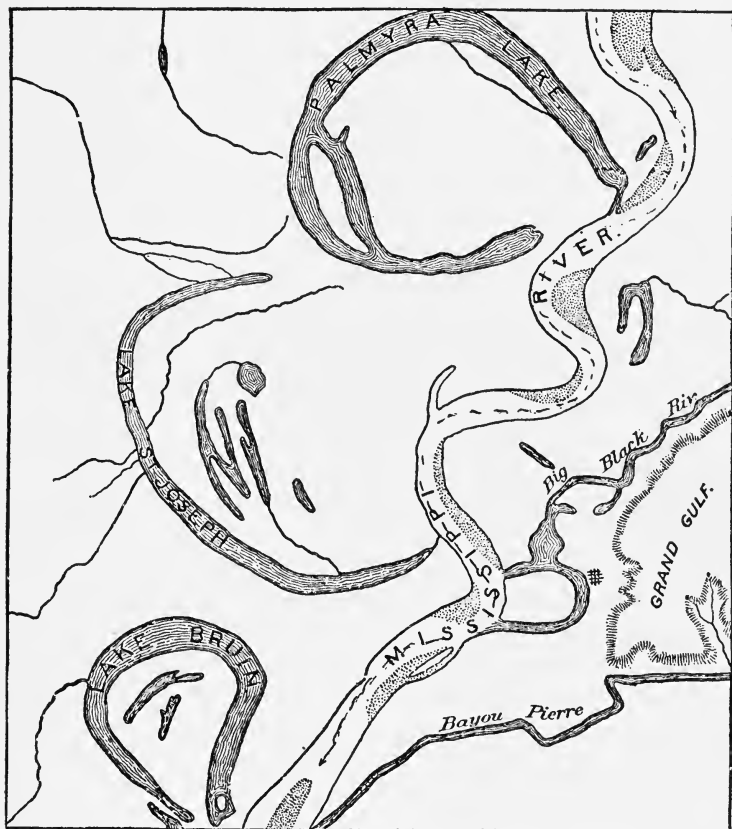
FIG. 150.—OXBOW LAKES, SAND DEPOSITS, AND MAIN CHANNEL OF PORTION OF THE
MISSISSIPPI RIVER

row neck of land and forms a *cut-off*, as at X in Fig. 147.   For
a time the water flows through both channels; but the new is
shorter and the current through it consequently swifter, so that
it rapidly increases in size until all of the water passes through it.
In this way streams tend to straighten themselves.   Fig. 149.

The ends of the old channel are almost at right angles to the new channel; water entering the old is checked in velocity and deposits materials that slowly close the entrances to the abandoned channel, changing it to an *oxbow* or crescent *lake*.

The crescent lakes of large rivers are arcs of larger circles than are the crescent lakes of smaller streams. There is a relation between the size of a stream and the size of the curves it makes on its flood plain. The curves of the lower Mississippi are arcs of circles of approximately five to ten miles in diameter. A line along the outside of the curves on the east side of the Mississippi is about fifteen miles from the corresponding line on the west side, making the *meander belt* or meander zone of the Mississippi about fifteen miles wide. Meanders move down stream.

TRANSPORTATION

Transportation.—A glass of water dipped from any muddy stream will become clear after standing for a longer or shorter period, and layers of sediment will form on the bottom of the glass. This solid material distributed through the water, in spite of its greater density, is said to be carried *in suspension*.

The particles have been obtained by corrasion of the bed or of the banks, or may have been washed into the stream. It is possible that the particles may travel to the mouth of the stream without a stop, but under ordinary conditions they settle to the bottom when the current slackens, to be picked up again and carried farther when the current is again increased.

The finest particles of rock waste are heavier than water, and would settle in water at rest or in water moving in lines parallel to the surface. But the irregularities in the stream beds are continually sending numerous currents upward, thus counteracting the tendency of the particles to settle. In comparison with a large particle a small particle has a larger area, and it must therefore set a relatively larger mass of water in motion in order to sink.

The *transporting power* of a stream depends mainly on the volume and the velocity of the stream. A stone weighs less in

water to the extent of the weight of water it displaces; this causes most common rocks to lose about one-third of their weight in water. *The transporting power of streams increases as the sixth power of the velocity.* For example, if the velocity is trebled, the transporting power, instead of being trebled, is increased 729 times, that is, $3 \times 3 \times 3 \times 3 \times 3 \times 3$. Torrents, in their steep upper courses, are able to roll along bowlders of many tons weight. A change in velocity, even if slight, makes a great change in the amount of sediment that may be transported.

In swift streams much rock waste too coarse to be held in suspension is *rolled along the bottom*, and sometimes in mountain torrents the collisions between the stones thus moved produce a loud and almost continuous noise. In the lower portion of rivers the amount of sand and small pebbles that is rolled along the bottom is probably a very important part of the total amount of rock waste transported.

Work in many streams is done at flood time only. During the summer most streams are low and do little work.

Water in passing over soluble substances dissolves them in part. In limestone regions the water becomes "hard," that is, with soap it does not easily form lather or suds, and when boiled a scale forms on the inside of the boiler or of the kettle.

The amount of mineral matter *carried in solution* by streams varies greatly. It depends, among other things, upon the nature of the region over which the streams flow. It is well known that the water of streams in sandstone regions is softer than that of streams in limestone regions; that is to say, they contain a smaller percentage of mineral matter in solution. The total amount of mineral matter carried to the ocean in solution is about one-third as great as that carried in suspension.

A small amount of rock waste is transported on the *surface* of streams, lodged in ice or attached to the roots of trees or to other floating objects, called *drift*. Drift tends to go toward shore when a stream is rising and the water surface in the middle of the channel is highest. But when a flood is subsiding, the water surface is concave and the drift tends to leave the banks and to

seek the middle of the channel. Lumbermen take advantage of this in floating out their logs.

Hilly, forested portions of the land should not be stripped of their forests and cultivated, because this causes the streams to wash the soil away. Neglect of these precautions has done much damage in some of the older States. The Forest Service of the National Government is endeavoring to avert the fate that has overtaken certain portions of Spain and China.

The Mississippi River removes yearly, by rolling along its bed, enough waste to cover a square mile to a depth of 19 feet; in suspension waste enough for 241 feet more; in solution 50 feet more if it were all limestone—a total of 310 feet. This is enough waste to lower the level of the whole Mississippi River Basin at the rate of 1 foot in about 4,000 years.

The Po removes enough waste to lower its whole basin at the rate of 1 foot in every 729 years.

COMMINUTION OF LOAD

Grinding and Polishing.—Streams push and roll angular fragments of rock along their beds and over one another, colliding as they go, until their corners are knocked off and they are rounded and worn smooth. In this way large angular stones become small *pebbles*, characteristically smooth and rounded; just as boys' marbles may be made by placing small pieces of marble in a cylinder, the rotation of which causes the pieces to wear one another round.

DEPOSITION

Deposition.—A river carrying waste tends to deposit its waste whenever its velocity is diminished. The velocity is diminished by decreasing either the slope of the bed or the depth or volume of the water. A slight check in velocity causes only the coarsest materials to come to rest. Further checking deposits materials not quite so coarse. By this process deposits of different sized materials tend to form in different places at the same time, and in the same place at different times. As a result, stream deposits
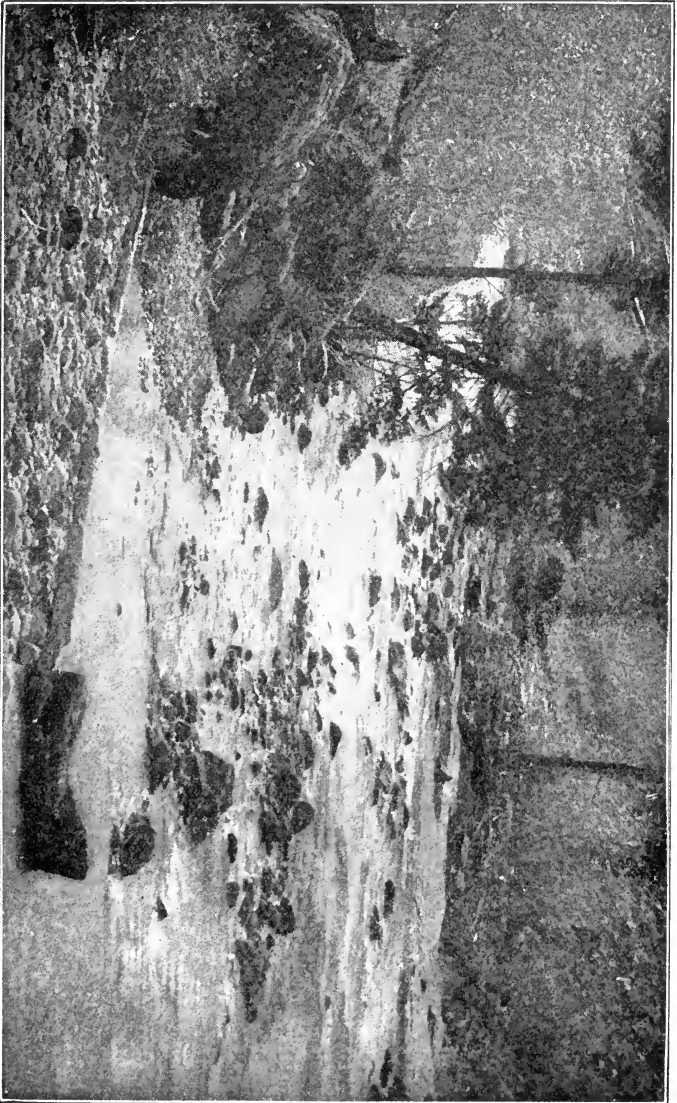
FIG. 151.—THE ASSORTING ACTION OF RIVERS

Large stones in stream, cobbles to the left and this side of log; pebbles beyond the log; sand and drift on the opposite side. Mouth of Red Cañon, Colorado. (Detroit Photographic Co.)

are generally *assorted* according to size and *stratified*, that is, arranged in layers.

Alluvial Fans and Cones.—The effect of a sudden change of slope is well illustrated in Fig. 134, of the gully. The water loses velocity as it approaches the level land, and here the coarsest materials are dropped. As the velocity diminishes the particles deposited are smaller and smaller, gravel will be carried farther

FIG. 152.—ALLUVIAL CONE AT MOUTH OF AZTEC GULCH, COLORADO

than the bowlders, sand farther than the gravel, and finally clay farther than the sand. From the foot of the slope the deposits spread out in a semicircular form, made up of concentric bands of assorted materials called *alluvial fans*, if of gentle slope, but *alluvial cones* if the slope is steep.

Streams from mountains sometimes form fans which join laterally, forming plains. Because such plains from the Sierra Nevada are higher than those from the Coast Ranges of southern California, the San Joaquin River lies nearer to the Coast Ranges than to the Sierras. For a similar reason the Po lies nearer to the Apennines than to the Alps.

Sand Bars.—A decrease of slope within the bed of a stream causes deposition forming *sand bars*. These bars sometimes begin

about obstructions that check the velocity of the water. Their formation and growth resemble that of snowdrifts and sand dunes. They have a gentle slope up which sand and pebbles are rolled, and like dunes, they migrate. They are most noticeable in times of low water; during high water they may be scoured out, but they may form again about the same place.

Nearly all streams, large and small, are undergoing this *scour-and-fill* process. The scouring effect is produced artificially in
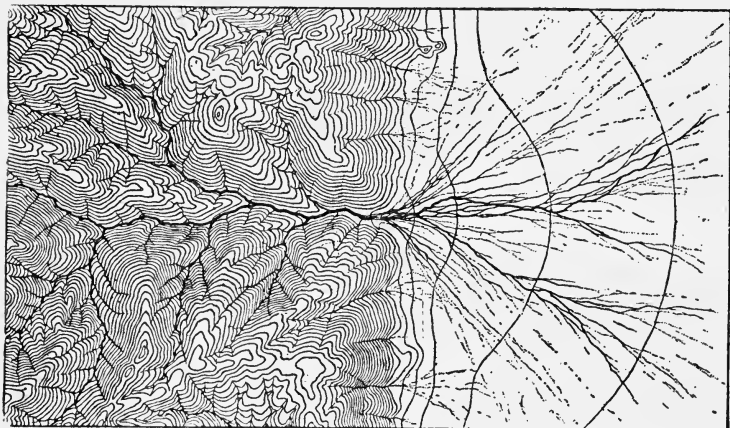
FIG. 153.—ALLUVIAL CONE, WITH TRIBUTARY AND DISTRIBUTARY STREAMS
Note contours on cone. (U. S. Geological Survey.)

South Pass, one of the mouths of the Mississippi, by means of *jetties*, which narrow the channel. The water above the jetties rises. The higher head of water causes the water to flow through the narrower space with greater velocity, scouring out the deposits and preventing the formation of a bar that would impede navigation.

Braided Streams.—Some rivers have in the dry season very wide beds with but small volume of water. The wide and shallow stream cannot then carry the load brought by its tributaries and deposits much of the load on its own bed, forming numerous interlacing channels. Such a stream is said to be *braided;* in dry

seasons much of its water flows underground. The Platte River is an example of a braided stream.

Deposits on Flood Plains.—Water particles move about each other with much less friction than they move over solids, and also with less friction than between water and air. This accounts for the fact that the deepest portion of the cross-section of a stream is the swiftest portion, and also for the further fact that in this deepest portion the velocity at the bottom is less than that near the top.

When the water of a river spreads out in shallow sheets, as it does when it overflows its flood plain, the velocity on the flood
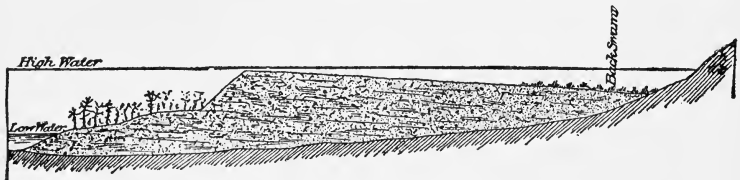
FIG. 154.—SECTION ACROSS ALLUVIAL PLAIN ON ONE SIDE OF A LARGE RIVER
Vertical scale exaggerated.

plain is much diminished by friction, whereas the velocity in the channel, where the water is deep, is greater than the velocity in the same place at low water. This not only causes deposition on the flood plain, but is likely to cause corrasion in the bed elsewhere, thus increasing the available materials for deposition on the flood plain. The deposit is called alluvium, or silt. The lands *subject to floods* tend to build up to the level of the floods, and are very properly called *alluvial* or *flood plains.* Because every flood renews the fertility of the flood plain, we find here the most fertile lands. The flood plain of the Nile was the granary of the ancient world. When the current is swift, it may wash fertile soil away, or cover it with gravel and bowlders.

When water leaves the main channel and spreads over the flood plain its velocity is checked the most close to the stream, and consequently more and coarser deposits are made here than farther back. This excess of sandy deposits on the flood plain close to the stream is called a *natural levee.*

In the lower Mississippi, below the mouth of the Red River, the slope is so gentle that sediment is deposited along the bed of the river, raising the level of the surface of the river. Not infrequently the surface of the river is higher than the land back of the natural levees, and this gives the river the appearance of
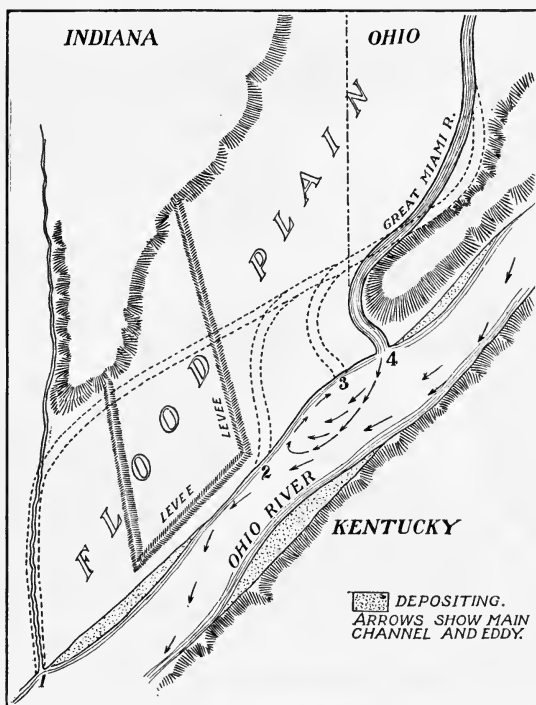
FIG. 155.—THE MEANDERING OF THE GREAT MIAMI RIVER

In a wide alluvial plain at its junction with the Ohio River. At different periods it has consecutively entered the Ohio through the different mouths as indicated by the dotted lines. As late as 1786 it occupied the bed numbered 3 in the map. Most of the surrounding plain is covered several times a year by water in times of flood, sometimes to the depth of 15 feet. The amount of sediment deposited is remarkable.

A stone monument that marks the Ohio-Indiana state line at this point when set up was of a height that a man on horseback could barely reach the top; at the present time the top is but two feet above the surface of the plain.

Another feature of this deposition of sediment is that the older deposits now buried to the depth of many feet are far better suited to agricultural requirements than the present surface sediments for the reason that the earlier deposits come from the forest-clad hills rich in humus, while the present are the impoverished wastings of newly-tilled, bare fields.

flowing along in the top of a ridge it has built across its flood
plain.

The slope of the flood plain, away from the river, is usually
steeper than the general slope of the river toward its mouth.
As a result of this, when the Mississippi overflows its banks and
spreads out over its flood plain, those lands most remote from the
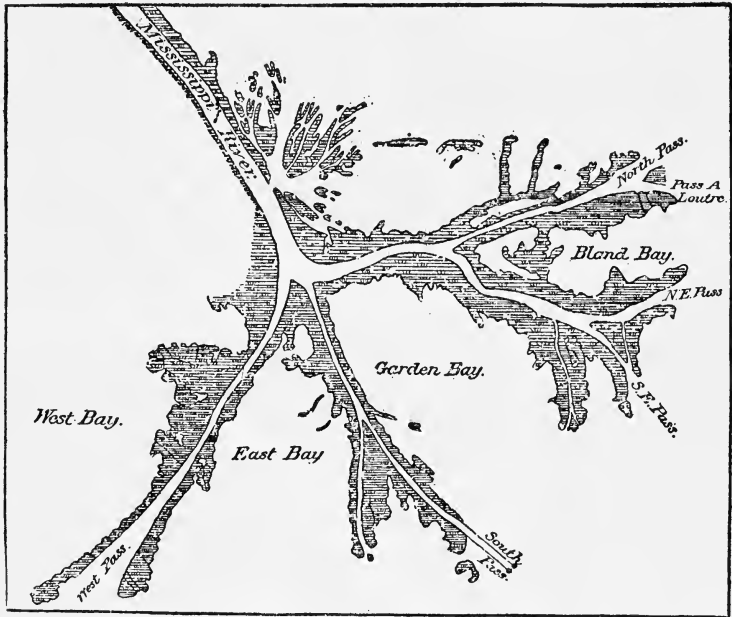
FIG. 156.—MOUTHS OF THE MISSISSIPPI RIVER
Only the natural levee portions of the deposits appear above water.   (U. S. Geological Survey.)

river are first and most deeply drowned, in some places to a depth
of more than thirty feet.

As the river continues to build up its front lands, there comes
a time when the lower swampy back lands offer a more favorable
route for the river than its normal meandering course. The river at
some flood stage seeks this new and more favorable route. This
sudden change of the river is called *migration*, and is to be distin-
guished from the gradual shifting of the channel called meandering,
which is confined to the meander zone.

From Memphis to Vicksburg the Yazoo River, on the east side of the flood plain, occupies an abandoned channel of the Mississippi. The Yazoo is not capable of forming meanders as large as those it follows. South of Vicksburg, where the Mississippi follows the east side of its flood plain, there is a similar abandoned channel on the west side of the flood plain, now occupied by the Tensas River, which is likewise incompetent to produce the wide meanders of its course.

Protection from Overflow.—Two methods are advocated for protecting the flood plain of the Mississippi from overflow. One is to *maintain outlets* to distribute the floods as quickly as possible. On the east side, just below Baton Rouge, an outlet could be maintained into Lake Pontchartrain, by way of Bayou Manchac, a former distributary; on the west side, one through the Atchafalaya, one through Bayou Plaquemine, and one through Bayou La Fourche.

The other method is to build *levees* sufficiently high to restrain the highest floods. This involves the building of high levees along both sides of the Mississippi (except where it flows near the high land, where but one levee is necessary) and along all important tributaries and distributaries.

Levees are built of flood plain materials, the largest being about 40 feet high and 200 feet wide at the base. In times of danger the height of the levee may be temporarily raised by bags of earth. The levees are built alongside the river where the banks are convex; but where the banks are concave the levee is built farther back because of the cutting and caving of the banks on this side.

When the water is critically high, State guards patrol the levees on the lookout for leaks and to prevent tampering with the levees. Steamboats are required to keep as far away as possible from the levees, lest the waves generated by them cause the levees to break. The greatest natural enemies of the levees are the crayfish and the muskrat.

Because the flood plain is highest near the river, *small streams*

starting near the main stream *flow away* from it toward the *back swamp*. The Yazoo River enters the flood plain and flows along the back swamp region parallel to the main stream until captured by the migration of the Mississippi to that side of its flood plain at Vicksburg. In Louisiana the Atchafalaya continues along the back swamps to the sea. The Red River, receiving the drainage from the Tensas Basin of the Mississippi flood plain to the north, is, more and more, sending its waters to the Gulf by way of the Atchafalaya.

When a river empties into a quieter body of water, as the sea or a lake, its velocity is checked and waste is deposited in and around its mouth, forming a *delta*.

The several channels into which the main stream divides in the delta are called *distributaries*. Those at the mouth of the Mississippi, called "passes," are bordered by continuations of the natural levees of the flood plain.

The river-borne waste, which consists of the finest materials, may be carried far to sea before being deposited, sometimes as far as 200 miles from shore.

QUESTIONS

1. On the U. S. Topographic Maps of your vicinity, study carefully your nearest or most interesting river or stream. Apply a string carefully along its course and determine the length of the stream in miles and kilometers. Determine its limiting divides. Estimate the area of its basin in square miles and in square kilometers. Map it on manila paper on as large a scale as is convenient.

2. Proceed similarly for your State, mapping the canals as well as the principal rivers and lakes.

3. On a U. S. Base Map, mark the principal divides and guess at, or estimate, the areas of the principal drainage regions in percentages of the whole.

4. After you have studied a real gully, describe how, in your opinion, it was formed.

5. If the average annual output of the Mississippi River is 44.7 cubic miles of water, how deep a lake would this make if its area was that of your county? your State?

6. Draw or trace the tributaries of the Maumee River of Ohio, Schoharie Creek, New York, and of some other stream system, and account for the ways the tributaries join their master streams.

7. Give at least two reasons why some streams do not corrade their beds.

8. With a diagram explain how meanders and oxbow lakes are formed.

9. Draw a top view, showing tributaries, distributaries, and contours of an alluvial cone or fan. Draw cross section showing location of coarsest and finest deposits.

10. Draw a portion of the Platte River showing a braided stream.

11. Draw and label an ideal cross section of a flood plain, showing a river flowing along in its bed in the top of a ridge it has built for itself. The bottom of the bed is to be below sea level; the river bank full and higher than the back swamps, which are beginning to fill with water.

12. Summarize in tabular form under headings, (1) kinds, (2) places, and (3) products, the five different ways in which streams work.

13. On transparent paper trace the divides and subdivides in Fig. 142. Then without consulting the map, draw in, in blue, the streams where you think they should be. Then compare your work with Figs. 142 and 143.

14. Similarly trace divides and subdivides in the mountainous portion of Fig. 153. Then draw in, in blue, the streams where you think they should be. Compare Fig. 153.

CHAPTER XXI

LIFE HISTORY OF A RIVER

Base Level.—The life work of a river, with reference to the region it drains, is to wear down the land and to carry it into the sea. Its work will never be finished until the region is worn down to sea level. The *level of the sea is the base level* below which the lands cannot be eroded; but we may also have local base levels, such as a lake or the level of a stream into which a tributary empties.

Stages of Development.—It is convenient to speak of the different stages of a river's development as *youth, maturity,* and *old age,* and to characterize the general features of a region as young, mature, or old. These terms are relative, and do not lend themselves to expression in numbers of years.

Youth.—A stream that is *degrading* and has most of its work before it is said to be young. Young streams are characterized by *steep* slope, *rapid* current, and great power to *corrade their beds.* Young streams have narrow *V-shaped valleys. Lakes* are characteristic of young rivers, disappearing before maturity. At first a young stream has *few tributaries,* especially on plains and plateaus, where the tributaries may begin as mere gullies. The *divides* are not well marked, especially on plateaus and plains, where large level interstream areas are found. *Rapids and falls* may be present in a young stream, but they, too, disappear before maturity. Falls, rapids, and lakes give a young stream a *profile* that is in places *convex upwards.* Young streams are usually *clear.* The *upper course* of all great rivers is young.

Maturity.—A river or any part of it is said to be *graded* or mature when it has a slope *just suited* to its load and volume.

It has so destroyed its falls, rapids, and lakes, and so *aggraded* or built up its too gentle slopes, that it has just the *right slope* to carry its load of waste with its volume of water. Its profile is called the *profile of equilibrium*. This perfect adjustment of slope, volume, and load is difficult to attain. If attained, any change in any one of the three factors disturbs their balance. Although no river is graded throughout its entire course, most rivers have graded portions. In maturity the *divides* are *well defined* and adjusted, the *valleys broad*, and the *numerous tributaries* obey Playfair's Law of entering their main stream at the level of the main stream. The river *tends to meander* over *flood plains, becoming wider* toward the mouth. The *profile of equilibrium* is a curve, concave upward,
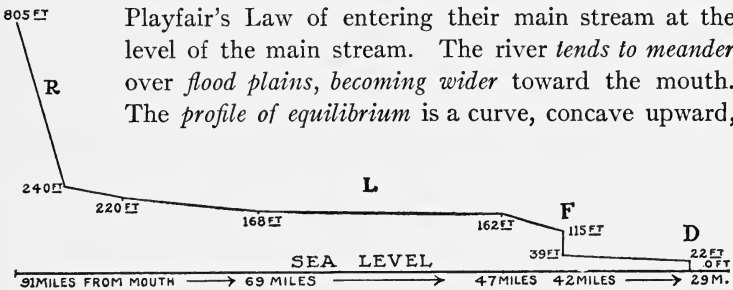
FIG. 157.—PROFILE OF PASSAIC, SHOWING CHARACTERISTICS OF YOUTH
Rapids at R; lake when floods at L; falls at F.

steeper near the source, becoming more gently sloping, and passing imperceptibly into the base level of erosion at the mouth. The *middle course* of great rivers is in the graded or mature stage.

Old Age.—In some rivers, and especially near the mouths of large rivers, the slope becomes too *gentle* for the stream to carry all its load of *waste*, and so a part is *deposited*. Old streams have generally *wide, flat-bottomed, shallow valleys, wide flood plains* over which the *streams meander*, forming *oxbow lakes*. Since the *flood plain is highest near* the river, streams formed on the flood plain are usually prevented from joining the river. The deposits tend to build up the stream bed and, at the mouth, to form a delta that extends or prolongs the flood plain, and the river breaks up into distributaries. The *lower course* of many great rivers is in the old-age stage.

When all the streams of a region have reached old age, and

when the region is worn down nearly to base level, it forms what is called a *peneplain*. A peneplain is a region that is "almost-a-plain," and is the last stage of an eroded mountain or plateau.

Normal River Cycle.—Because every stream tends to pass through youth, maturity, and old age, these stages constitute the *normal cycle*, and their record the *life history* of a river. Many streams never complete their normal cycle because it is interrupted in some way.

Interrupted River Cycles.—The normal cycle of river development may be interrupted by *change of slope*, resulting from *depression* or *elevation*, and by *change of climate* from *moist to dry* or *dry to moist*, or from *warm to glacial* or *glacial to warm*. The general effect of elevation is to lengthen the cycle, of depression to shorten it.

Effects of Depression.—If depression occurs *at the mouth* of a river, the sea will enter the lower portions of the river valleys, *drowning* them and producing *bays*, estuaries, or fiords. Tributaries near the mouth of a river enter bays, and the master stream is said to be *dismembered*. The lower Susquehanna, with its tributaries, the James, the York, and the Potomac, when drowned and dismembered, becomes Chesapeake Bay, with its many branching bays.

Effects of Elevation.—Elevation of a region *at the mouth* of a river lengthens the river. When two or more rivers thus lengthened unite, they form an *engrafted river*. Rivers may also be engrafted by the extension of their deltas into the same bay. The tributaries of the Mississippi River below Cairo have been engrafted upon it.

If elevation takes place *at the source*, the slope is increased, and the river is *rejuvenated*. A meandering river, if rejuvenated, forms *entrenched meanders*. Rivers entrenching themselves in flood plains sometimes leave portions of the old flood plain persisting as *alluvial terraces*.

If the uplift is *across its course*, the river may corrade downward as rapidly as the uplift is made, thus producing *water gaps*. The Green River passes through the Uinta Mountains and the

Hudson through the Highlands. Because such rivers had their approximate location *before* the mountains were uplifted they are called *antecedent rivers*.

Effects of Change of Climate from Moist to Arid.—In general the river cycle is lengthened. When the annual rainfall of a region diminishes the *rivers become smaller* and eventually cease flowing, except immediately after rains. *Forests disappear* except along stream courses. When forests are removed there is little to retain the run-off, and the *streams*, quickly flooded, quickly subside. Their dry stream beds are called gulches or *wadies*. The *lakes* by evaporation become salt, and generally decrease in size, finally becoming *salinas* or salt plains. When the inflowing streams bring much sediment, *playas* or mud plains may be formed.

The region between southern Russia and Pekin, China, exhibits these phenomena in different stages. Increasing dryness in what is now the desert portions of the Chinese Empire may have caused the great migrations of the Asiatics which resulted in the invasion of Europe by the Huns and Mongols.

Similar climatic changes have taken place in the Great Basin portion of the United States between the Rockies and the Sierra Nevada Mountains, especially in Utah and Nevada.

From Arid to Moist.—Increased rainfall shortens the river cycle. The increased rainfall brings about reforestation. The rain and the forests restore and *enlarge* the *rivers* and make them in volume more *nearly uniform* throughout the year. The playas and salinas become *lakes*, and *salt lakes*, when filled to overflowing, become fresh. *Plants* and *animals* gradually return and increase.

The deposits of rock salt in regions now moist, as in New York, Michigan, Kansas, and Louisiana, indicate former arid conditions in these regions.

From Warm to Glacial Climate.—As the climate becomes colder, plants and animals adapt themselves to the cooler climate, migrate, or perish. With increased cold and increased snowfall, more snow may fall than melts during the year. This occurs first upon the higher lands; but the areas of permanent snow gradually spread until the entire region is snow covered. The rivers get smaller and

smaller and finally disappear, except near the borders of the glacier.

From Glacial Climate to Warm.—The disappearance of the glacial ice produces floods in all rivers. The rivers become longer as the glaciers retreat. The melting ice leaves irregular deposits, whose depressions are occupied by lakes and swamps. A new system of drainage must be developed where the old has been obliterated. In general, the river cycles begin anew. Some rivers reoccupy their preglacial valleys in part, and in part develop new channels, with falls and rapids. The lower Hudson occupies its preglacial channel. The Genesee has developed a new channel, with falls and rapids at Rochester.

QUESTIONS

1. Make a comparative table of the characteristics of young, mature, and old streams. In the characteristics column, place such items as steepness, swiftness, corrasion of bed with products; corrasion of banks, relations to falls, rapids, and lakes; profiles, divides, tributaries, transportation methods, deposition and uses to man.

2. How, from an ordinary map, can you tell the stage of a river?

3. Is a muddy stream more apt to be old or young? a clear stream? Why?

4. Compare the effects of elevation and of depression on the length of the river cycle, with examples.

5. Do the same for a change of climate from moist to arid, from arid to moist.

6. Similarly for from warm or temperate to glacial, with change from glacial.

7. In what ways, and with what results, may a normal river cycle be interrupted?

8. State the advantages and disadvantages to man of the different stages in the life history of a river.

9. What are portages?

10. What is it to rectify a stream?

11. Account for sunken or incised meanders.

12. Why may a river valley be in some portions young and in other portions mature or old?

13. What is imperfect drainage?

14. What would be the effect on Lakes Erie and Ontario if eastern Canada should be slowly uplifted?

15. Distinguish an estuary and a delta.

CHAPTER XXII

FALLS, RAPIDS, AND LAKES

Location of Falls.—Falls and rapids are numerous among mountains and plateaus. They are characteristic of the upper courses of great rivers, and of young streams among hills. In many rivers falls and rapids mark the head of navigation. Small and light boats, like canoes, can be unloaded and carried around them; but large boats pass them by means of canals with locks.

Economic Importance of Falls.—Falls and rapids furnish valuable water power. This is the foundation of the manufacturing interests of New England. The establishment of mills at falls quickly develops villages, which may become flourishing cities, as Lowell, Rochester, and Minneapolis have done.

Electric power developed from water power at Niagara Falls is transmitted as far as Syracuse, 180 miles from the falls, and this illustration of the use of water power at a distance from the falls has done much to increase the value of undeveloped falls that are located in mountainous regions, or where manufacturing establishments would be at a disadvantage for some other reason.

When a fall is at the head of navigation of a river, it becomes a railroad center, and the loading and unloading of vessels furnish labor, which aids in the development of a city.

Some Important Falls.—At *Niagara Falls*, the outlet of Lake Erie plunges over a precipice 160 feet high on its way to Lake Ontario. Goat Island divides the stream, making two falls; the larger, on the Canadian side, is called from its shape the Horseshoe Fall; the smaller, the American Fall, enters the side of the gorge.
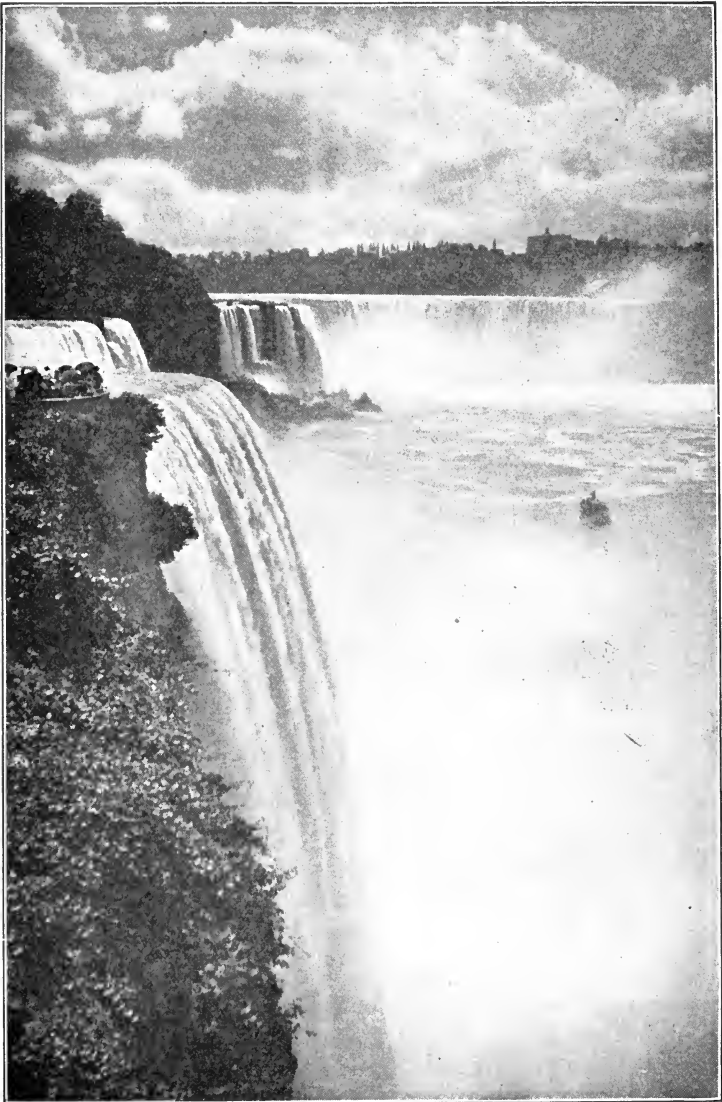
FIG. 158.—NIAGARA FALLS.

The enormous volume of water passing over this fall gives Niagara its grandeur and impressiveness and makes it one of the wonders of the world.

The upper sixty feet of the face of the fall is a hard limestone, in nearly horizontal layers; below this is a hardened mud or shale with occasional thin bedded limestones, which is very easily corraded. At the foot of the Horseshoe Fall the water is some 200
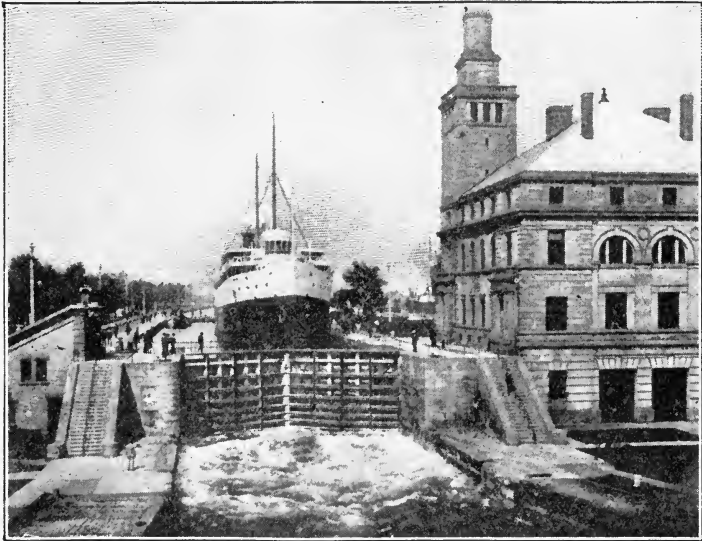
FIG. 159.—LOCK IN ST. MARY'S CANAL

feet deep, the soft rocks at the base being worn away to this depth by the force with which the water strikes it and by bowlders which the water whirls around. Below the falls the river follows a gorge some seven miles long. Only a small portion of the water of the Niagara River is diverted from the falls for power purposes.

The Genesee Falls.—The Genesee River flows over the same rock formations as the Niagara, but the volume of the water is less, and we have here three separate falls, each of which has at its crest a hard limestone or sandstone and beneath this an easily

eroded shale.   Below the falls the river flows through a gorge
similar to that at Niagara, but narrower.

St. Anthony's Falls.—The Mississippi River at Minneapolis,
Minn., flows over a precipice capped by a somewhat thinner layer
of limestone than that at Niagara; and as the volume of water is
large and the cap rock was not resistant enough to preserve the
fall, it was therefore necessary to build a wall of cement under-
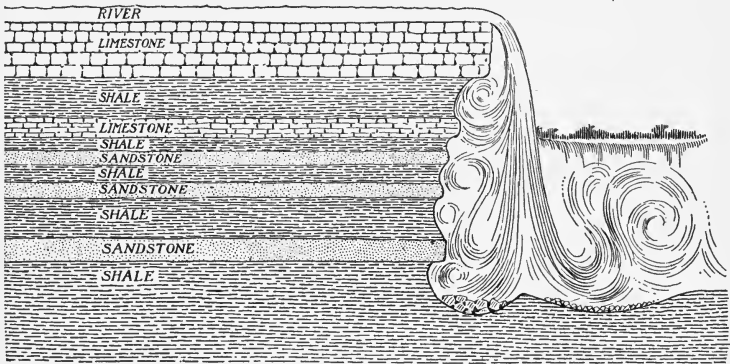
FIG. 160.—HOW NIAGARA FALLS WERE FORMED

neath the Fall of St. Anthony in order to preserve the falls and
their valuable water power.   Here again the river, below the falls,
flows through a gorge several miles long.

Shoshone Falls.—The Snake River in Idaho flows over a hori-
zontal sheet of hard lava which overlies softer rocks, forming
this fall.

A Line of Falls.—In the southeastern part of the United States
falls are found in all streams at the outer margin of the piedmont
plateau, where they enter the coastal plain.   The term *fall line*
has been applied to a line connecting the falls and rapids at the
heads of navigation in these rivers.

How Falls are Formed.—It will be noted that in each of the
four falls described above the cap rock of the precipice over which
the water falls consists of nearly horizontal layers of rock that
resists corrasion well, and that underneath this in each case is a

soft rock. This is the structure which has led to the formation of most falls. The weak rocks are corraded more rapidly than the resistant rocks, increasing the slope of the stream at the point where the hard and soft rocks meet, until finally a fall results.

The Meaning of the Gorge.—Many falls are, like Niagara, situated at the up-stream end of a gorge of considerable length, which has been formed by the recession of the fall. It has been shown by careful surveys that the center of the Horseshoe Fall at Niagara is travelling toward Lake Erie at the rate of about five feet a year. Similar though less rapid recession takes place in all falls of this structure.

In Fig. 160 a section of Niagara is shown. The water swirling around at the foot of the fall cuts backward into the face of the precipice, and spray, frost, and ice assist in the undermining, forming a cave. The cap rock is worn but slightly as a rule, but undermining proceeds with comparative rapidity, causing the cap rock to fall of its own weight. The crest of the fall thus travels up-stream until it disappears.

LAKES

A lake or a pond will always be formed in all depressions in the land if rainfall or inflow exceeds evaporation and possible seepage. If the yearly rainfall and inflow exceeds the yearly evaporation from the surface of the lake, the lake is *permanent*, and water accumulates in the basin until it finally overflows at the lowest point in the rim of the basin. *Temporary* lakes are formed where the water reaching the depression temporarily exceeds the loss during the given time, but where the yearly supply is less than can be evaporated.

Two conditions are therefore necesssary for the formaticn of a permanent lake—a basin without an outlet that reaches to the bottom of the basin, and an excess of water received over that lost. In arid regions there are many basins that are not lakes because of insufficient rainfall or tributary streams, but in well-watered regions every basin contains a lake. Lakes always indicate imperfect drainage.

Origin of Lake Basins.—Some lake basins, Lake Superior and the Caspian Sea, for example, are believed to be the result of the *uplift* of intervening land masses that separated them from the ocean. Some of the early myths and legends of the Greeks seem to indicate a former passage through the Black and Caspian Seas to the Arctic Ocean. Other lakes are believed to be due to the *depression* of their basins. Examples of this type are Lake Baikal, over a mile deep, and the lakes in the Great Rift Valley, extending from the Sea of Galilee through the Dead and Red Seas into the Lake region of Africa.

Lake basins are formed by obstructing river valleys by lava flows, landslides, or glacial deposits. The Finger lakes of central New York are the unfilled portions of pre-glacial river valleys.

Other lake basins are formed by the natural processes of rivers. Lake Pipin, in the Mississippi River, is formed by delta deposits which accumulated in its valley at the mouth of the Chippewa River of Wisconsin. Oxbow lakes are abandoned portions of streams that have been closed at one or both ends. The lakes along the Red River of Louisiana are made by the more rapid building up of the flood plain of the Red than of the flood plains of its tributaries.

The *craters* of some dormant and some extinct volcanoes become partially filled with water. Such lakes are generally deep, circular, and with precipitous banks. Crater Lake, Oregon, is a typical example in the United States. Lake Avernus, on whose shores the ancients believed was situated the entrance to the Lower World, is one of several crater lakes west of Naples. Other crater lakes are found near Rome. In southern Germany are found older crater lakes, with low, gently sloping banks.

At the base of Mt. Shasta, and several other volcanoes, lake basins are found in depressions between lava flows.

Many lake basins are found in and among the uneven deposits of till left by glaciers. The numerous "kettle lakes," such as Lake Ronkonkoma on Long Island, belong to this class. In some instances basins have also been scoured out of the solid bed rock by a glacier.
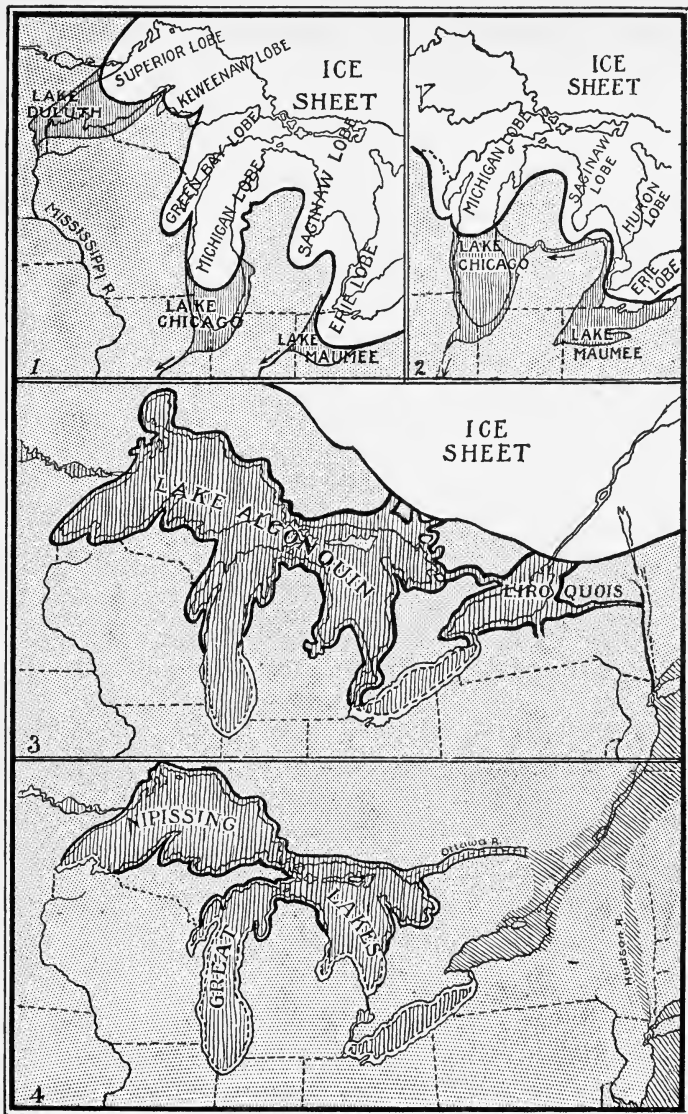
FIG. 161.—DEVELOPMENT OF GREAT LAKES AT END OF ICE AGE
Stages indicated by outlet: In 1, separate; in 2, Lake Maumee into Lake Chicago only; in 3, through the Mohawk; in 4, through the Ottawa.

FIG. 162.—DELTA BUILT INTO A LAKE
Silvaplana, Switzerland.

REFERENCE TABLE OF PRINCIPAL LAKES

NAME	AREA IN SQ. MI.	ALTITUDE IN FT.	MAXIMUM DEPTH.	COMPARISONS
Caspian	170,000	—85	3,200	California 158,000
Superior	31,200	602	1,008	So. Carolina 30,000
Victoria Nyanza	26,000	800	240	West Virginia 25,000
Michigan	22,500	581	870	....
Huron	22,320	581	700	....
Baikal	13,000	1,700	5,600	Maryland 12,200
Erie	9,960	573	200	New Hampshire.... 9,300
Ontario	7,200	247	738	New Jersey 7,800
Tchad (dry season)	6,000	900	8	....
(wet season)	40,000	...	20	....
Titicaca	3,200	12,500	700	....
Nicaragua	2,800	...	...	Delaware 2,000
Great Salt Lake	2,200	...	...	....
Champlain	480	...	...	New York City 327
Dead Sea	360	—1,268	1,300	" "

Destruction of Lakes.—Lakes are temporary features in the early stages of the development of the drainage of a region, and disappear as the river system develops. Many lakes have been *drained* by corrasion of the outlet channel; in time all lakes whose
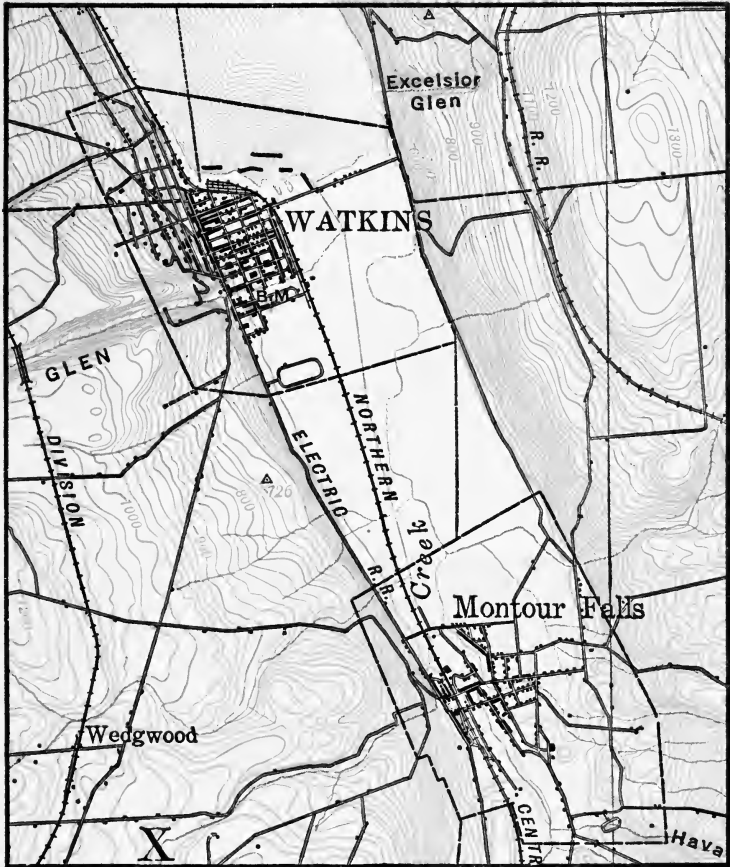
PLATE I. CONTOUR MAP. DELTA AT THE HEAD OF SENECA LAKE, N.Y.

From U.S. Geol. Survey.
Scale: 1 inch = 1 mile. Contour interval, 20 feet.

bottoms are above sea level must disappear through this action, unless some other agent destroys them first. Other lakes have disappeared through the opening of a new outlet, for example, former Lakes Chicago, Agassiz, and Warren (Fig. 161) were drained when the melting of the glacial ice uncovered new and lower outlets.

FIG. 163.—HOW VEGETATION DESTROYS A LAKE

Pond lilies in center, smartweed at edge, farther back cat-tails, blue flags, sweet flags and sedges; still farther back soft turf with grass, moss, sedge and milkweed.

A second method of destroying lakes is by *filling*. Some five miles of the southern end of Seneca Lake, New York, (Plate I) has been filled with sediment brought in by streams; and deltas are forming in nearly all lakes where streams enter, diminishing their size. Lake St. Clair, between Lakes Huron and Erie, has been greatly diminished by the growth of a delta. If sufficient time were allowed, this cause alone would also destroy all lakes.

Some lakes are filled with vegetable matter; a certain kind of moss sometimes grows on the surface of the water and holds wind-blown sand and dust, which gradually spreads over the lake, forming a floating bog. A railroad line in Minnesota crossed such a bog. Cattle grazed upon it before the line was built; but the

engineers discovered that the floating bog was a mass four feet thick of moss and dust, and that beneath it was twenty feet of water. Eel grass and wild rice also assist in filling many lakes.
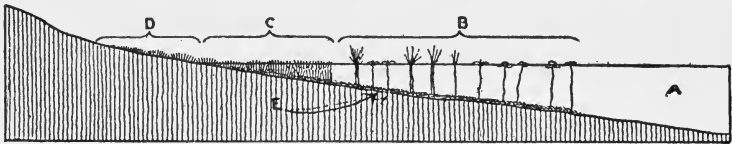
FIG. 164.—A, LAKE. B, LILIES AND BUSHES. C, BEGINNING OF SPHAGNOUS GROWTH
D, BOG CLIMBING HILLSIDE. E, DISINTEGRATED PEAT
(U. S. Geological Survey.)

Marl deposits, which form in some lakes to a depth of many feet, also assist in filling them. Marl consists chiefly of the shells of animals and the remains of lime-secreting plants.

These methods of filling gradually convert a lake into a swamp or marsh, and many of our fresh water marshes are former lakes destroyed in this way. The student will doubtless be able to find examples of such marshes near his home.
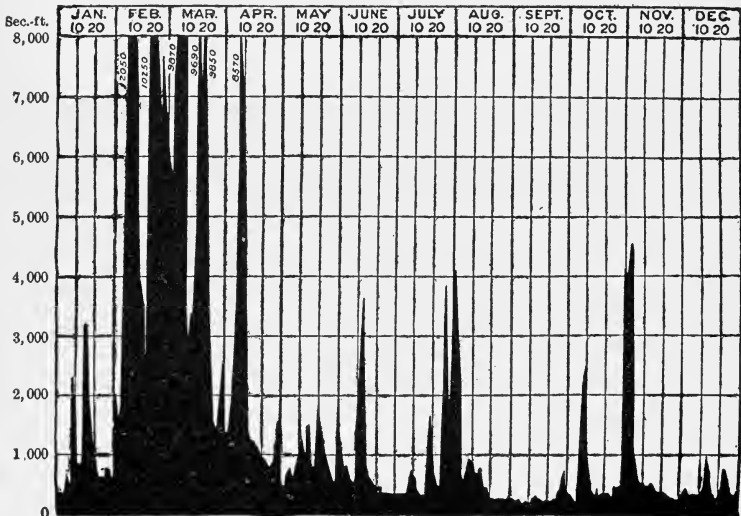
FIG. 165.—STREAM FLOW VERY IRREGULAR; NOT INFLUENCED BY LAKES
Discharge of Neuse River at Selnia, N. C., for 1899.

A third method of destroying lakes is by *evaporation*. The great
Lake Bonneville, that once covered a part of the Great Basin as
large as Lake Huron, was partially destroyed by evaporation. Its
supply of rain water was cut off by a change in climate, and the lake
shrank gradually, until to-day Great Salt Lake is all that remains.
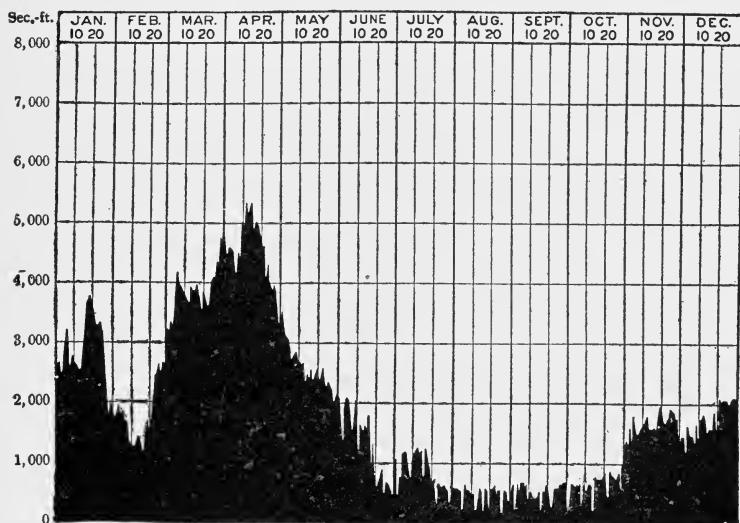
Fig. 166.—Stream Flow Partially Regulated by Numerous Lakes
Discharge of Seneca River, Baldwinsville, N. Y., for 1899.

Summary.—When first formed, lakes will have characteristic
shapes, depending upon the origin of their basins—round and deep
if old craters, branched and tree-like if due to damming of rivers
with tributaries, and with smooth parallel sides if reamed out by
glaciers. As time goes on, streams build deltas in lakes, fill them
with sediment, and deepen their outlets. Vegetation assists in
filling the lake basins. Gradually the lake changes into a swamp
that in rainy seasons is a lake, or it may become dry and form a
playa. Again, it may become a salt lake, and ultimately change
to a *salina* or salt plain. If drained, it may form a lacustrine plain.
Such is the *life history of lakes*.

Functions of Lakes.—Lakes are essentially great *reservoirs* of water. If large, they *clarify* the muddy waters of inflowing streams, so that rivers that are the outlets of lakes are generally clear. Even the greatest rain does not raise the level of large lakes very much, so that their outlets are not subject to great floods. It takes a long time to lower the flood level of the lake. It is for this same reason that in times of drouth outlets of lakes vary in volume less than other rivers. The Great Lakes thus *regulate* the flow in the St. Lawrence River; but the neighboring Ohio River, without any lake, is subject to great floods. Figure 165 shows the fluctuations in volume of a stream without lakes, and Fig. 166 that of a stream of about the same average flow but having lakes in its course. Note the great fluctuation of the former and that the average summer flow of the latter is greater than that of the former. Large lakes *ameliorate the climate* of their vicinity, particularly on their lee side; this is because water changes its temperature slowly, making the lakes in summer cooler, and in winter warmer, than the neighboring land.

Economic Importance of Lakes.—So important are lakes as reservoirs that where nature has not provided them, artificial ones are made. New York City, at an estimated cost of $161,000,000, is building in the Catskills the great Ashokan Dam for a reservoir which, when fed by smaller reservoirs, will eventually furnish 500,000,000 gallons of water daily.

The Great Lakes are of great importance as highways. The annual tonnage of the Great Lakes ports is about 80,000,000 receipts and over 80,000,000 tons of shipments. In early days the smaller lakes were important highways.

There is a growing appreciation of the great value of lakes as pleasure and health resorts. In this way they contribute much to the national well-being.

QUESTIONS

1. Why are falls and rapids incidents in the life history of a river?
2. Discuss the advantages and disadvantages of falls.
3. Locate the following falls: Shoshone, Missouri, Zambesi, Tequendama, Parana, Rhine, Montmorency.

4. Name the cities along the fall line in southeastern United States.

5. Explain how the steamer gets through St. Mary's Locks (Fig. 159).

6. Discuss: "Rivers are the mortal enemies of lakes."

7. How did *fresh* water Lake Bonneville change to Great *Salt* Lake?

8. Explain the differences in the stream flow of the Neuse, Seneca, and West Gallatin rivers. (See Figs. 165, 166, and 138.)

9. Locate the following lakes: Nipigon, Ladoga, Aral, Maracaibo, Albemarle Sound, Malar, Baikal, Tanganyika, Balkash, Atabasca.

10. Let each member of the class draw large scale map (1 to 1,000,000), based on its central meridian, of one of the principal lakes of the world and then make a comparative study of it based on references to encyclopædias and atlases.

CHAPTER XXIII

GLACIERS

Introduction.—In almost every part of the United States snow sometimes falls. In the southern lowlands it may last but for a few hours or days; whereas in the mountains and in the northern section of the country it may remain for months, or even throughout the year. Mount Washington has snow fields far into the summer, and Mount Hood is perpetually snow-capped. Traveling northward into Canada we find more extensive snow fields at ever lower levels, until they finally reach sea level within the Arctic Circle.

Origin.—Wherever more snow falls than disappears during the year, the excess accumulates; and by compression and successive freezings and thawings gradually changes to ice. Gravity causes the mass of snow and ice to move slowly toward sea level. *These moving masses of ice are glaciers.*

The *snow line*, above which there is perpetual snow and above which glaciers originate, is about three and one-half miles above sea level at the equator, and descends toward sea level with increase of latitude northward and southward, reaching sea level within the polar circles. The more extensive the area above the snow line the more extensive the glaciers.

Two types of glaciers result: those formed in valleys among mountains, called *valley* or *alpine* glaciers; and those which form extensive ice-sheets, and known as *continental* glaciers.

Distribution.—Valley glaciers are found on every continent except Australia, occurring in Africa and South America even under the equator; also upon some mountainous islands, as New Zealand. In North America, small glaciers occur in the United States in the Cascades, the Sierras, and the Rockies, increasing in
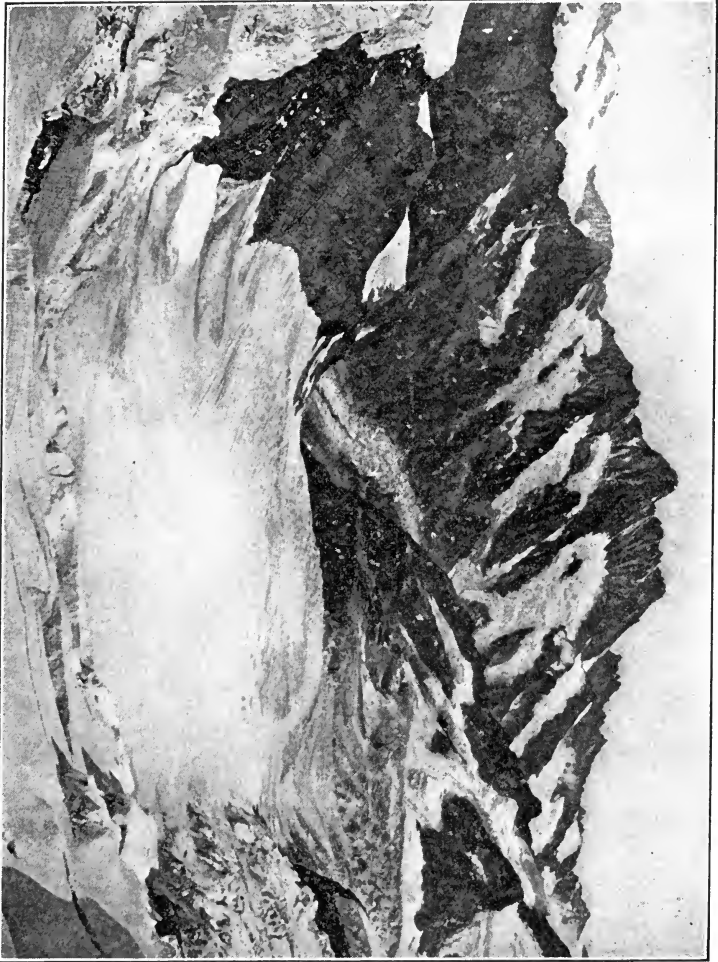
FIG. 167.—THE "SEA OF ICE," AS SEEN FROM EISMEER STATION, JUNGFRAU RAILWAY
A typical snow field in foreground. Typical "hillside glaciers" on mountains opposite. River of ice in bottom of valley.

extent in the Canadian Rockies and in Alaska. Some of these glacial regions, as the Alps, Canadian Rockies, and Alaska, attract many tourists on account of their peculiar grandeur and beauty.

Continental glaciers occur on all land areas where the snow line descends to the general level of the land. Glaciers form only on

land, and the ice which forms over the polar seas is not glacial ice. The most extensive continental glaciers are the ice-sheet which covers Greenland, and that which covers the Antarctic continent. The Greenland ice-sheet is about 500,000 square miles in area, while that of the Antarctic continent is greater than the United States in area. Several Arctic explorers have penetrated far toward the center of the Greenland ice-cap and some have crossed
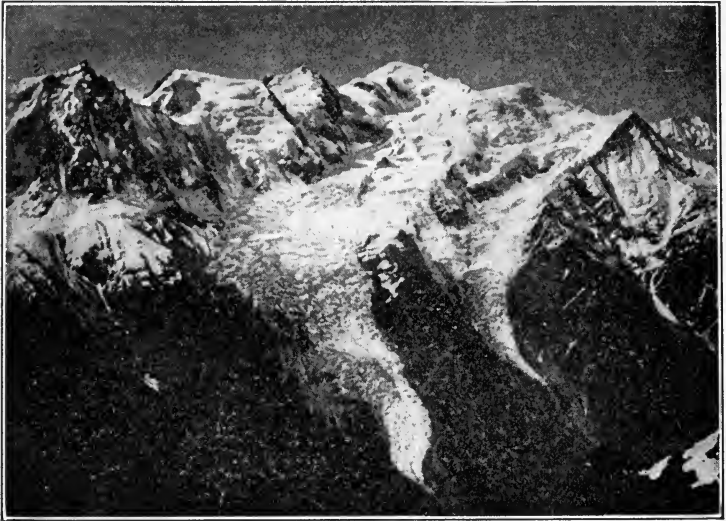
FIG. 168.—MT. BLANC, ABOVE THE SNOW LINE (TO RIGHT OF CENTER)
Snow fields ending in ice rivers that taper in size until they melt. The view is taken from across the valley of Chamonix.

it. In the interior it rises to an altitude of perhaps 10,000 feet, with a temperature constantly below freezing, and is one of the most absolutely desert regions of the earth.

Movement.—From their sources in the fields of granular snow and ice, called *névé*, the valley glaciers move down the valleys as *rivers of ice*, descending into the midst of forests, and even cultivated fields. They evaporate and melt as they move forward, becoming smaller and smaller, and finally disappear where the melting back just balances the forward movement of the ice.

These ice rivers behave much the same as rivers of water, erod-ing their beds and transporting their load of waste. Like ordinary rivers, too, they move faster in the middle than at the sides, faster at the top than at the bottom, and the line of swiftest flow lies nearest the convex side of a curve in the ice stream. The glacial river also has its rapids and falls, analogous to those in an ordinary river. While we know that glaciers move, the movement of most
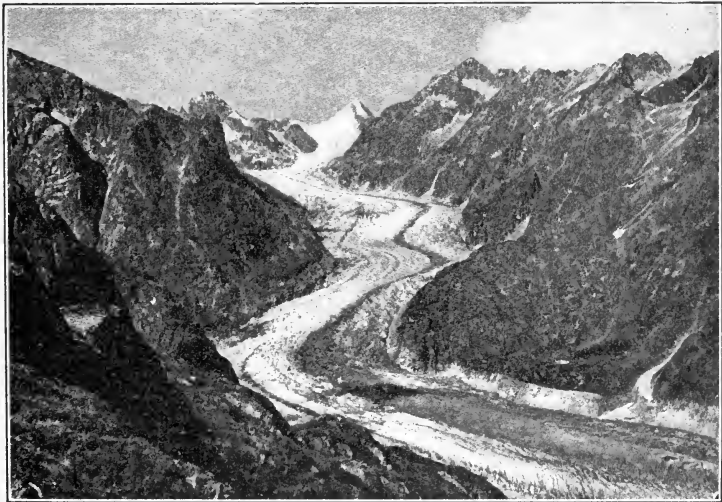
Fig. 169.—A View of Glacier, to Show Streamlike Appearance, Moraines, Crevasses

glaciers is so slow as to escape the notice of all but the most ob-servant. It required careful measurements to discover the manner of their movement.

The Swiss glaciers move generally only a few inches a day, moving fastest in summer; whereas some of the Alaskan glaciers move as much as seven feet a day.

Cause of Motion.—About the only thing regarding the method by which the glacier moves upon which all are agreed is that it *does not* move as a solid block of ice slipping down the slope.

One explanation of its motion supposes that the glacial ice is *granular;* and that the pressure above causes the grains to move

on and over one another. This may be illustrated by the movement of moist brown sugar when piled up.

Another explanation attributes the movement to alternate freezings and thawings. The great pressure above causes the ice to melt, particle by particle. Each particle, as water, occupies less space, the pressure upon the particle is decreased, and the particle freezes again *at a lower level*, only to be re-melted by the pressure. The glacier movement is thus the sum of the movements of its grains.

A simple experiment may be made that suggests the probability of each of the above explanations: (1) Take a long block of ice, and rest the ends upon supports. After some time the block will be bent, much as a thin board supported in the same way, although the surrounding temperature is below freezing. (2) Support a block of ice by a fine wire around it. The wire will quickly cut through the block, the two pieces again freezing together below the wire, even though the temperature is above freezing. The pressure of the block melts the ice, and the water thus formed immediately freezes again with release of pressure.
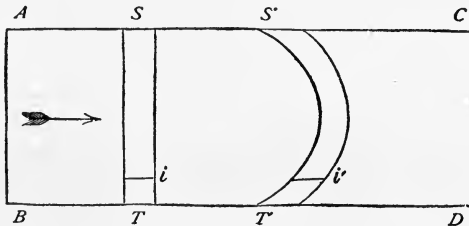
FIG. 170.—REPRESENTATION OF MOVEMENT OF A GLACIER

The strip *S T* changes to *S' T'*. Because ice cannot stretch, it tends to crack at right angles to the line from *T'* to *i'*, so that the crevasses formed point obliquely up stream.

Effect of Movement.—As a result of glacier movement, the snow is slowly drained away from the mountain slopes. Because of the unequal movements in the glacier it becomes very much broken. These breaks are called *crevasses*.

Where a glacier passes from any slope to a steeper, the bending and the more rapid movement causes a series of *transverse*
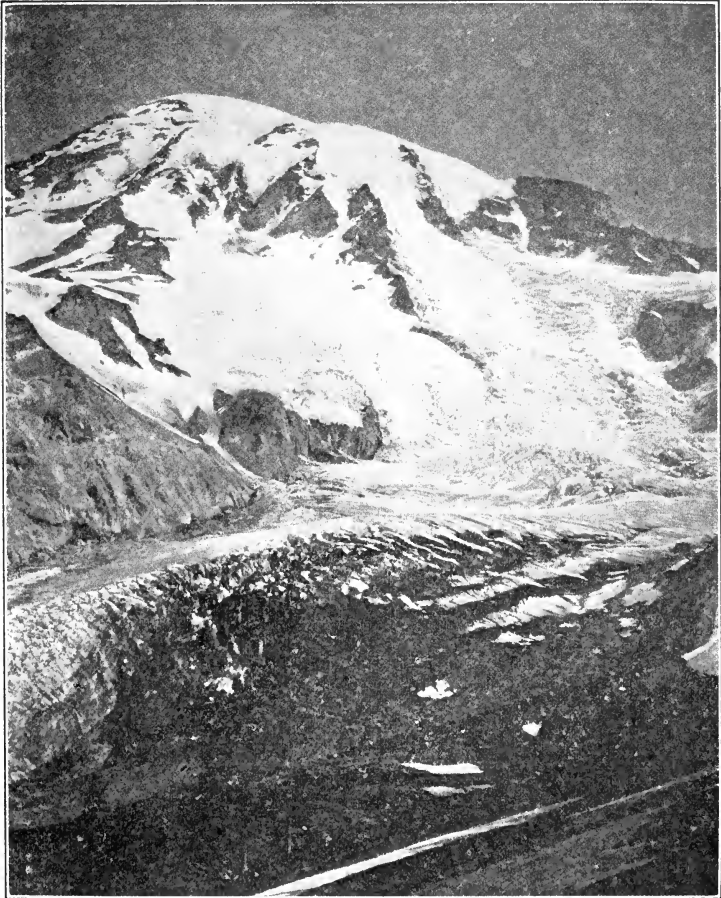
FIG. 171.—NISQUALLY GLACIER, MOUNT RAINIER, WASHINGTON
Five miles long and in places nearly one mile wide.   See also Fig. 228.

crevasses to form across the glacier.   They are more common in
the upper courses of glaciers, although the Rhone glacier ends in
such an *ice rapid*.   If the slope becomes again less steep, these
crevasses disappear by closing up and melting of the surface.

Because of the more rapid movement of the glacier at the mid-
dle than at the sides, there develop a series of oblique cracks,
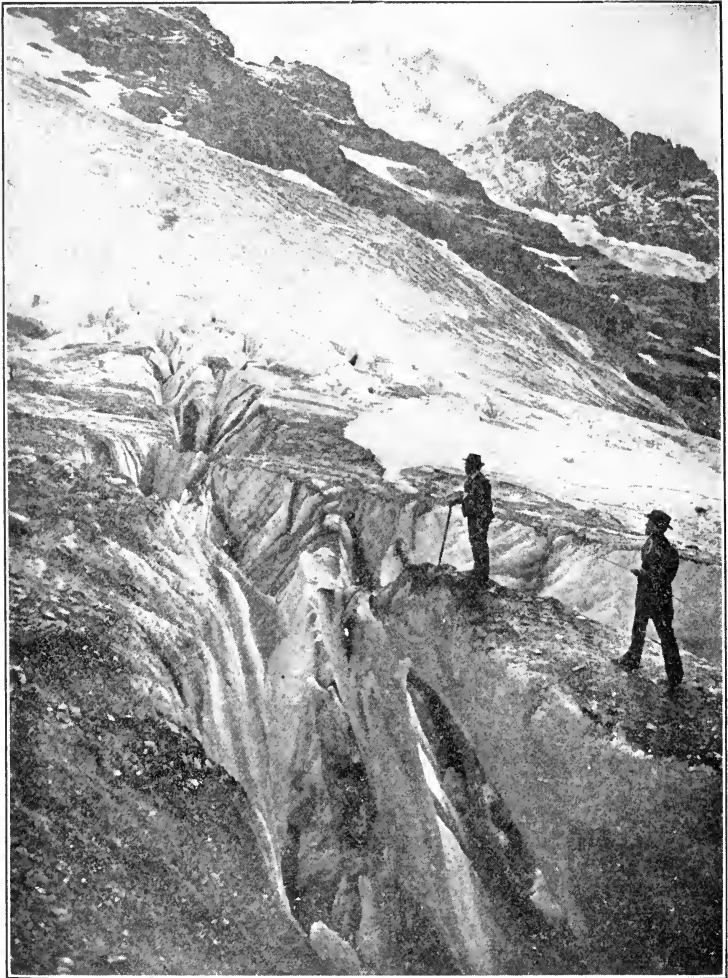
FIG. 172.—CREVASSES IN THE EIGER GLACIER
Note the surface moraine and the rope around the men.

which become ever wider as they advance down the slope. They
are the *lateral* crevasses, and they make walking upon the lower
courses of glaciers very difficult and dangerous, especially when

the winter snows have temporarily bridged them over. Sometimes a glacier passes from a narrow to a wider valley, and the ice, spreading out laterally, produces *longitudinal* crevasses.

Glacial Mills.—The surfaces of most valley glaciers are too much broken to permit the formation of streams upon them from the melting ice in summer; but occasionally such streams are
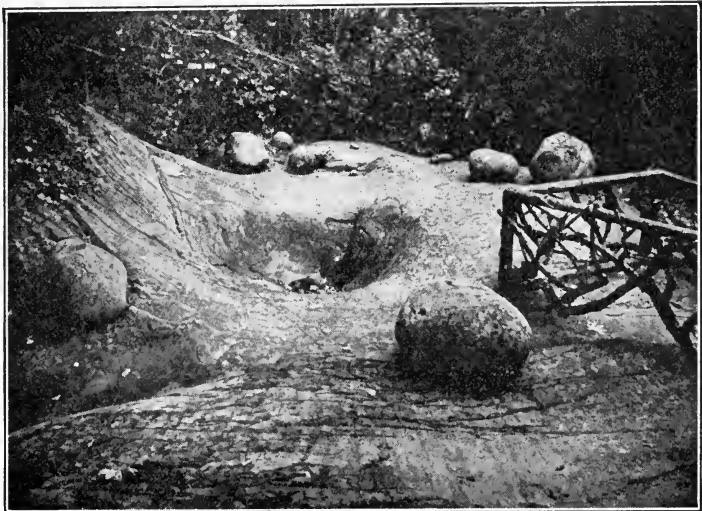
FIG. 173.—GLACIAL SCRATCHES (TOWARD US), GLACIAL BOWLDERS, AND POTHOLE
Glacier Garden, Lucern.

formed. These sooner or later tumble into a crevasse, and armed with the bowlders and finer materials which also find their way there, grind depressions in the bed rock beneath the ice. These are *glacial mills*, and their grist is the materials which serve them as tools. Larger and more numerous streams form on continental glaciers, and the *pot holes* ground out beneath them are larger.

Work of Glaciers.—Glaciers *drain* away precipitation in the form of snow, and like rivers, *corrade* their beds, *transport* their load of waste, and when they melt *deposit* it.

(*a*) **Drainage.**—An area about equal to that of the United States is drained by continental and valley glaciers.

(*b*) **Corrasion.**—Ice, like water, has little power to corrade; but when supplied with rock waste imbedded in its under surface, it becomes a powerful agent of erosion. The weak and weathered portions of the bed rock are removed, and the fresh and harder portions rounded, striated and grooved, the *striæ* and *grooves*

FIG. 174.—UPPER GRINDELWALD GLACIER
Glacial scratches proceeding from under the ice on the left side.

being parallel to the direction of movement of the ice. Such rounded masses of the bed rock are called *roches moutonnés*.

Valley glaciers ream out their valleys, changing V-shaped valleys to the U-shape. Continental glaciers plane down the uplands, rounding off the irregularities of the hills and ridges that may end in *cirques*, great amphitheatres surrounded by high cliffs.

(*c*) **Transportation.**—All glaciers carry waste. The continental glacier gets its load from the surface over which it moves; the valley glacier gets the greater part of its load from the bordering slopes. Whether carried upon the surface of the glacier, within the ice or beneath it, the materials are known as *moraine*. Mate-

rials along the sides of a valley glacier constitute the *lateral* moraine; that beneath the ice the *ground* moraine; and that about the end of the glacier the *terminal* moraine.   When two glaciers join, the united lateral moraines between them, continued upon the glacier below the junction, is the *medial* moraine. If the medial moraine is abundant, it may so protect the ice be-

FIG. 175.—FAMOUS ROSEGG GLACIER
Showing tongue of ice with crevasses, moraines, and ice-born stream.

neath from melting that the morainic ridge may stand up fifteen or twenty feet above the general surface of the glacier.   Large slabs of stone are often left perched on pedestals of ice by the melting of the ice around them.   Such perched stones are known as *glacial tables*.

(*d*) **Marking.**—While the materials in the ground moraine are subjected to the crushing weight of the glacier, the bowlders and pebbles in it being often *polished* and *striated*, the materials of the
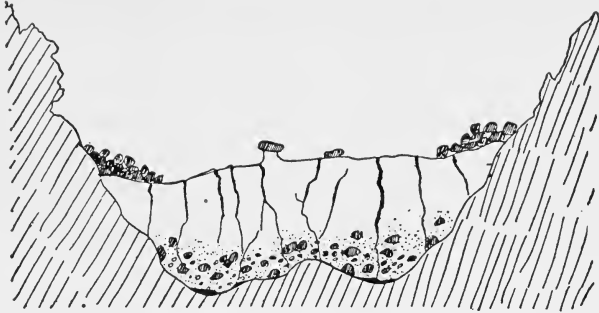
FIG. 176.—CROSS SECTION OF A GLACIER
Showing lateral and ground moraine, crevasses, and ice table.   (Walther.)

moraines are, for the greater part, not rounded as are those carried by rivers.

(e) **Deposition.**—When a glacier melts, its load of waste is deposited—not in layers and assorted, as is the waste carried by rivers, but pell-mell, without trace of assorting.   (Figs. 178 and 181.)

The terminal moraine marks the limit reached by the glacier. Since glaciers vary their rate of movement with the season, a
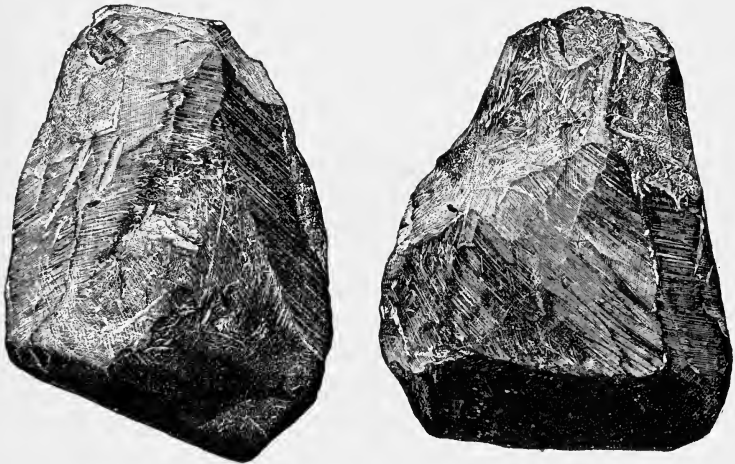
FIG. 177.—TWO VIEWS OF SAME GLACIATED PEBBLE OF LIMESTONE, FROM CHICAGO
The 18 facets indicate alternate fixity and change of stone in the ice.

series of concentric ridges may mark successive retreats of the glacier front. These may later be overrun by the glacier during a period of extension down the valley. The retreat of the ice-front is in no sense a backward movement of the ice, as ice-movement is always down the valley or slope; it means only that the rate of forward movement does not equal the rate of melting back, and the ice-front takes a position farther up the valley.
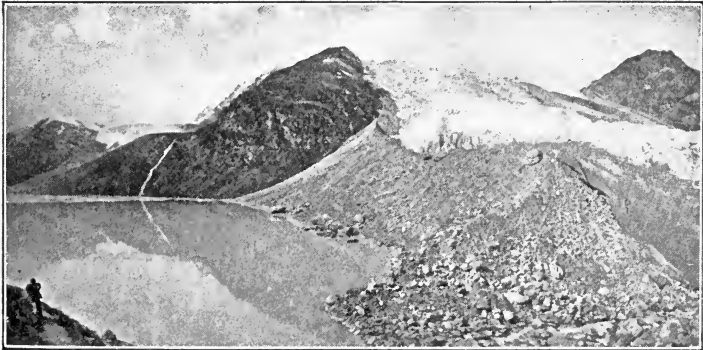
FIG. 178.—MORAINE DEPOSITS AT THE END OF GLACIER, SWITZERLAND

The Sub-glacial Stream.—From the end of every valley glacier, and at frequent intervals along the front of the continental glacier, issues a sub-glacial stream. These streams, supplied chiefly from the melting ice, are much stronger in summer than in winter. They are usually muddy from the load of *rock flour* they bear, derived from the ground moraine.

In valley glaciers the sub-glacial streams usually deposit their load in some lake or river; but in continental glaciers they often build extensive apron-like deposits in front of the glacier. These deposits along the edge of the ice-sheet are known as *outwash plains*. Where glaciers reach the sea, the sub-glacial stream may issue beneath the sea level; and the glacier, instead of melting back, may break off in blocks and float away as *icebergs*.

Sometimes the channels of streams beneath ice-sheets become clogged with pebbles and coarse sand. Such a ridge, exposed by melting back of the ice-front, is known as an *esker*. The deposits

sometimes made at the edge of the ice-sheet, in part the work of the sub-glacial stream and in part from the melting ice, and showing a sort of stratification, are known as *kames*.

Former Extension of Glaciers.—As we may trace the shore line of a lake that has disappeared, by the characteristic shore line features, so we may recognize the former existence of glaciers in regions where now no glaciers are found. Glacial records are so characteristic as to be usually unmistakable. We observe the work of the glaciers now existing, and we know that glaciers of the past did the same sort of work. Therefore, when we find polished and striated surfaces on the valley sides far above the present glaciers in the Alps, we do not hesitate to expand our glaciers to those heights; and when we find U-shaped valleys in any region, though now far removed from any modern glacier, in imagination we restore the glacier, for ice alone seems competent to make U-shaped valleys.

Thus extended, the Alps become a very much larger glacial region, extending to the plains of northern Italy; and the miniature glaciers now found in the United States become the centers of similar regions.

Of even more interest, and of much greater economic importance, is the former extension or existence of continental glaciers. While doing the same *sort* of work as valley glaciers, the records made by continental glaciers are more varied and more enduring. These records are continent wide, and may be read alike in the planing down of the highlands, and in the filling and leveling up of the lowlands. Reading the records we discover that there was a time, in the not distant past as earth-time is measured, when much of northern Europe, extending to and including the British Isles, and most of North America down to the latitude of New York City, were covered by continental ice-sheets. This time is known as the *Ice Age* or *Glacial Period*. Many other parts of the earth have had glacial climates, some of them probably several times.

The Ice Age in North America.—If we travel across the United States from north to south we are impressed by the unlikeness of the topography in the north and in the south.
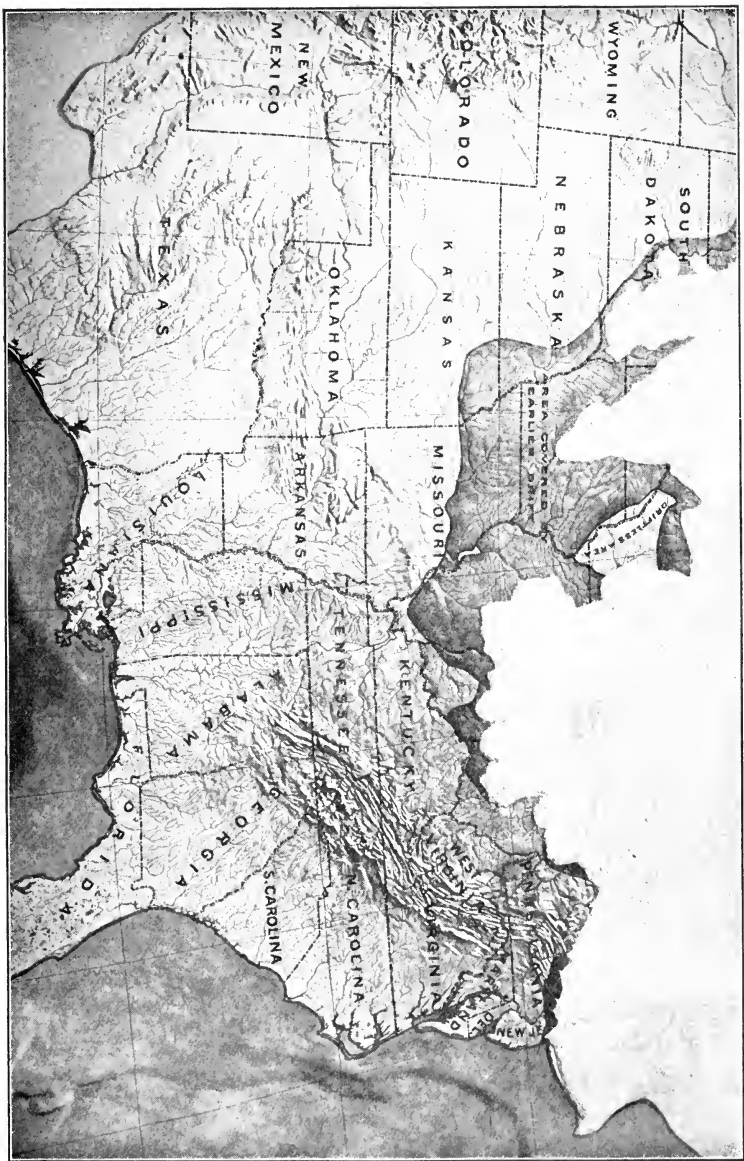
EXTENT OF THE ICE SHEET IN NORTH AMERICA. (E. E. Howell.)
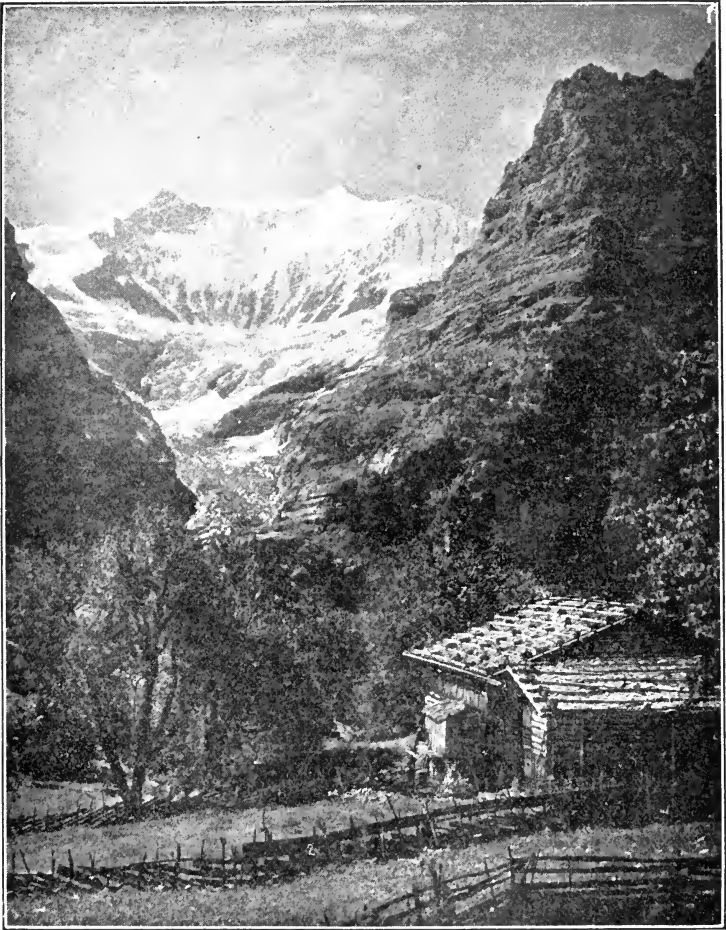
FIG. 179.—THE END OF THE GRINDELWALD GLACIER

Occupying the bottom of a great U-shaped valley. Note the cirque-like cliffs at the base of the Viescherhorn in the background. The cliff on the right, smoothed to the top, indicates a much more extensive glacier here in former times.

In the north the rivers are young, often having rapids and falls; and lakes are numerous. The uplands are level; or, if uneven, the hills and ridges are covered with a cloak of unassorted and usually

coarse mantle rock. Numerous bowlders, wholly different, from the bed rock of the region, are widely scattered, especially in the east. The mountains have numerous lakes and swamps in their valleys. The soils are all transported, being entirely unlike the decomposition products of the bed rock.

In the south the rivers of the upland are mature, having long ago removed their rapids and falls. There are no lakes or swamps

FIG. 180.—TYPICAL ROUNDING BY GLACIAL ACTION
Note erratics deposited by the glacier. U-shaped valley in background. Kerguelen Island.
(Penck.)

in the mountains or in the uplands; and the uplands are hilly and cloaked with residual soils.

The line which separates these two types of topography follows roughly the Missouri and Ohio rivers to their sources in the Rocky Mountains and in southwestern New York; thence westward by an irregular line to Puget Sound and eastward and southeastward through New York City to the east end of Long Island. This line marks the southern limit of the ice during the Glacial Period, and is the southern boundary of the deposits made by the continental ice-sheet.

As the ice-sheet moved down from the north, it invaded a region probably about as maturely dissected as Kentucky and Tennessee

now are. River systems were widely branching, and lakes had disappeared. When with change of climate the ice-sheet began to melt back, a land surface wholly changed was revealed. Ridges were planed down, and valleys partially or wholly filled. Wherever the ice-sheet paused for a time in its retreat, there was formed
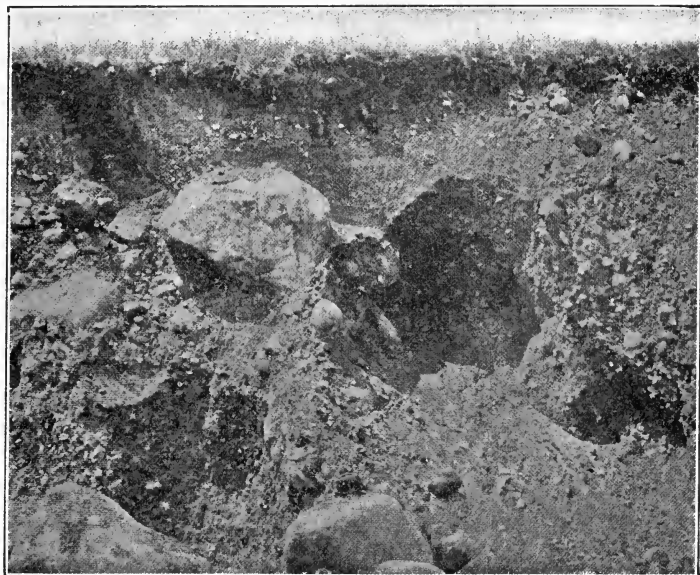
FIG. 181.—TYPICAL UNASSORTED DRIFT NEAR LAKE GRINNEL
(N. J. Geological Survey.)

a terminal moraine. If the ice advanced for a season, former moraines were obliterated, to be succeeded by new when again retreat began. The ice-sheet did not advance and recede equally along its entire front, and records of various advances and retreats remain. Many terminal moraines or halting-places, roughly parallel, are found between the Ohio River and the Great Lakes.

In melting, the ice often left great bowlders perched in unstable positions. Such bowlders are often *rocking stones*, and are unquestioned work of the ice, as running water would not leave them thus.

FIG. 182.—MORAINE TOPOGRAPHY, LAKE GRINNEL (N. J. Geological Survey.)

By overruning the ground moraine, long, lenticular hills, called *drumlins*, were fashioned.

The general name for all deposits left by the ice is *drift;* and while *valleys* parallel to the direction of ice movement were often kept free of drift, or even deepened by the ice, valleys transverse to the direction of movement were generally drift-filled.

From the time of the advance of the ice-sheet south from the present position of the Great Lakes, then probably a river valley, until its retreat north of them, all *drainage* was southward to the Gulf or eastward to the Atlantic. The Great Lakes themselves developed outlets southward to the Mississippi when first freed from the ice.

With retreat of the ice-front northward from the divide between the Hudson Bay and Gulf of Mexico drainage basins,

a great lake formed, which developed an outlet now occupied by the Red River of the North. With the melting of the ice dam this lake disappeared, and its silt covered bed is now one of the greatest wheat producing regions in North America. To this ancient glacial lake the name Agassiz has been given.
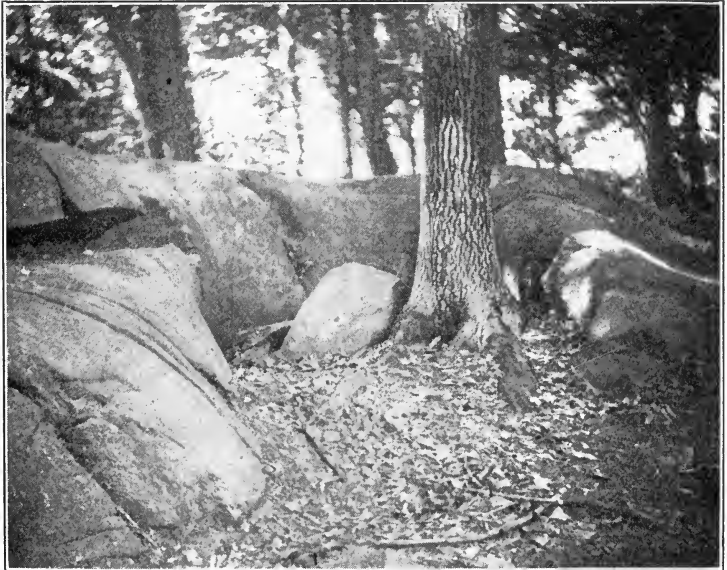
FIG. 183.—POTHOLE, BRONX PARK, NEW YORK CITY
Made in glacial times; the stone in it beside the tree is an erratic from the Palisades.
(Martin Steljes, Photographer.)

Further retreat of the ice-sheet revealed the more favorable route eastward through the Mohawk Valley, and the southward outflow of the Great Lakes ceased. The Mohawk route was in turn abandoned for the present route of the St. Lawrence, when the glacier had sufficiently melted.

With the melting of the glacial sheet all rivers issuing from its front were swollen beyond their usual volume, and beyond the capacity of their ordinary channels. The burden of rock flour carried by these rivers was thus spread along their banks as nat-

ural levees, forming a peculiarly fine and even-textured deposit known as *loess*. Great thicknesses of *loess* are found along the Missouri River at and below Kansas City, and along the Mississippi southward as far as Baton Rouge. That it was deposited at least in part by the rivers is indicated by the occurrence in it at Vicksburg and elsewhere of numerous snail shells; also by its gradual thinning and final disappearance in a few miles back from the river front. Similar deposits in Germany and China have been attributed in part to the wind; but the glacial origin of the material is undoubted.

Lakes and Marshes.—Mention has already been made of the occurrence of numerous lakes in the glaciated area of the United States, and of their absence south of this area; and the origin of some of the lake basins has been suggested. Lake Agassiz was perhaps the least common type of glacial lakes, although the lakes produced by temporary ice dams were perhaps the most extensive. The Great Lakes, which individually were probably in basins in part produced by glacial drift interrupting the drainage in a pre-glacial valley, were for a time united into one greater lake by the ice-sheet blocking the outlet through the St. Lawrence. While all were united, and stood at a common level, they were separated into three somewhat distinct basins by the high land south of Georgian Bay, which rose as an island in the midst of their icy waters. To the Superior-Huron-Michigan division the name *Algonquin* has been given; greater Ontario has been called *Iroquois;* and modern Erie bears the name of its larger ancestor.

The margins of these greater lakes have been traced by the beaches and other shoreline features then developed. With the melting of the ice these lakes gradually assumed their modern proportions. For their development see Fig. 161.

Other larger lakes, like the *Finger* Lakes of New York, and most of the lakes of northern New York and New England, occupy basins produced by drift deposited in valleys, and represent the unfilled remnants of pre-glacial rive .

Westward from New York, and   :th of the Great Lakes, by far the most numerous type of gl   l lakes occupy local depres-

sions in the drift. As the ice-sheet receded it left an uneven surface, and in the depressions lakes were formed. These were often shallow, and quickly changed to the marsh stage; and in this way the numerous high-level marshes of the northern United States and Canada were formed.

Still another type of lake was produced near the southern limit of the ice-sheet when the glacier came down to the sea. In southeastern New York, and along the New England coast, deep and sometimes circular lakes occur. These *kettle* lakes probably represent the resting place of a detached mass of ice over which drift was deposited. Shallower lakes of the same type are rush-filled, or have become dry lake beds.

Economic Importance of the Drift.—The presence of the drift in the northern section of our country has played an important part in determining the lines of its economic development. The general result of the deposit of the drift was to leave this region more nearly level than before the coming of the glacier. This has favored the building of roads and railroads in the section, which in turn promoted commerce.

A deeper covering of mantle rock is found in the glaciated than in the unglaciated regions, and this favors the more even and constant flow of rivers. The numerous lakes here also equalize the flow of streams, and transportation by water is made possible. River transportation in the South is both local and limited; whereas in the North our lakes, our rivers and our canals make carriage by water second in importance to carriage by rail.

Mining in the drift-covered section is of little importance, since the thick coat of drift has made the discovery of important mineral deposits difficult. With the exception of oil, gas, and salt, important mineral deposits have been discovered and developed only where the drift covering is thin or where streams have cut deep valleys.

The soils of the two sections are very unlike, but it is difficult to determine whether the drift has furnished a better or poorer soil than would have developed from the bed rock beneath. In the eastern part of the drift-covered section the soils are too coarse
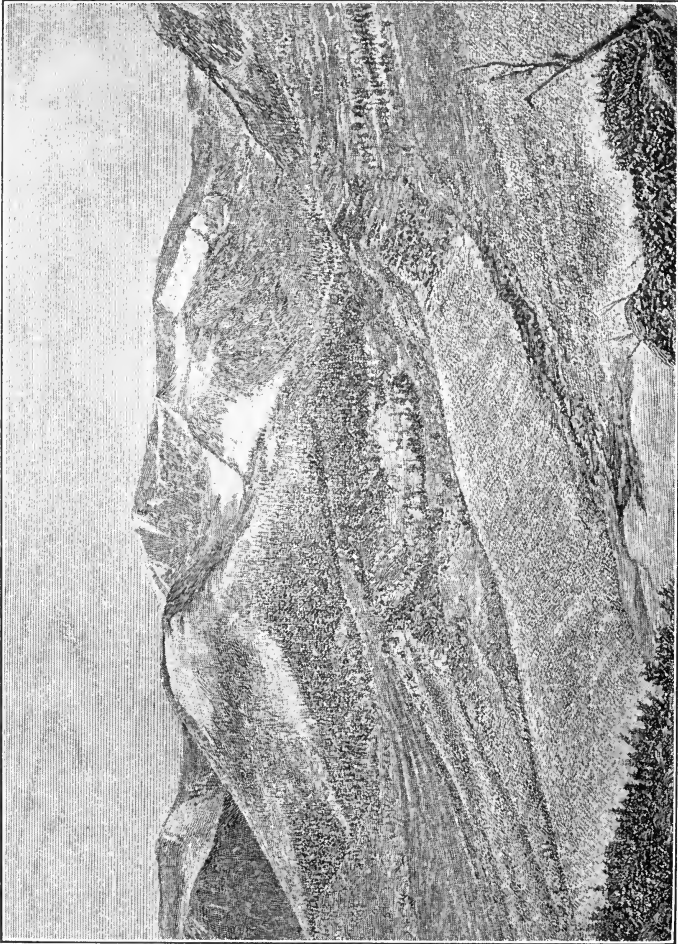
FIG. 184.—LATERAL AND TERMINAL MORAINES AT MOUTH OF BLOODY CAÑON
Evidences of former glaciation.

and sandy, and the surface is cumbered with glacial bowlders; but farther west the soils are fine textured, free from bowlders, and very productive. It is probable, however, that the difference in character of crop raised in the two sections is more a difference due to climate than to difference of soil.

The economic products obtained from the drift are clay, sand,

and gravel. The clays are manufactured into bricks, tiles, and crockery; the sands into glass and brick; and the gravels are used for road-making.

Causes of the Glacial Period.—Much speculation has been indulged in regarding the causes of glacial periods. No single cause has been generally considered competent. Glacial conditions now exist on high mountains in all latitudes; in high latitudes even down to sea level.

These facts have suggested the two hypotheses most acceptable. The one supposes that glacial climates were produced by the elevation of extensive land areas. The elevation of the regions east and west of Hudson Bay, the centers of accumulation of the ice during the last glacial period, by only a few thousand feet would make those regions again glacial centers. A glacial sheet once formed, the temperatures about its borders are made lower, and the sheet extends. It would thus require an elevation no greater than has frequently occurred to bring another glacial sheet to northern United States.

The other hypothesis makes the development of glacial sheets the result of increased length of winter combined with increased distance from the sun. At present our winter occurs when we are 3,000,000 miles nearer the sun than we are in summer, and moreover our winter is about seven days shorter than our summer. The shape of the orbit of the earth changes, becoming less nearly a circle, and the position of the earth's axis so changes that there comes a time when we are *farthest* from the sun in winter, and our winter is longer than our summer. This hypothesis makes our glacial climates the result of *long aphelion winters*. According to this hypothesis, glacial conditions now exist in the southern hemisphere; and the fact that the only extensive land area in southern latitudes is covered by a thick sheet of ice seems to support the hypothesis.

Still a third hypothesis is that the changes in climate that produce glacial ice-sheets, and later melt these same sheets, are largely the result of a change in the amount of carbon dioxide and water vapor in the air. With decrease in the percentage of these constituents the climate grows colder, and with increase, warmer. This

hypothesis would bring glacial climates to both hemispheres at the same time, instead of alternately, as required by the second hypothesis stated.

QUESTIONS

1. What fractional part of the land area of the globe is now drained by glaciers? How does this area compare with that of the United States?

2. What area has been, but is no longer, so drained?

3. Name and locate fifteen mountainous regions with glaciers.

4. Discuss the effects of three elements entering into the explanation of movements of glaciers.

5. Apply to the explanation of the directions of different kinds of crevasses the statement that "ice cracks at right angles to the line of strain."

6. Tabulate a careful comparison of glaciers with streams, as to movement, works, deposits, etc.

7. "Crag and tail"—Which side (or sides) of a glaciated hill has bare crags and which side has a tail of stones? Why?

8. Discuss the effects of glaciers or ice-sheets in passing over valleys at right angles to the direction of ice movement. On valleys parallel to ice movement.

9. In what direction will the top of an ice table finally tip, and why?

10. Why are there almost no lakes in Pennsylvania and so many in New York?

11. Why is the land in southeastern Ohio so hilly and in northwestern Ohio so nearly level?

12. Most New England fences are built of stone. Why?

13. Explain how soil left by a glacier may be better than the soil removed from the same place by the glacier. How glacial soil may be worse than the soil removed.

14. Which explanation of the causes of the ice age seems to you the most probable? Why?

15. Will northern United States be again covered with an immense ice-sheet?

CHAPTER XXIV

PLAINS AND PLATEAUS

The Earth a Spheroid of Rotation.—The form which gravitation gives a liquid or a gaseous mass is that of a sphere. If the mass is in rotation while in this condition, it becomes a spheroid, flattened more or less at the extremities of its axis, as the rate of rotation is greater or less. The earth is such a spheroid, flattened at the poles just the amount required by the present rate of rotation.

The fact that the earth is a spheroid of rotation does not prove that it assumed its form while in a liquid or gaseous state. The water of the ocean would assume a spheroidal form because of rotation, whatever the shape of the solid parts, and since the ocean is the base level of erosion, all land would in time conform to its shape. Thus, in a general way, the ocean determines the flattening at the poles and the form of the earth.

Relief.—The relief features of the earth are departures from the perfect spheroid of rotation. The highest points of the continental masses rise a trifle less than six miles above sea level, and the deepest parts of the ocean are about six miles below. The extreme departure from a perfect spheroid is therefore twelve miles, which is less than one three-hundredth of the radius of the earth. This slight irregularity gives us land on which to live.

The relief features of the land are much smaller departures from the perfect spheroid than those forming the ocean basins and continents, yet they modify the climate of the region, its adaptability to agriculture, and the habits and occupations of its inhabitants.

The large relief features of the land are plains, plateaus, and mountains.

Plains.—*A plain is a broad, relatively smooth surface that nowhere appears conspicuously higher than adjoining land or water.*

The bed rock below plains usually has horizontal strata, but this is not necessarily the case where plains have been formed by a glacier, like that of northwestern Ohio, neither is it necessarily the case in deltas, flood plains, lava plains or plains of denudation.

The Formation of Plains.—The smooth surface of most of the true plains is due to the fact that the material forming the surface was deposited as sediment in water. Such deposits are always smooth, and have a nearly horizontal surface. The only important plains formed by other processes are those formed by glaciers, where they have smoothed the rock and covered it with a level deposit of till, and old lands worn down almost to sea level.

The plains formed by deposition possess characteristics which depend upon the body of water in which the deposition occurred, and the sea, the lake, and the river each contributes its own type. Such plains are known respectively as *marine, lacustrine, and alluvial plains.*

River deposits become flood plains upon the subsidence of the river, and lacustrine deposits become plains through the destruction of the lakes. Marine deposits may become marine plains either through the uplift of the land or the subsidence of the sea. There are many evidences that changes of relative level of land and sea are now in progress; for example, a Spanish powder magazine, built near New Orleans during the eighteenth century, is now under water; certain orchards along the New Jersey coast are now submerged; and the Temple of Jupiter Serapis, near Naples, Italy, which is known to have been on dry land in 235 A.D., and which was rediscovered in 1749, was found to have been submerged between those dates to a depth of 21 feet and to have been elevated again. The double caves in Fig. 185 show that the California coast has been uplifted. Both caves were cut by the waves. These illustrations indicate recent changes of level. The finding of the skeleton of a whale in the glacial gravels near Lake Champlain, indicates an earlier change, and the remains of sharks'

teeth and other marine animals in the sedimentary rocks of our mountains, indicate still earlier changes. Finally, it must be recognized that the very existence of dry land is evidence of change of relative level of land and sea, for without it erosion would long since have reduced the land to sea level. Each of these changes was necessarily accompanied by a change in the location of the shore line.
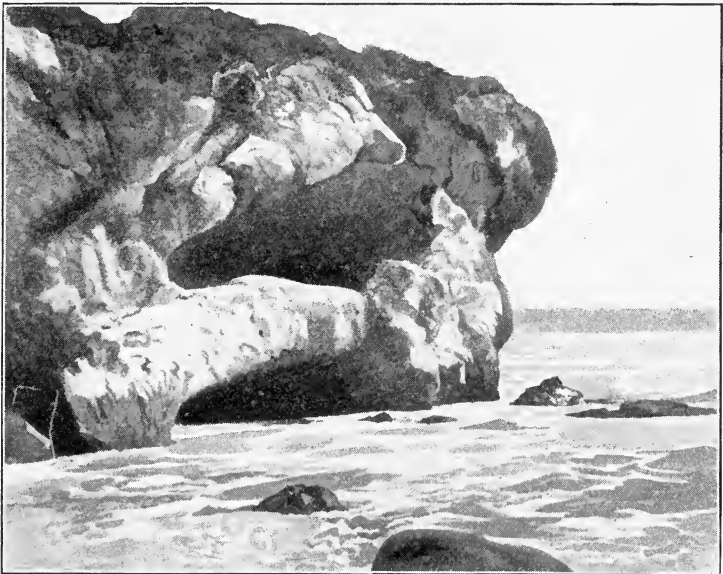
FIG. 185.—TWO CAVES NEAR MALLAGH LANDING, CAL.
The upper cave was formed when the land was ten feet lower than now. The lower one is now being formed.

Some of the changes may have been due to depressions of the ocean bottom, which would allow the water to settle away from the land; others to the accumulation of sediment, or lava, on the sea bottom, which would cause the water to overflow the land; still others to the withdrawal of the sea water to form a continental glacier; and yet others to the uplift of the lands.

Such changes have repeatedly exposed fresh areas of the ocean

floor, forming marine plains, or have tilted land, draining lakes and forming lacustrine plains.

Marine Plains.—Marine plains are those composed of sediments deposited in the sea. Near the shore the sea bottom is almost everywhere white sand which has been freed from the softer particles of rock waste under the vigorous action of the waves, and consists almost entirely of quartz. Beyond the sand deposits of mud are formed, which are composed of exceedingly fine particles of the softer and more perfectly decomposed minerals. Deposits of this kind border all continents, and form *continental shelves*. When a portion of the continental shelf becomes dry land it is a *marine plain*, and when near a coast it is called a *coastal plain*.

Plains thus formed consist of gently sloping strata of gravel, sand, and mud, varying as the conditions under which they were deposited varied.

Some of the strata of the marine plain are porous and allow ground water to flow through them readily; others are impervious. These conditions make possible the numerous *artesian wells* bored in the marine plains bordering eastern United States.

The Atlantic Coastal Plain.—Bordering the Atlantic Ocean from New York to Florida and the Gulf from Florida to Mexico is a fine example of a coastal plain, that in some localities is a hundred miles wide. See Fig. 186.

That it was formed under the sea and was a part of the continental shelf is shown by the remains of marine animals and plants found in the strata, and by the fact that the strata are of the same kind as those now forming the ocean floor and are often continuous with them. That the region has only recently been raised above sea level is also shown by the numerous marshes, the unconsolidated deposits, and by the simple drainage. The streams of the outer portion have few tributaries, their valleys are but slight depressions, and the regions between them are so level and sandy that most of the water sinks into the ground. Fig. 186 shows the flatness of this portion. On the inner half of this plain the valleys are deeper, the streams have more tributaries,

and the drainage is more mature. The marshes have been drained and well-defined divides begin to appear. These conditions are the natural results of the slow elevation of a marine plain, and control the industries of the regions.

In the Carolinas rice is raised in the marshes. Between the marshes are wide areas of sand, of little value for agriculture,

FIG. 186.—THE GREAT PINE PLAINS OF SOUTHERN NEW JERSEY
A part of the Atlantic Coastal Plain, much of which is like this.

which are chiefly occupied by pine forests. Farther inland the soil is fertile, and much cotton is raised; and in certain localities gardeners maintain successful truck farms.

At the western border of the Atlantic Coastal Plain the land rises somewhat abruptly to the Piedmont Plateau. The rivers of this region usually have falls or rapids where they descend from the plateau to the plain, which furnish water power and mark the head of navigation.

Because of these conditions many important cities have grown up along the inner margin of the plain. A line connecting these cities, called the " fall line," marks the approximate location of the shore line while the strata forming the coastal plain were being deposited. Among the important cities located along this line

are Trenton, N. J., Philadelphia, Pa., Washington, D. C., Richmond, Va., Raleigh, N. C., Camden, S. C., Columbia, S. C., and Augusta, Ga.

Ancient Coastal Plains.—Most of the sedimentary rock of the world is of marine origin, and it is probable that when every region of the world where the bed rock was formed from marine sediments first appeared above the sea, it was a coastal plain.

It is evident, however, that only those that recently became dry land can be properly called coastal plains, because erosion would have long since dissected the original surface of the older ones unless some of the other methods of plain making had been in action, and in this case the plain should not be classified with coastal plains. A region in Wisconsin, and another in western New York, were doubtless at one time coastal plains.

Lacustrine Plains.—When a lake is destroyed either by draining, filling, or by evaporation, the former lake bottom becomes a *lacustrine plain*. Such plains are always small compared with marine plains, their strata are nearly horizontal, the surface is level, and the soil, as a rule, is more uniformly fertile and of finer texture than that of the coastal plain.

If the lake was quickly drained, as by the melting of a portion of a glacier which dammed an outlet, the margin of the former lake would be marked by deposits of sand and gravel of greater value for building purposes than for agriculture.

The inner portion would consist of muds brought in by streams, and would be very fertile. If a lake was slowly drained or filled, and supported a large growth of eel grass or marsh grasses, the soil of the resulting plain would be likely to be of uniform fertility throughout its whole area. Where lakes have been destroyed by evaporation a level surface results; and since only water evaporates, all of the dissolved mineral matter that was in the water is deposited on the plain. Such plains are called *salinas*. They are not fertile, but often contain valuable deposits of salt, soda, and borax.

In Bolivia there is a salina several thousand square miles in

area—a level, white plain, covered by a layer of salt four feet thick. In the Great Basin (U. S.) are many deposits of minerals formed in this way.

The Valley of the Red River of the North.—One of the most level regions of the world and one of the greatest lacustrine plains is the Valley of the Red River, which flows north between Minnesota and North Dakota. It is the floor of former Lake Agassiz,

FIG. 187.—THE LACUSTRINE PLAIN
In the Valley of the Red River of the North. The points on the sky line are houses.

which existed while the continental glacier blocked the drainage lines toward the north. The soil here is fine and rich, and produces enormous quantities of excellent wheat.

Lake Bonneville.—Great Salt Lake is a shrunken remnant of a greater lake known as Lake Bonneville, which once occupied the eastern portion of the Great Basin. The sediments deposited in this lake, which was as large as Lake Huron, filled the valleys

between north and south mountain ranges, forming many small lacustrine plains.   Fig. 188.

Other Lake Plains.—In several places along the south shore of the Great Lakes large bodies of water accumulated, toward the close of the Glacial period, between the ice front and the high land to the south. The sediments deposited in these lakes filled the irregularities in the lake bottom, and when the water disappeared with the melting of the ice, a number of important lacus-
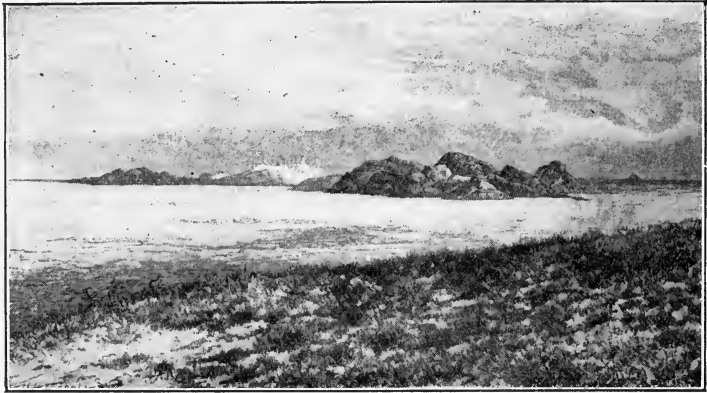
FIG. 188.—THE FLOOR OF ANCIENT LAKE BONNEVILLE IN UTAH
The hills and mountains are nearly buried by accumulated sediment.

trine plains were exposed. The prairies of northern Illinois were once covered by the waters of Lake Chicago, an extension of Lake Michigan, and are now lake plains.   In New York State, a southern extension of Lake Ontario gave us the lacustrine plain that extends from the Mohawk Valley to Syracuse. This plain provided a favorable location for the Erie Canal and the New York Central Railroad. It was also used by the early settlers of the West as the main highway toward their new homes.

Some of the former lakes of the group of Finger Lakes of New York State are now lacustrine plains; one of them, the valley of Mud Creek, just west of the Canandaigua Lake, is sixteen miles long and from one-half to one mile wide.   It is level and is one of the most fertile regions of the State.

River Plains.—The leveling action of water is nowhere better shown than in a river valley. All the deposits of a river have the nearly horizontal surface of the plain, because of the leveling action of the floods which sometimes cover them. The principal classes of river plains are *flood plains* and *compound alluvial fans*.

The materials forming the flood plains are not arranged in continuous horizontal strata, but are exceedingly irregular, owing to
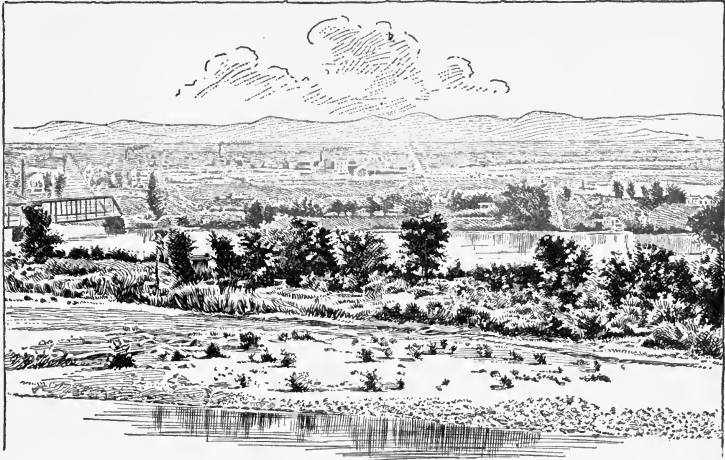
FIG. 189.—THE FLOOD PLAIN OF THE GRAND RIVER AT THE MOUTH OF THE GUNNISON, GRAND JUNCTION, COL.

The Grand River flows through a barren region, much of which is reclaimed by water led from the Grand by irrigating canals.

the meandering of the channel and to the fact that during floods a river often corrades new channels to great depths. As the flood subsides, the depressions thus formed are filled with layers of sediments, which sometimes differ from those eroded in fineness and also in inclination. In this way the nearly horizontal original deposits of flood plains are cut away first in one place and then in another.

The surface of the flood plain is usually higher near the channel than elsewhere, through the building of natural levees. As the stream shifts its course, old levees and abandoned channels interrupt its level surface; but these slight irregularities do not affect

the level appearance of the plain, as is clearly shown in Fig. 189 of the Flood Plain at Grand Junction, Colorado.

Economic Importance of Flood Plains.—The soil of flood plains is rich in plant food and is easily tilled. The large proportion of silt in the deposits makes the capillary distribution of the ground water well nigh perfect, and since the water table is usually near the surface, flood plains rarely suffer from drought. The neigh-

FIG. 190.—THE FLOOD PLAIN OF THE CANADIAN RIVER, OKLAHOMA

boring river provides an easily traveled highway, which makes flood plains exceptionally accessible. These two characteristics, fertile soil and accessibility, have made flood plains so desirable for settlement that they are nearly everywhere densely populated.

The flood plain of the Mississippi below the mouth of the Ohio is from 20 to 50 miles wide and about 600 miles long. Memphis, Vicksburg, and Baton Rouge are located on the plain, and fine crops of corn, cotton, and sugar-cane are raised there.

The flood plain of the lower Rhine is one of the most densely populated and carefully cultivated regions of Europe. The flood plain of the Yellow River, in China, probably has a denser population than any other region in the world.

The advantage which the less strenuous struggle for existence gave the ancient inhabitants of flood plains over the inhabitants of less favored regions, is shown in history. Egypt developed on the flood plain of the Nile, and Chaldea and Babylon on the
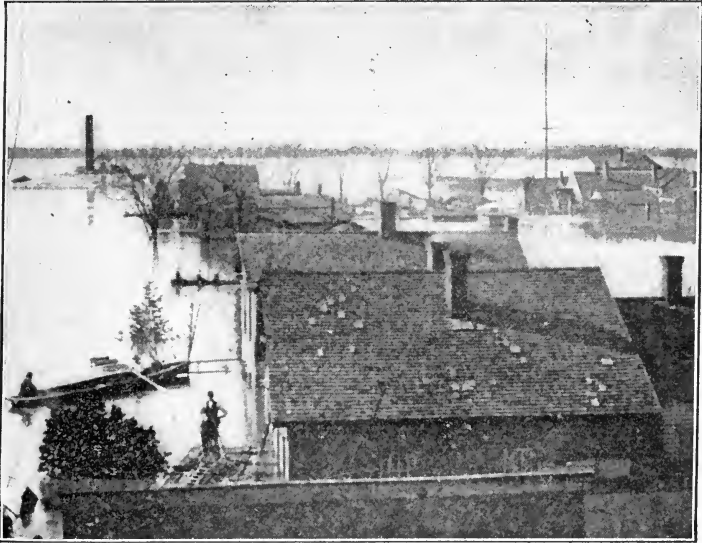
FIG. 191.—THE OHIO RIVER AT FLOOD STAGE
New Albany, Ind. The streets of the town are under water, and boats replace carriages.

plains of the Euphrates and the Tigris. These nations were so important among the ancients that the period prior to 800 B.C. is sometimes mentioned as the " fluvial period " of history.

The chief objection to life on flood plains arises from the danger of floods. Fig. 191.

In 1897 the Mississippi flooded 13,000 square miles of its lower flood plain, destroying property valued at $15,000,000. In 1903 a flood in the Ohio destroyed $40,000,000 worth of property.

Among the most disastrous floods are those of the Yellow River of China. In 1897, 50,000 square miles of its flood plain were inundated, covering many villages. More than 1,000,000 people were drowned, and an equally great loss of life from

famine and disease followed the flood. During one of its floods, that of 1902, the Yellow River shifted its course so that it emptied into the Gulf of Pechili, 300 miles north of its former mouth in the Yellow Sea.

The disastrous effects of floods may be prevented by building artificial levees or dikes along the banks. This has been done along a large part of the lower Mississippi, and the lower Rhine has not only been confined within high banks, but its course has been " corrected," or straightened.

Very extensive dikes have been built along the Po River by the Italian Government. A line of master dikes, intended to confine the river during the highest floods, is built on each side of the river for long distances, and between them in many places are secondary dikes which confine the river during all except the highest stages of water. More than 1,000 miles of such dikes have been built along the Po and its tributaries.

This treatment will prevent floods if the levees are sufficiently high and strong; but it also prevents the annual contribution to the fertility of the soil which the floods bring, and there are regions where the inhabitants prefer to let the floods spread over the flood plains. In such localities buildings are located on the higher lands. Loss of life will be prevented in a large measure if the inhabitants are warned of the danger of the flood. The United States Weather Bureau is devoting special attention to this subject, and is able to give people warning of the approach of a flood and to tell them the probable stage of the water.

Peneplains.—When erosion has been long continued in a region, all elevations are gradually worn down toward base level. One after another they disappear, and if sufficient time were allowed, doubtless even the hardest rocks would reach base level, producing a featureless plain.

It is not probable that this has ever been accomplished, but we find many regions in which erosion has almost reached base level. Such a region is called a *peneplain* (almost a plain). Peneplains present a very even sky line, broken only by occasional masses of the harder rocks that have resisted erosion. These masses some-

times rise high above the general level, and are then called *monad-nocks*. Fig. 192 shows the uplifted peneplain of New England and Mount Monadnock, which is taken as the type of such relict mountains. There are several monadnocks in New England besides the one which bears the name, and there are others in Georgia and elsewhere.

The mantle rock of a peneplain may consist of sediments depos-

FIG. 192.—THE UPLIFTED PENEPLAIN OF NEW ENGLAND
Note that the ridges are of uniform height and that the sky line is straight.

ited in former lakes and rivers, or of drift deposited by the continental glacier; but these local deposits do not indicate the true history of the region. It is the inclination of the strata of bed rock that shows the size of the folds removed and the extent of the work of erosion, and it is the erosion of the bed rock, rather than differences in the thickness of the mantle rock, which gives the region its plain-like characteristics.

Glacial Plains.—In some regions a continental glacier spreads till or bowlder clay over large areas of somewhat irregular bed rock, producing level lands like the well-known till plain of northwestern Ohio. Fig. 193.

Water from melting ice carries rock waste from the front of the glacier and deposits it in imperfectly assorted layers, forming an " out-wash plain " in front of a continental glacier, and " valley train " in front of a valley glacier.

The Great Western Plains extend from the Gulf of Mexico to the Arctic, and from the Mississippi River to the Rocky Mountains.

FIG. 193.—TILL PLAIN NEAR COLUMBUS, OHIO

The mantle rock here is unstratified glacial drift (till) spread smoothly over somewhat uneven bed rock.   Many prairies are of this origin.   Photographed by Professor E. Orton.

On the west they reach an altitude of about 6,000 feet, but their width is so great and the rise so uniform that the eye does not detect it.

The Great Plains are not so smooth as most plains formed by deposition; they have been corraded by streams to some extent, but some areas are smooth, and when their great extent is considered, the irregularities become insignificant.

The mantle rock of the region, in some sections was deposited by ancient rivers, in other sections it was deposited by modern rivers, and in still others it resulted from the decay of the bed rock.

The bed rock is not everywhere parallel to the surface of the plain; it has been tilted and bent since it was deposited as a sedi-

FIG. 104.—PHYSIOGRAPHIC REGIONS OF THE UNITED STATES
Photograph of a model made by Edwin E. Howell.

ment, and afterwards eroded until the slope of the surface is nearly uniform from the mountains to the prairies on the east. It is this fact that shows that the region is a worn down plain.

Economic Importance of Plains.—Plains are the great agricultural regions of the world. The soil is fertile and well watered as a rule, and means of communication, such as canals, roads, and railroads, are more easily constructed and maintained than on uneven lands. These conditions are most favorable for agriculture. Such regions are always developed more rapidly than either plateaus or mountains.

The desert regions of the world are often plains. They are deserts in some cases because they are arid, in others because they are frozen. In the United States many thousand acres of land formerly included in the " Great American Desert " are now under cultivation, which is made possible by irrigation and by the recently developed process of dry farming. The *tundras*, or frozen plains of Alaska, Canada, and Asia, are of course unfavorable for agriculture.

PLATEAUS

Definition.—Both plains and plateaus are regions of broad, relatively smooth upper surface and usually horizontal bed rock. Although plateaus are, as a rule, higher than plains, it is not possible to distinguish between them on the basis of altitude. The Piedmont Plateau, between the Appalachian Mountains and the Atlantic Coastal Plain, is much lower than the plains of the Mississippi Valley; and the Appalachian Plateau has an altitude of 2,500 to 5,000 feet, whereas the Great Plains east of the Rocky Mountains reach an altitude of 6,000 feet. The only possible distinction seems to be based upon the *relative altitude of the plateau and the surrounding regions.*

A plateau is a region of broad summit area that is conspicuously higher than adjoining land or water on at least one side.

Comparison with Plains.—The steep slope of the plateau front gives to plateaus certain distinct characteristics. The rivers

which flow from the plateaus to the adjoining lowlands are swift and, other things being equal, have greater corrading power than those of plains. This enables them to form deep valleys or cañons and to establish a drainage system which will dissect

FIG. 195.—FAULTS IN STRATIFIED GLACIAL DEPOSITS, ROCHESTER, N. Y.

the plateau. On the other hand, the rivers of plains are without this steep slope, and therefore corrade less rapidly, giving greater permanence to the level surface of the plain. It should not be inferred from the above statement that the greater rate of corrasion of the plateau stream would reduce the plateau to base level before the neighboring lowland reaches it; there is more rock to be corraded in the plateau than in the plain, and as the plateau

is eroded the streams gradually lose their steepness, and have no greater power of corrasion than those of the plain.

How Plateaus are Formed.—Plateaus may be formed by the elevation of the region along a fault plane, by the depression of the adjacent country, and by lava flows. The lava plateau of Oregon and Idaho (Fig. 194) is an illustration of the last process. It is probable that our plateaus and mountains reached their present altitudes through many slight changes of level, rather than
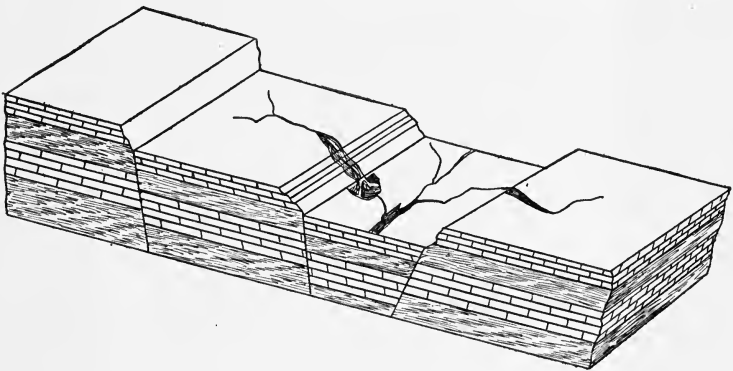
Fig. 196.—A Fault Plateau

a single mighty uplift. Since erosion began its work of wearing down the region as soon as it appeared above the sea level, it is evident that the present altitude of a plateau or of a mountain simply shows to what extent the uplifting forces have outstripped the wearing down forces.

Fault Plateaus.—The plateaus of northern Arizona, cut by the Colorado River, consist of a series of broad level areas, each one of which is separated from the next by a steep cliff, giving the region the appearance of a giant stairway. One of the cliffs, Hurricane Ledge, is 1,800 feet high. Such plateaus are formed by breaking the bed rock and displacing the rock on one side of the break; they are sometimes called *Fault Plateaus*. A break in rock, along which one side has been elevated or depressed, is called
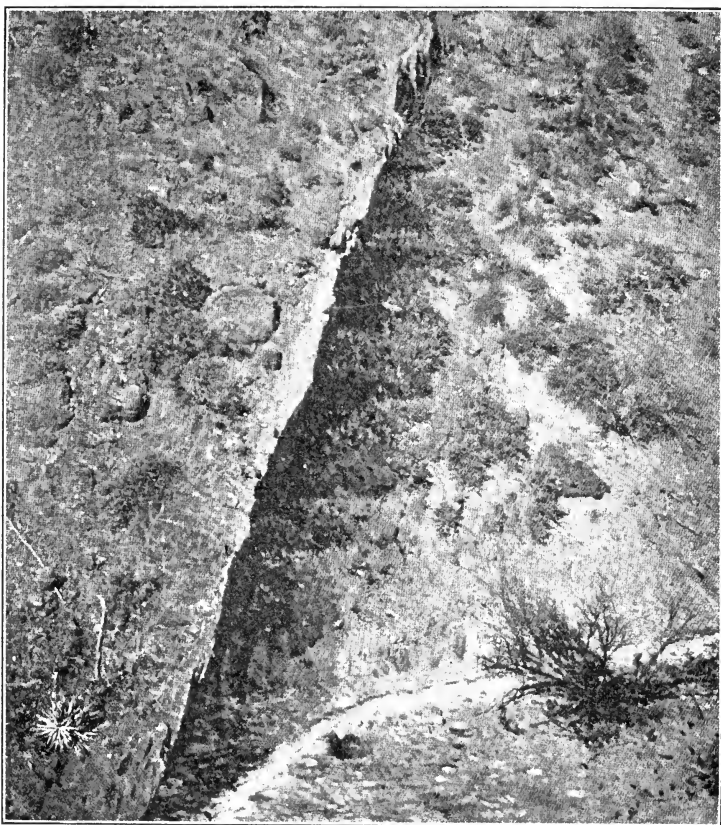
FIG. 197.—A FAULT PLANE

The rock on the right of the fault is "Ruin Granite," that on the left is quartzite, and the more rapid erosion of the granite has exposed the fault plane.

a *fault* (Fig. 195), and the cliffs which separate the " steps " of a fault plateau are called *fault cliffs*. Fault cliffs do not retain the slope of the fault plane. They are quickly eroded, so that their slope gives no indication of the angle of the fault; but the position of the cliff does indicate the location of the fault. Fig. 196.

Life History of Plateaus.—The changes produced by weathering and corrasion are of the same nature in a mountainous region or

on a plateau as on a plain, and the terms youth, maturity, and old age are employed to designate the stages in the life history of each. The principal difference is in the rate at which the changes are accomplished. The streams of a plateau front have steep slope, and therefore corrade their beds more rapidly than the same volume of water would wear away a plain. The great velocity also tends to keep the stream straight, thus minimizing the work of widening the valley by lateral corrasion. Weathering, the chief method by which the valleys are widened, on a young plateau always fails to keep pace with the downward corrasion; hence, in youth, the drainage courses of plateaus are almost always cañons or gorges.

A Young Plateau has a comparatively smooth upper surface, often cut to great depth by swift streams, forming cañons and narrow valleys. Fig. 199. The plateau cut by the Grand Cañon of the Colorado is young. Fig. 194.

As maturity is approached, the velocity of the streams diminishes, because they have cut down toward the base level of the region, and weathering gains on corrasion, transforming the cañons into V-shaped valleys. During this process numerous tributaries develop, and the flat, upper surface becomes a system of ridges separating the valleys.

Mature Plateaus. — The Appalachian Plateau, which extends along the western border of the Appalachian Mountains from the Hudson River to Georgia, is mature. The evidence of its once continuous upland surface lies in the fact that the tops of its numerous ridges form a nearly level sky line, and that the horizontal strata exactly match on opposite sides of the valleys. Fig. 198.

The altitude of this plateau on the east is 2,500 to 5,000 feet, which is greater than that of the mountain ridges east of it.

Roads, railroads, and towns are situated in the valleys. This region is one of abundant rainfall, and this, with the steep slope, has given the streams exceptional corrading power, thus developing one of the most perfect illustrations of a mature plateau to be found in this country. Fig. 200 shows a cross section of this region drawn to scale. The numerous streams are subject to de-

FIG. 198.—THE APPALACHIAN PLATEAU IN WEST VIRGINIA
Note that the hilltops form a straight sky line, indicating that the surface was smooth before the valleys were corroded.

structive floods and are loaded with rock waste. They are separated by narrow ridges, often 1,000 feet high, and so steep as to render agriculture impracticable. The nearly horizontal layers of rock are exposed in many valleys and have revealed the valuable mineral resources of the region—iron ore, coal, petroleum and natural gas. The region is well forested, and lumbering is an important industry. The only cities in the region owe their
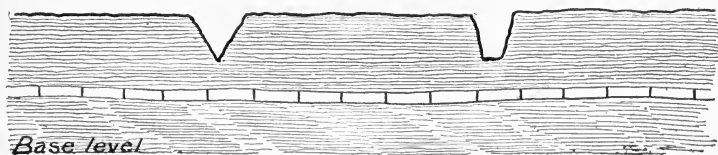
FIG. 199.—DIAGRAM OF A YOUNG PLATEAU

growth to the development of these resources. Charlestown, W. Va., is an important city illustrating this fact. It is a center from which much coal and petroleum is shipped.

Old Plateaus.—If a plateau should be completely reduced to base level it would become a plain, showing no evidence of the existence of the plateau. Many worn down plateaus show evidence of their former altitudes in the remnants of the higher,
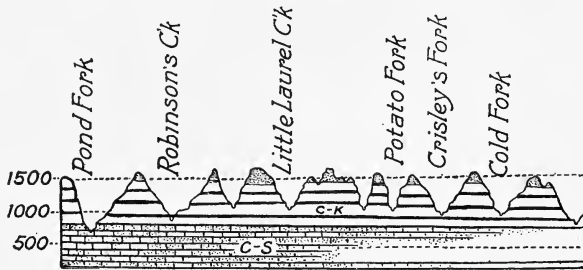
FIG. 200.—Cross Section of the Appalachian Plateau, near Charlestown, W. Va.
Scale, 1 inch equals two miles.

more resistant layers which have been preserved. In New Mexico there are a number of elevated areas that have been preserved, either because of the durability of the upper layer of rock, or because of their location with respect to drainage lines, and which show that many hundreds of feet of rock have been removed and

FIG. 201.—Diagram of an Old Plateau
Showing a Butte and a Mesa.

that the region was formerly a plateau. These flat topped areas are called *mesas*, if large with nearly vertical sides, and *buttes* if small. Figs. 202, 203 and 204.

Economic Importance of Plateaus.—High plateaus are colder and usually more arid than the adjoining lowland. In tropical regions this is an advantage, and the upland is usually an important agricultural region. For example, the plateau of Mex-
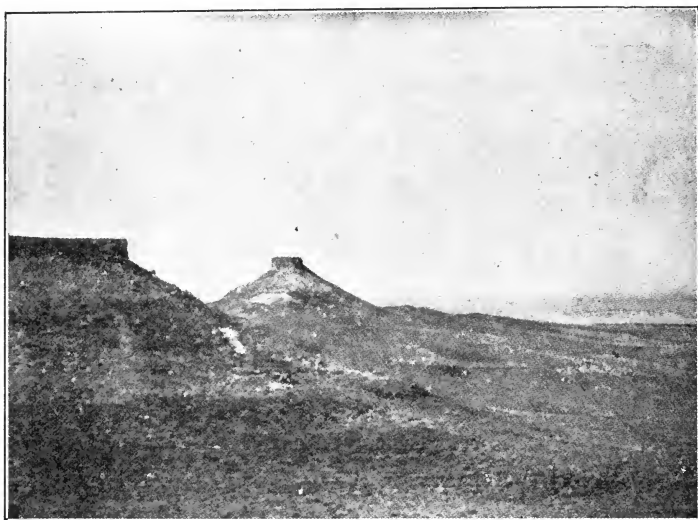
FIG. 202.—ANTELOPE BUTTE
These are monuments which show that much rock has been eroded
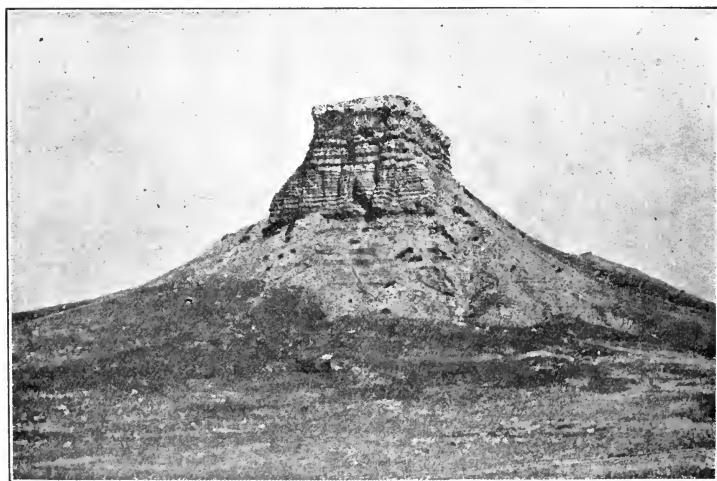
FIG. 203.—RED BUTTE, WYOMING
The upper layer is gypsum, 30 feet thick.

ico furnishes the northern grains to a region where semi-tropical products abound on the lowland. In temperate climates the low temperature is a disadvantage. In the plateau of Thibet the great elevation causes the climate to be almost arctic, and much of the region is abandoned to wild animals and tribes of nomads. The centers of the settled and agricultural population of Thibet lie in

Fig. 204.—A Smaller Butte

the south. Some of the deeper valleys here are fertile and warm enough to produce two crops a year.

Arid Plateaus.—The depth of the river valleys, even in moist plateaus, tends to lower the level of the ground water, thus increasing the difficulty of getting water. In regions of limited rainfall, therefore, plateaus are less suited to agriculture than plains.

Some farms flourish on our arid southwestern plateaus near the mountains, where mountain streams may be used for irrigation, and some other sections are fair grazing lands; but as a whole the region is unoccupied, just as is that of Thibet.

QUESTIONS

1. What spherical bodies owe their shape to gravitation?
2. Do solids assume a spheroidal form when rotated?
3. In what state must the earth have been when its spheroidal form was assumed?
4. Does this support the Nebular or the Planetesimal Hypothesis?
5. What benefit does man derive from the relief of the earth?
6. Why does the finding of the skeleton of a whale in glacial gravels near Lake Champlain indicate a change of level of the land in that region?
7. What sort of evidence would show that a given plain was of lacustrine rather than of marine origin?
8. Fig. 192 shows a dissected region with hilltops forming a straight sky line. What would determine whether it was an uplifted peneplain or a dissected plateau?
9. How was the original upland surface made level?
10. Are all lacustrine plains fertile? Why?
11. What facts prove that the Atlantic Coastal Plain was once a part of the continental shelf?
12. What evidence have we that the continental shelf was once a part of the continent?

CHAPTER XXV

MOUNTAINS

Peaks and Mountain Groups.—There is uniformity neither in structure nor in mode of formation of the isolated peaks and groups of elevations to which the term mountain is popularly applied. Vesuvius and Etna are popularly called mountains, although they are merely heaps of erupted materials about the vents from which they issued. Their formation was due to the action of internal forces which did not distort the bed rock.

The Henry Mountains, in southern Utah, consist of a group of *domes* formed by the intrusion of lava beneath horizontal layers of bed rock, which were lifted to a great height and have since been eroded. They were formed by the action of internal forces which distorted the upper strata of bed rock.

The Uintah Mountains, of Utah and Wyoming, consist of a broad fold or ridge, in the formation of which several thousand feet of sedimentary rock were uplifted and faulted. Their formation is due to the action of internal forces which folded and faulted the bed rock.

Lookout Mountain is a remnant of an old plateau, and the Catskill Mountains of New York are a part of the dissected plateau described in the last chapter.

Each owes its form to the action of external forces, which eroded the surrounding bed rock without displacing its nearly horizontal strata. Each of the peaks mentioned above "mounts toward the sky," and is a conspicuous feature of the landscape. Each conforms with the popular definition of a mountain given in the dictionaries. *A mountain is a conspicuous elevation of limited summit area.* It is manifestly impossible to formulate a scientific definition of the term mountain based upon *structure* or mode of

formation. Mountains cannot be distinguished from hills on the basis of absolute altitude. The Alleghany Mountains are much lower than the Black Hills, but they are the most conspicuous elevations in their section; whereas the Black Hills are "dwarfed by the Rocky Mountains."

Some mountains, like Mt. Etna and Pike's Peak, consist of a single sharp summit or *peak;* others consist of long ridges.

A mountain *ridge* is a mountain having much greater length than breadth.

A mountain range is a ridge, or group of parallel ridges, formed by the same mountain-making effort. They are formed by the action of great internal crushing forces which fold or fault and tilt the bed rock, and are always regions of disordered strata. All of the ranges of the world are alike in these particulars, and for this reason it was formerly customary to say that mountain ranges thus
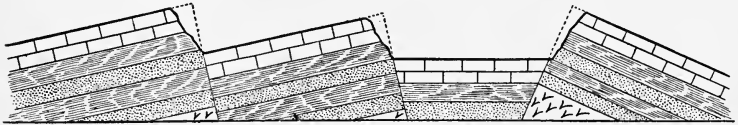
FIG. 205.—CROSS SECTION OF FAULT MOUNTAINS

formed were the only true mountains. There are two types of mountain ranges, the folded range, in which the bed rock is compressed into folds, and the fault mountains, in which the bed rock was faulted and tilted.

A mountain chain is a group of approximately parallel ranges formed by different mountain-making efforts.

The term *cordillera* is applied to groups of mountain chains and ranges; for example, the cordillera of the western United States includes the Rocky Mountain chain, the Sierra Nevadas, and the Coast Range.

Fault Mountains.—In the Great Basin region there are many ranges of very simple structure. They resemble fault plateaus, except that the bed rock has been tilted as well as faulted. The slope on one side is steep, that on the other side is gentle,
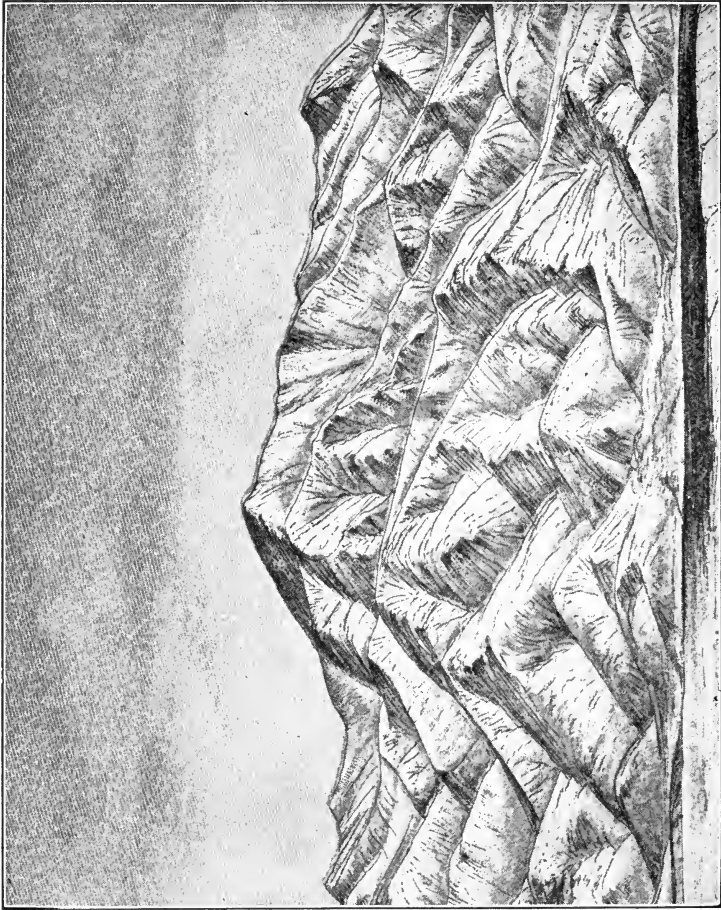
FIG. 206.—THE DISSECTED MOUNTAINS OF UTAH

still too steep to permit the mass to be called a plateau.   The
strata of bed rock are parallel to each other and to the gentler
slope of the block.   Fig. 205.

In southern Oregon are many such mountains, that were formed
so recently that there has been time for little corrasion by the
streams.   It may be that they are still in process of formation,
as earthquakes are still frequent in the region.

Some of the ranges here are forty miles long, and in some places they rise 2,000 feet above the valleys. There are few settlers in this region, and their ranches are located in the stream valleys. The region is arid, and many of the lakes are salt.

There are *older fault mountains* in Nevada and Utah which are very much dissected. In some instances these blocks are eighty miles long and twenty miles wide, rising from 2,000 to 7,000 feet above the valley. The crests are notched and uneven, and the slopes much corraded, forming sharp spurs and deep valleys. Fig. 206.

The loftiest range in this country, the Sierra Nevada, is an uplifted fault block, but the faulting and tilting occurred in a mountain region after the strata had been folded and compressed. A great fault, some 400 miles long, formed along the western border of the Great Basin, and a great mountain was uplifted and tilted downward toward the west. The steep slope of the block thus displaced is on the eastern side, facing the Great Basin. On the west the gentle slope leads down to the valley of California.

On the eastern side of the Great Basin the Wasatch and the Teton ranges are fault mountains, their steep slopes facing west.

The Sierra Nevada and the Wasatch Mountains are older than those of Oregon, and have been much dissected.

Fault Mountains seem to have been formed by enormous lateral pressure, which faulted and tilted large blocks of the earth's crust.

Folded Mountains.—The great mountain systems of the world are of this type. In most cases sedimentary rocks, formed in

FIG. 207.—CROSS SECTION OF THE JURA MOUNTAINS

nearly horizontal layers on an ancient sea bottom, have been crushed together and folded so as to form mountain ranges.

One of the best examples of folded mountains is the Jura Mountains, between France and Switzerland. They consist of a series
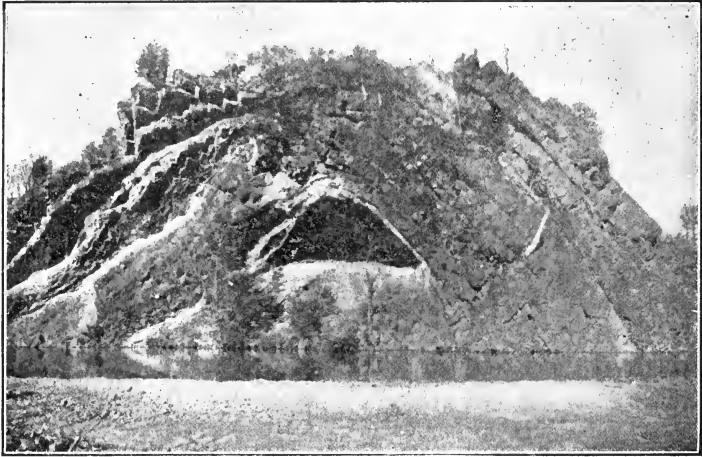
Fig. 208.—An Anticline near Hancock, Md.

Fig. 209.—A Syncline in Shale, Upton, Pa.

of parallel ridges. The rocks forming them are sedimentary and contain marine fossils; they were, therefore, formed on the sea bottom and were originally nearly horizontal. A cross section shows that they are now bent so that the layers are parallel to the mountain slopes, except where they have been eroded.

As shown in Fig. 207, each ridge consists of layers of rock which form an arch. Such an upward fold or arch is called an *anticline*.
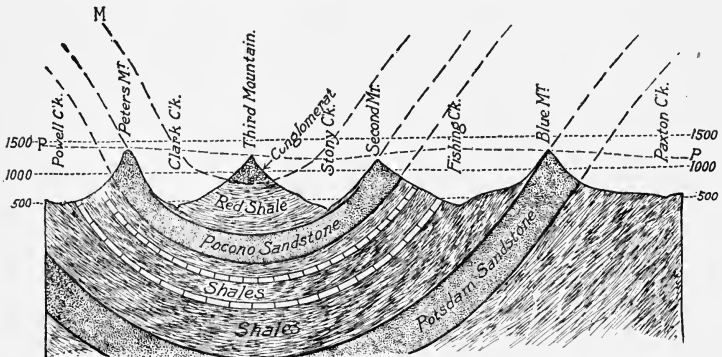
FIG. 210.—CROSS SECTION OF THE APPALACHIAN MOUNTAINS, NEAR ELLENDALE, PA.

Fig. 208. Each valley consists of a downward fold of the same layers. A downward fold or inverted arch, in a series of layers of rock, is called a *syncline*. Figs. 209 and 210.

The Jura Mountains have been only slightly modified by erosion. The upper layers of the folds have been removed and the valley floors covered with rock waste; but the drainage of the region is controlled by the form of the mountain. Small streams flow down the steep sides and enter the main stream at approximately right angles.

Appalachian Mountains.—These mountains consist of folds like those of the Jura, but the folds are on a larger scale and are more complex. Many great faults are found, and the *throw*, or vertical displacement of one side of the fault in some cases is several thousand feet. The mountains are eroded so that the original summit lines have entirely disappeared, and the present ridges are

the outcrops of resistant rocks which have withstood the action of the weather.

Fig. 210 shows a cross section of the Appalachian Mountains near Harrisburg, Pennsylvania. The rocks under Third Mountain form a syncline which shows that the top of this mountain was once the bottom of a valley. If the anticline which corresponded to the Third Mountain syncline should be restored, we should have a mountain of several times the height of those now occupying the region. The dotted lines suggest the probable height. It will be noted that the four ridges have about the same altitude, and the picture, Plate II, shows that the sky line formed by their summits is practically a straight line. This indicates that at some time in the past the mountains which occupied this region were reduced to a peneplain, because there is no other way in which erosion can produce an even surface.

Rocky Mountains.—When the early explorers first saw these mountains in the distance, they reported the existence of vast ranges which glistened in the sun as though composed of crystals. Closer observation led others to call them the Stony Mountains, which name was changed to the more correct term of Rocky Mountains. Their striking feature is shown by these attempts to name them. They are great masses of bare and often crystalline rock, many peaks in Colorado reaching an altitude of between 14,000 and 15,000 feet. The base is covered by a cloak of coarse waste washed down by the mountain torrents, and here the slopes are forested; but the timber thins out and disappears at about 11,500 feet above the sea level. The irregular line which marks the upper limit of trees is known as the *timber line*. Above this line the talus slopes are small, and the bare rock cliffs and peaks above them are the characteristic features of the scenery.

West of the Front Range, near Denver, Col., are other nearly parallel ranges of similar character, which approach each other quite closely in places and again bend away, leaving broad *parks*. These parks are in some instances 50 miles wide, and have a comparatively level floor of rock waste washed down from the mountains. South Park, just west of Colorado Springs, is an example.
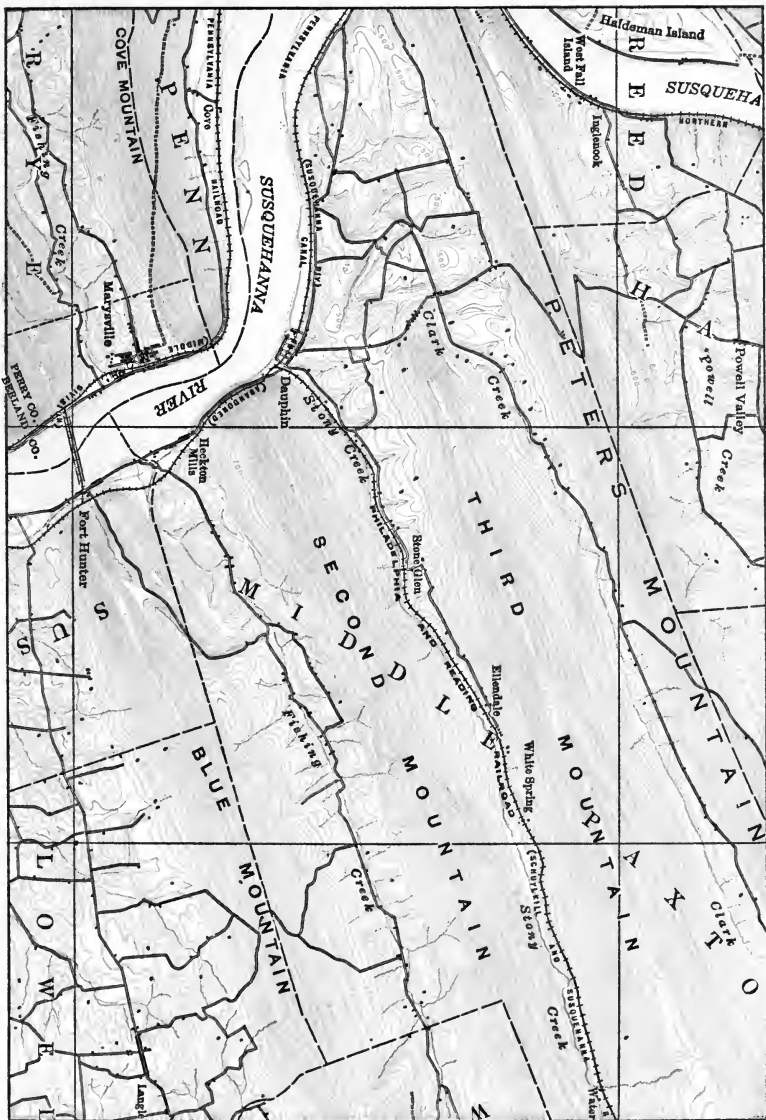
PLATE II. CONTOUR MAP. THE APPALACHIAN RIDGES NEAR HARRISBURG, PA.

From U. S. Geol. Survey.   Scale: 1 inch = 1 mile.   Contour interval, 20 feet.
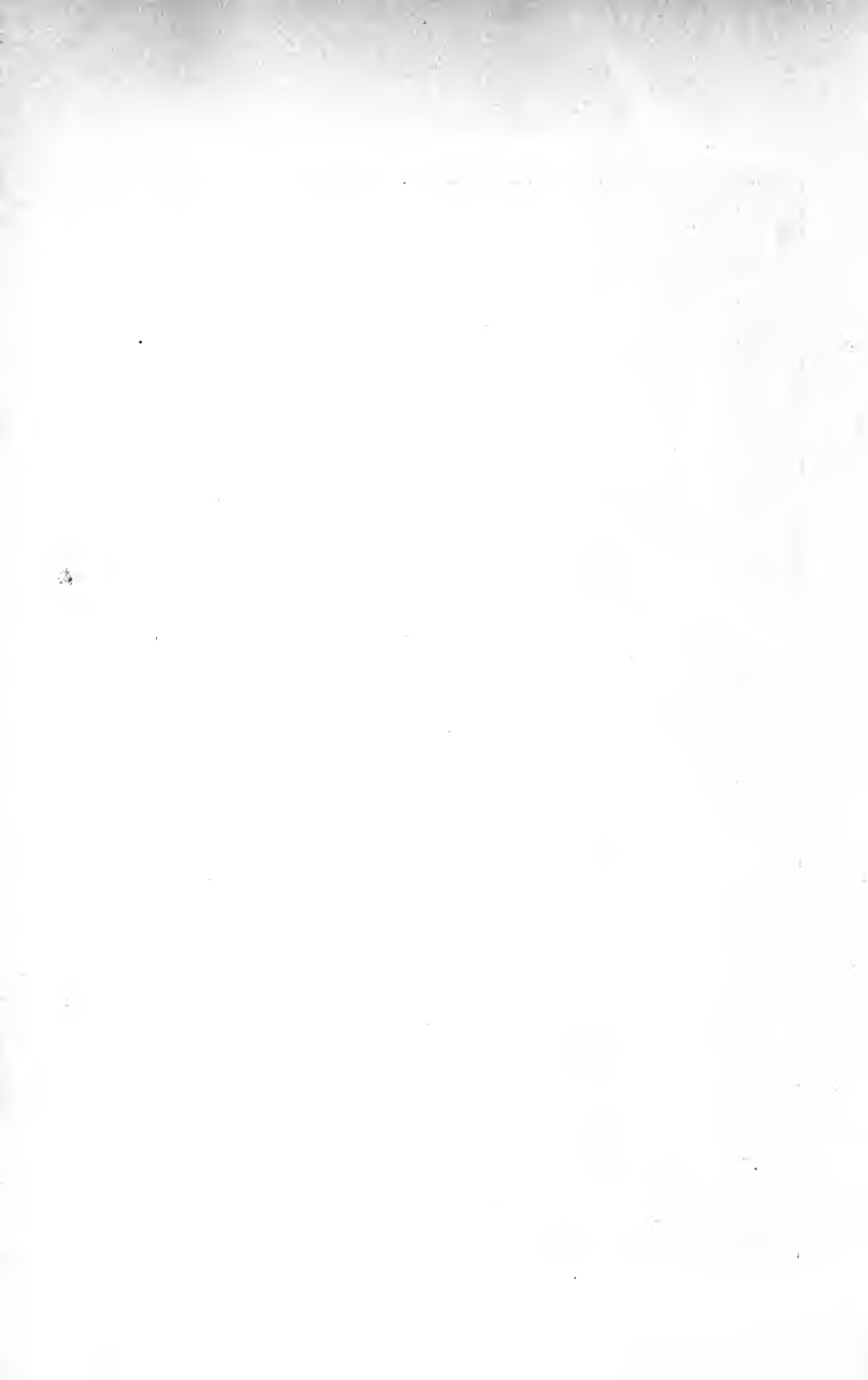
Fig. 211.—The La Plata Mountains of Southwestern Colorado

Showing the characteristic ruggedness of the Rocky Mountains. Mt. Hesperus has an altitude of 13,200 feet. (U. S. Geological Survey)

It has an area of more than 1,000 square miles, and an altitude of about 8,000 feet. This is between 2,000 and 3,000 feet higher than that of the Great Plains east of the Front Range. South Park is drained by the Platte River, which flows down the eastern slope of the Front Range.

Structure.—The central mass of the Rocky Mountains is granite, or granitic rocks, but at the base, resting upon the granite, sedimentary rocks are found. These are tilted, and may be traced some distance up the slopes on either side. In some of the ranges these rocks undoubtedly once extended entirely over the surface and have been eroded. Other ranges may have been islands in the sea in which the sedimentary rocks were deposited, and therefore received no sediments. In either case it is evident that the uplift occurred after the sedimentary rocks were formed, because they are tilted and are now many thousands of feet above sea level. Examination of these sedimentary rocks shows that they were deposited long after those of the Appalachian folds. The sedimentary rocks of the Appalachian plateau dip downward toward the Mississippi Valley, and are covered with rocks thousands of feet thick made from sediments which accumulated *after* the Appalachian Mountains were formed; *and these upper rocks are involved in the folds of the Rockies.* It is thus proved that the Rockies are younger mountains than the Appalachians.

This conclusion is also reached from a comparison of the amount of work that erosion has already accomplished with the amount it may still accomplish in the two chains.

When the earth's crust was folded to form the Rocky Mountains, the greater thickness of the layers of rocks involved required greater lateral force than was required to form the Appalachians; and this greater force produced a greater uplift, and at the same time fractured and faulted the rocks so that there were extensive outpourings of lava over the region. This accounts for the many igneous dikes and lava flows found there.

This region, after having been nearly base leveled, or reduced to a peneplain on which some of the harder areas formed monadnocks, was uplifted. This revived the streams at the edge of the moun-

tains and produced many of the gorges, as the Royal Gorge of the Arkansas.

Origin of Mountains.—If a metal ball could be heated or cooled uniformly throughout its mass it would retain a spherical form. To do this would require perfect conductivity of heat; but a poor conductor like the earth cools more rapidly at the surface than in the interior, and therefore contracts unequally.

Both the Nebular and the Planetesimal Hypotheses assume that the earth has long had a solid and highly heated interior, and they both agree that the crust of the earth, or the lithosphere, as it is often called, has probably been at approximately the present temperature for millions of years. During these years the interior has been losing heat and contracting.

The generally accepted theory of the origin of mountains is based upon these assumptions. This theory maintains that *the interior of the earth has contracted materially since the lithosphere reached its present temperature and size, causing it to wrinkle because it is too large for its shrunken interior.*

In mountain ranges there is evidence of enormous lateral pressure, which folded and compressed strata once horizontal. It is easily shown that the contraction of the interior of the earth, after the lithosphere had reached a permanent size, would cause lateral pressure. In Fig. 212, if L represents the lithosphere, and C represents the shrunken interior, the action of gravity on a section of the lithosphere, S, would be like driving a wedge into the lithosphere, and would compress it laterally. Every other section would do the same, and this action explains the existence of a certain amount of compression, but does not satisfactorily account for all of it.

There have been many changes of
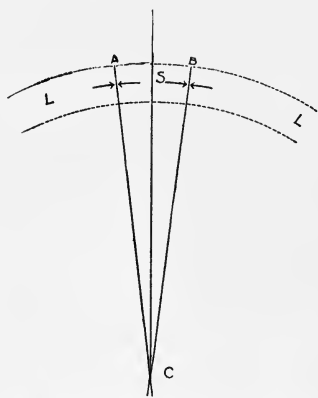
FIG. 212.—DIAGRAM OF GRAVITY AND LATERAL PRESSURE

temperature in the strata of the lithosphere, and every rise of temperature must have added to the lateral pressure, due to gravity, through the expansion of the heated layers. Lava flows and intrusions have heated adjoining rock, expanding and adding to the gravitational pressure. Rock strata are being constantly buried beneath the sediments and every layer deposited above a given layer tends to raise its temperature and to produce lateral pressure. This action occurs chiefly on the borders of the continents.

There are undoubtedly radio-active substances in the bed rock which, like radium, slowly emit heat. Such substances tend to raise the temperature of the rocks containing them, producing further expansion and corresponding increase in lateral pressure. Such temperature changes have undoubtedly developed local lateral pressure on a large scale.

Erosion in Mountains.—All of the lofty mountain ranges show evidences of erosion on a grand scale. Their *peaks* and *horns* have been carved out of the solid rock of wavelike folds and rounded domes; their ledges and cliffs have been profoundly riven by frost and changes of temperature, and their slopes scarred and gullied by mountain torrents and glaciers.

The following conditions which prevail in mountain regions explain the effectiveness of the agents of erosion:

First, their *altitude* usually leads to heavy *rainfall* or *snowfall*, on at least one side, which means in either case rapid erosion on the side or sides receiving the precipitation. Moreover, their altitude subjects them to *greater daily range* of temperature and the increased rate of weathering due to this extreme variation. If the fluctuations of temperature center about the freezing point of water, the rate of weathering is further increased by the alternate *freezing and thawing* of water in the crevices and pores of the rock. Fig. 93 shows how much the solid rock of Pike's Peak has been broken by this action.

Second, their steepness gives to their streams and glaciers a *velocity* and power of corrasion which exceeds that possessed by the streams of plains or by continental glaciers, and rock waste is removed.

Their steepness also enables *gravity* to remove rock waste from the face of the cliffs and ledges, thus constantly exposing fresh rock to the action of the weather. For the same reason the *creep* of the rock waste down the slope of the mountain is exceptionally rapid.

These various agents change land forms, which without their action would have been bounded by smooth curves and uniform slopes, into *crags*, *needles*, and *peaks*. Many such were named *Sierras* by the

Spaniards because they resembled a saw. Fig. 211 of the La Plata
Mountains shows this effect.

*The first effect of erosion, then, is to increase the strength of the
relief of the mountain region.*   The irregular surface of the slope of
the dissected ranges of Utah, Fig. 206, illustrates this action.   With
the lapse of time the peaks are worn down and rock waste covers
the whole mountain, which once more consists of rounded domes
and ridges.   In this stage they are known as *subdued mountains.*
Fig. 214.   As time passes the region approaches more and more
nearly to the peneplain.   The more resistant rocks wear down
more slowly than the weaker, and often stand up conspicuously
above the peneplain.   Mount Monadnock, in southern New
Hampshire, is a typical illustration.

*As soon as erosion begins to round the mountain form, it begins to
decrease the relief of the region,* and continues to decrease it until
the close of the cycle of erosion.   The present height of all moun-
tains depends quite as much upon the *vigor of the agents* of erosion,
the *time which these forces have been in action,* and the *ability of the
rocks to resist erosion,* as upon the magnitude of the uplifting forces
and the time during which the action of the uplifting forces con-
tinued.

Life History of Mountains.—We have seen that mountains are
acted upon by two sets of forces, the one tending to make them
higher, the other tending to make them lower; the first acts from
within the earth, the second from without.

Mountains have their *period of growth* and their *period of decline.*
Growth lasts as long as the uplifting forces are more effective
than the agents of erosion, and decline begins when the rate of
erosion exceeds the rate of uplift, and continues until the uplifting
forces renew their activity and raise the region more rapidly than
it is eroded, or until the region becomes a peneplain.

*Erosion begins as soon as the region is raised above the sea, and
continues as long as any portion of the region remains above sea
level.*   The uplifting forces are not necessarily continuous in their
action, but may be intermittent, ceasing entirely for a time.
They usually are more active during the early history of a range

and perhaps stop permanently, in some cases, when the earth's crust becomes strong enough to resist their action. There is evidence that after the Appalachian Mountains were worn down to a peneplain, the uplifting forces acquired renewed vigor, and that the region had more than one period of uplift.
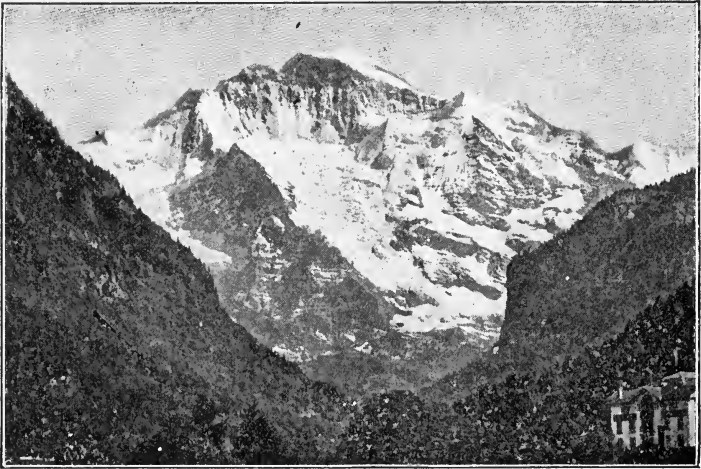
FIG. 213.—THE JUNGFRAU, A YOUNG MOUNTAIN
Note the U-shaped glacial valley in the foreground showing former extension of Alpine glaciers

During the warfare of constructive and destructive forces, the characteristics of mountains change so that one may readily distinguish young mountains from old ones.

The Rocky Mountains are younger than the Appalachians, and differ markedly from them. For example: The Rockies have bare ledges and cliffs, with small talus slopes; the Appalachian rocks are usually waste covered. The Rockies have a very irregular sky line; the Appalachians present an even sky line. The Rockies rise 8,000 or 9,000 feet above the platform on which they rest; the Appalachians 900 to 1,200 feet. Avalanches and landslides occur occasionally in the Rockies but not in the Appalachians. The streams in the Rockies are young; those in the Appalachians are more mature.

Young Mountains, Figs. 211 and 213, are characterized by irregular sky line, bare ledges, steep slopes, streams in the torrential stage, and the summit lines still in their original positions. During youth, avalanches, landslides and earthquakes occur at times.

Subdued Mountains, illustrated in Fig. 214, have uniform slopes, low, rounded form, and few bare ledges; earthquakes or avalanches

FIG. 214.—SUBDUED MOUNTAINS IN NORTH CAROLINA
Compare the broad rounded summits with those in Fig. 211.

are rare or unknown; the sky line is more regular than that of young mountains, but less regular than that of old mountains; water gaps and passes have developed.

Old Mountains.—As mountains grow old and the region approaches a peneplain, monadnocks stand out here and there with uniform and forested slopes of deep rock waste. The original summit lines have disappeared and new ones have developed, following the outcrops of more durable rocks. The peneplain of New England, Fig. 192, and the region south of Lake Superior are old mountain regions.

The uplift and decline of mountains takes place so slowly that the change produced during a lifetime passes unnoticed, and men have come to think and speak of them as everlasting. History fails to give us assistance in determining the rates at which these changes progress. Polybius' description of the Alps as they were when Hannibal crossed them in 218 B.C. is practically a description of the Alps to-day. The Alps are still young mountains, and the lapse of 2,000 years has not materially changed them. It is evident from these considerations that the life history of mountains cannot be expressed in terms of years or even in thousands of years, and that the time required to wear down our old mountains to the present peneplains was very long.

Climate of Mountains.—The snow-capped mountains of the Torrid Zone exemplify upon their slopes all the climatic changes that one would experience in traveling from the Torrid Zone to the Polar regions. As one ascends, the palms and bananas of the Torrid Zone gradually disappear, and are replaced by the deciduous trees and wild flowers of the Temperate Zone. These in turn are replaced by the cone-bearing trees, which, as the ascent is continued, become low and dwarfed; finally all trees disappear. Above this point grasses and bright Alpine flowers flourish; but these also disappear as the ascent continues, and the snow-clad top is a Frigid Zone in miniature. In a similar manner the forms of animal life that inhabit the bases of such mountains gradually disappear, and are replaced by forms which characterize the higher latitudes.

The great variety in mountain climate is due to the fact that the vertical temperature gradient in air at rest is more than 1,000 times as great as the average horizontal temperature gradient. That is to say, the average annual temperature decreases more than 1,000 times as fast as one ascends as when one travels poleward.

Numerous observations both in balloons and on mountains have established the fact that the average rate at which the temperature falls as we ascend is one degree Fahrenheit for every 300 feet.

The timber line and snow line are more or less irregular, being usually higher on the south or sunny side of east and west ranges than on the shady side. In the equatorial region the snow line is about 18,000 feet above sea level, but its altitude diminishes as the distance from the equator increases, reaching sea level in the Arctic and Antarctic regions.

Many ranges are subject to excessive rainfall or snowfall on the windward side; and where they cross prevailing winds the climates of the opposite slopes are in sharp contrast. For example, on the western slope of the Sierra Nevadas, the moist wind is chilled as it rises, producing abundant rainfall, which supports forests; whereas the same wind on the eastern slope, having lost most of its moisture and being heated by compression as it descends, becomes a drying wind which takes moisture from the land, making it arid. A similar distribution of rainfall occurs in the Cascade Mountains, but the region east of them is less arid than that east of the Sierras, because the Cascades are lower. The heavier rainfall is also found on the west slopes of the Rockies and Andes, in the belts of the prevailing westerlies, and on the east slope of the Andes in the trade wind belts.

The south side of the Himalayas has much heavier rainfall than the north side in the summer, because they lie across the path of the southwest monsoon. As a rule, the contrast between the sides of ranges parallel to the prevailing wind of a region is less than that between the sides of ranges crossing the paths of the prevailing winds.

Mountain ranges sometimes deflect winds, changing their direction and bringing rain to regions that would not receive it under other conditions.

Habitability of Mountains.—The difficulty of crossing mountains, the danger from avalanches and landslides, the low temperature of the summits, and the great cost of transportation, combine to make mountain regions less desirable for habitation than plains or plateaus.

If the difficulty of making a living is overcome, many features of mountains attract men to them. The healthfulness, the gran-

deur of the scenery, and the military advantages of mountains have led many to make their homes among them.

Influence on Man and History.—Because of the difficulty of crossing mountain ranges, the difference in climate on the different sides, and the military advantages which they afford, *mountain ranges are the natural boundary lines for nations*. The Himalayas, which separate different races; the low Pyrenees, crossed by but a few roads and railroads; the Caucasus, the Alps, and the Andes, all illustrate the tendency of nations to select mountain ranges for their frontiers.

As the Indian and the pioneer gained a measure *of security* within their stockades, so a nation surrounded by mountain ramparts is in a measure secure from outside interference. It requires a greater incentive to cause outside nations to attack them than is required to lead them to attack nations not so surrounded. The elevation of their outposts enables them to see an approaching enemy that would be invisible on a plain, thus diminishing the chance of surprise. Narrow passes well fortified can be successfully defended against vastly superior numbers, because the invading army cannot approach the pass in line of battle and is met in small parties. The famous defence of Thermopylæ illustrates this advantage.

The soldier on the mountain meets a tired foe, and in hand-to-hand conflict this is an important aid. Artificial avalanches of bowlders have frequently decimated armies attempting to cross mountain passes. When Hannibal crossed the Alps his losses through this kind of warfare contributed in no small measure to his ultimate defeat.

Because of the security afforded, conquered races usually make their last stand in mountains, and have frequently been able to maintain their position through long periods, some of which extend even to the present day, as the Basques, the Welsh, the Highlanders, etc.

With the military advantage comes *a degree of isolation which favors the development of a distinct type of civilization and an individual language,* or dialect, in the region thus set apart from the

rest of the world. This tendency is illustrated in the many small principalities which developed in Europe during the Middle Ages, several of which exist to-day; and in the fact that in the California valleys there were almost as many tribes of Indians having characteristic languages and customs as there were valleys between the mountains.

The same isolation limits commerce and knowledge of the outside world, and compels the residents of mountainous regions to depend upon themselves for their wares and for their progress. If their number is small, as it is apt to be on mountain slopes, where the struggle for existence is so strenuous, there is rarely progress in the ways of civilization, but instead there is often a retrograde movement. Mountaineers are proverbially conservative, using the same processes and following the same customs that their forebears used and followed. In the southern Appalachians we find excellent illustrations of this effect; here are peoples following habits and customs of the eighteenth century. Mining cities in mountains are exceptions. To them the sudden wealth brings all that is good and all that is bad in our modern civilization.

Mountain ranges *retard the exploration and settlement of a region.* The outfit which an explorer must carry is heavy. If he follows the rivers, shelter and food for many weeks can be transported in a canoe by one man; but if he journeys over plains the number of men and wagons increases rapidly as the proposed journey is lengthened; and if he is to cross mountains pack animals must replace wagons, without further increase in the size of the party.

There is no better illustration of this retarding action than that found in the early history of this country. Before the year 1600, European explorers had visited the mouths of the St. Lawrence, the James, the Mississippi, and the Rio Grande, and had visited California. During the next century the English explored and settled the Atlantic coastal plain, but made few attempts to cross the low ridges of the Appalachians; the French, during the same period, explored the St. Lawrence and followed the Mississippi to the Gulf. They established settlements along the routes which

grew into towns still bearing French names, such as Detroit, Sault Ste. Marie, Fond du Lac, Prairie du Chien, St. Louis, and Baton Rouge. The Spanish settlers on the Gulf of Mexico, during the sixteenth and seventeenth centuries, extended their missions toward the north as far as Santa Fé, where the Rocky Mountains checked further progress in this direction. They therefore pushed westward to southern California. From there they followed the Pacific coast toward the north, establishing missions in the narrow area between the Coast Range and the Pacific. Their trail is now marked by cities still having Spanish names, such as San Antonio, Sante Fé, and along the coast, San Diego, Los Angeles, San Francisco, and Sacramento.

The Berkshire Hills, in Massachusetts, exerted an important influence in settling the contest between Boston and New York City for commercial supremacy. Freight brought from the West through the Mohawk Valley to Albany could be brought to New York by boat more cheaply than it could be hauled over the Berkshires by teams, and much of it was naturally deflected to New York. When railroads were built along the Hudson and through the Mohawk Valley, New York City acquired further advantage over Boston because of the Berkshires. Before a railroad line from Albany to Boston was completed, the position of New York as the chief seaport of the United States was fully established.

Mountains are *not absolute barriers*. They are difficult to cross, but when sufficient incentive is provided, men always succeed in crossing them.

In the case of the English colonists the necessary incentive came in the demand for more room and more virgin soil, and in the increased importance of the trans-Appalachian fur trade. During the French and Indian War which followed, the possession of the best passes through the mountains was stubbornly contested, as is shown by the large number of battlefields between the Hudson and Lake Champlain, and between the Mohawk and Lake Ontario.

The Rocky Mountains retarded the settlement of California more effectively than the Appalachians confined the colonists to

the Atlantic coast, and for a longer period, because of their greater height and breadth; but the necessary incentive came in the discovery of gold in 1848. Before the close of 1849, there were 100,000 people in California.

Barriers to Plants and Animals.—As the white man appeared first on the eastern shore of North America and gradually spread westward, so it is probable that each species of both animal and plant life appeared first in some definite locality and gradually spread from this center. Man is the only form of life that is capable of adapting itself to all conditions of altitude and climate, and is therefore the only species of life that has spread over an entire continent. Various physical features act as barriers which certain forms of life cannot cross, and among them, perhaps, the long mountain range is as effective as any feature. No physical feature is equally effective as a barrier to all species of animal and plant life. Mountain ranges, which have checked the spread of the white man for long periods, are but slight obstacles to the spread of birds.

The low temperature of the summit of mountains prevents certain forms of animal life from crossing them. The spread of some species of animals is checked by mountains because of the steepness of the mountain slopes; and still other species are prevented from crossing by predatory animals inhabiting higher altitudes. It is said that the Asiatic ranges limit the spread of even the mountain goat to such an extent that every range in the region has developed a distinct species.

The climate of high mountains prevents the spread of plants. Above the timber line no trees grow, even though their seed reach the region; and a short distance above the timber line no form of vegetation can develop. Certain winged seeds and those like the seeds of the thistle and the milkweed, may be blown over mountain ranges, and some are undoubtedly carried over by birds; but, as a rule, the native plants, like the native animals inhabiting the opposite sides of long mountain ranges, are of different species.

Economic Value of Mountains.—1. *Mining.*—The forces which formed our mountain ranges subjected the rocks of the regions to greater stress than the horizontal rocks of the plains and plateaus underwent, and the resulting *fractures and faults* are more numerous and are less uniform in shape than those of other regions. Each fracture in impervious rock becomes a channel through which underground water may circulate, and in which veins of various minerals may be formed by the waters.

Other features which facilitate the formation of mineral veins in mountain regions are the *heavy rainfall*, which increases the volume of ground water; the *elevation of the region* above the surrounding country, which gives the ground water circulating through the underground passages an increased " head " and increases the rate of flow; and sometimes *higher underground temperature*, due to intrusion of igneous rocks or other causes.

These four conditions—the greater number of underground passages, the greater volume of circulating water, the greater liquid pressure of the water, and the higher temperature of the water—account in a measure for the fact that most of the mines of ores that occur in veins are found in mountains.

In Fig. 215 it will be seen that all of the gold and silver mines of the country are in either the western mountain ranges or in the Appalachian region. The great number of gold mines on the western slope of the Sierra Nevada Mountains, where they have the maximum height and the maximum rainfall, cannot be accidental. Most of the copper mines and many of the lead and zinc mines are similarly located. Important copper mines are located among the worn down mountains near Lake Superior.

Coal, iron, and salt occur in *beds* rather than veins, and these are not chiefly found in mountains. See map of distribution of coal, page 253.

Mountain-making processes have metamorphosed many rocks, and some of them are mined or quarried in mountains. For example, anthracite coal comes chiefly from Appalachian mines, and much slate and marble are quarried in the Green Mountains. It is not only the more frequent occurrence of valuable ores and rocks
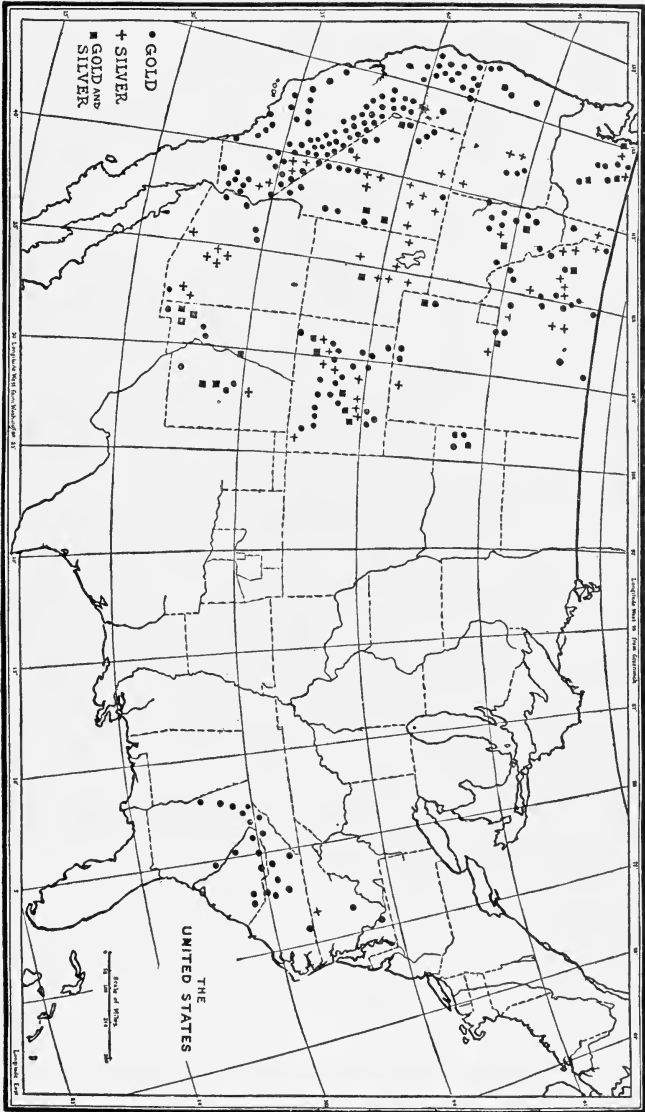
Fig. 215.—Distribution of Gold and Silver Mines (After Ransome)

in mountains that makes mining the most important industry there; this is also due to the fact that erosion has revealed the structure and deposits of the region, thus making the discovery of mineral deposits a simpler problem there than eleswhere. Mines are operated in young as well as old mountains.

2. *Water Power.*—The water power of mountain streams has long been utilized in cities along the fall line, and by the miner in western mountains, but only a small percentage of mountain streams can be thus utilized. The possibility of electric transmission of power has greatly increased the value of these streams, and the public interest in the "white coal," as water power is called, speaks for its rapid development. It is destined soon to become a second important industry in the mountain regions, and a great stimulus to our manufactures.

3. *Agriculture.*—The mountain slopes are obviously unsuited for agriculture; the soil is usually poor and its cultivation laborious. The grasses above the timber line, to be sure, furnish pasturage during the summer, and occasional less steep slopes allow the farmer to raise the necessary food; but his life is one of poverty and hardship until the coming of the summer visitor transforms him into a guide or a hotel keeper.

The valleys in mountain ranges are often fertile, and when well watered make valuable farms, but the farmer here is handicapped by the difficulties of transportation. He must haul his surplus products and his supplies over the mountain ridges which surround him.

4. *Irrigation.*—Although many mountain ranges cause arid regions on their leeward side, they also make it possible to restore fertility through irrigation. The United States Government is building many reservoirs in the mountain valleys of the West, where streams or canals may lead water from them to level regions during the growing season. Without these reservoirs most of the stream beds in the arid regions would be dry for most of the year.

5. *Timber Reserves.*—The growing scarcity of lumber has called attention to the fact that mountain slopes make excellent timber

reserves, and our Government has already set apart many square miles of them for this purpose. They are patrolled to prevent the destruction of growing timber by fires, and, properly guarded, will do much to supply the future generations with lumber.

Timber reserves act to some extent as do the reservoirs for irrigation, in that they conserve the rainfall and tend to make the streams more permanent.

The Geographic Cycle. —The major relief features of the land, such as continents, mountains, and plateaus, are acted upon by two sets of forces which in a way oppose each other. The *constructive forces* originate below the surface of the earth and depend upon the internal heat of the earth for their activity; and the *destructive forces*, or the agents of erosion, originate in the atmosphere and depend upon the heat of the sun for their activity.

The agents of erosion act upon all land that is above sea level, and only

FIG. 216.—IRRIGATION CENTERS OF THE WEST
The black portions show the land to be irrigated by the works the Government has built or is now building.

cease to act when the land disappears beneath the sea. Erosion is continuous in its action, whereas the constructive forces are irregular and often intermittent, causing the upbuilding to cease for a time. Although at the beginning the rate of upbuilding is much more rapid than that of erosion, the slower but continuous action of the destructive forces ultimately prevails. Every relief feature, therefore, has a *period of growth*, during which the constructive forces accomplish more work than the destructive

forces, and its *period of decline*, during which the agents of erosion prevail.

During the growing period the feature is said to be *young;* after erosion is well established and has developed so many hills and valleys that they become the chief characteristics of the region, it is said to be *mature;* finally, when both the constructive and the destructive forces have nearly ceased to act upon the region, it is said to be in its *old age.*

When land is first lifted from the sea the sedimentary strata are horizontal and the surface is a plain from which other physical features may be developed. The final condition of all physiographic features is a level surface, a peneplain, at or just below sea level. This is a return to the level surface from which the relief feature was formed; and *the time required for the upbuilding and destruction of a relief feature* is properly called a *geographic cycle.* The description of the various stages through which a relief feature passes constitutes the *life history of the land form.*

There is no positive evidence that any geographic cycle has ever been completed, but in many regions the constructive forces have remained inactive long enough for erosion to reduce the region to a peneplain before the activity of the constructive forces was resumed and a second geographic cycle begun. That the Appalachian Mountains were worn down to a peneplain and then uplifted is proved by the facts that many anticlinal ridges have disappeared and that in their places are many ridges with nearly level tops. Where erosion has once made a surface uneven, the only way in which it may again become level is by reduction to a peneplain. When a second cycle is established in such a region, the rivers begin their work with graded beds and quickly cut young valleys in them, thus recording the evidence of a second cycle. A cycle may be lengthened by elevation of the region, or shortened by depression, and the interruption may occur at any stage.

The length of a geographic cycle varies greatly in the case of the different features. Our great mountain ranges and plateaus have changed so slightly during historic time that it is evident that tens or even hundreds of thousands of years may be required

to complete their cycle. At the other extreme are the volcanic islands which sometimes have been raised from the ocean in a few days, only to disappear again beneath the sea in a short time.

It is obvious that in a given case the length of the cycle depends upon: (*a*) the total uplift; (*b*) the energy and the character of the eroding agents; and (*c*) the resistance of the rocks. The total uplift is not the "initial uplift" sometimes mentioned in this connection, because land forms are not made by a single effort, but grow gradually through many small uplifts. It is greater than the greatest height of the land form, because erosion is active during the period of growth. The energy of the agents of erosion depends upon the slope of the streams, the amount of precipitation, the strength of the winds and the variability of the temperature; or briefly upon steepness of the region and its climate. The resistance of the rocks to erosion depends upon the physical properties of the rock, such as brittleness, porosity and hardness, upon the chemical composition, upon the strength of the cement which consolidated the rock, and upon the structure. With so many variable factors there must naturally be great variation in the length of the cycles.

QUESTIONS

1. Why is "Rocky Mountains" a more correct term than the name "Stony Mountains," first given them? What is a stone?

2. Show how a syncline may become a hill.

3. In Fig. 205 a wedge-shaped block has dropped down. Does this indicate that the force that formed the faults on either side of it was a thrust (compressing the rock) or a pull (stretching)?

4. What kinds of rock form the summits of the ridges shown in Fig. 210 (Appalachian Mountains)? Why?

5. What do you think would have been the effect upon the settlement of the United States if a continuous mountain range of great height had been where the Appalachians now are?

6. Can you account for the presence of Arctic plants on the tops of isolated high mountains near the tropics?

7. Why is the western slope of the Sierra Nevada Range forest covered, whereas the eastern slope resembles the Great Basin in barrenness?

8. Mention several conditions which would tend to make the geographic cycle exceptionally long.

CHAPTER XXVI

VOLCANOES AND EARTHQUAKES

Volcanoes have long been objects of interest to students of history and mythology, and much has been written of the Mediterranean group even by early Greek and Latin authors. This same region is also classic ground from a physiographic standpoint, because of the careful scientific study that has been made here of the phenomena of an eruption.

Definitions.—A volcano is an opening in the earth through which *lava* and other heated materials are ejected. Some of the ejected materials pile up around the opening and form a *cone* of greater or less steepness, as the material forming it is coarse or fine, liquid or solid. In the top of the cone there is usually a cup-shaped depression called a *crater*.

Causes of Volcanic Action.—Some geologists maintain that the heat comes from the interior of the earth; others that it is produced near the surface by chemical or mechanical means. A later theory of the origin of the heat maintains that it is due to the action of radio-active substances like radium, which are known to be present in lavas. Whatever the origin of the heat, the fact remains that volcanoes are associated with young and growing mountains, and this suggests some relation between the uplifting forces and the origin of the heat.

The force which causes explosive eruptions is undoubtedly steam pressure. All lavas contain water in greater or less quantity, and when they are deep down in the earth the pressure keeps the water in the liquid state; but as the lava ascends, the pressure diminishes, until at last the water suddenly becomes steam. If the lava is very fluid, the steam rises quietly, unless it is confined, and oozing eruptions are likely to result. If the lava is confined

by any means, the pressure increases as more and more water changes to steam, and finally the covering rock bursts, just as a steam boiler does when the pressure becomes too great.

Phenomena of Eruptions.—From the following examples it will be seen that the phenomena of an ordinary explosive eruption
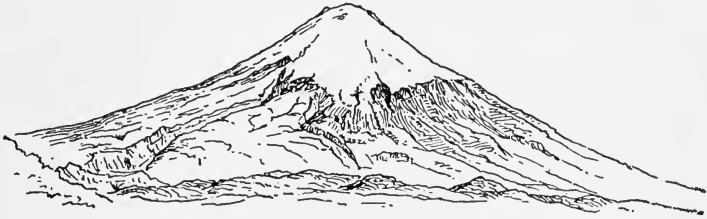
FIG. 217.—COTOPAXI, ECUADOR. SYMMETRICAL CONE (STÜBEL)

occur about as follows: A mighty *explosion* blows off the top of the cone, shatters the hardened lava, and sends *steam*, mingled with dust and ashes, high into the air, where it spreads out as a peculiar " cauliflower cloud." The falling *stones and ashes* destroy vegetation and may even bury whole cities. The rising steam, cooled by expansion and by mingling with the cold upper air, is condensed and falls as *rain*, accompanied by *lightning*. The rain brings down dust and ashes, and all together form immense *mud torrents*, capable of burying cities, as for example Herculaneum.

In volcanoes of the type of Vesuvius, after the explosion the liquid lava rises in the crater until it either overflows or, more frequently, until by its great pressure it rends the mountain and a *lava flow* escapes through the fissure thus formed. At first the
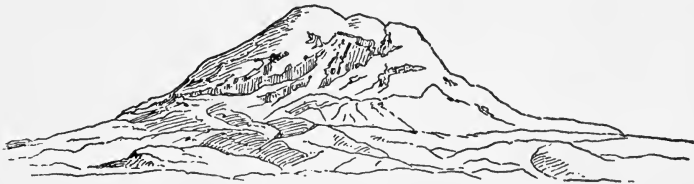
FIG. 218.—CHIMBORAZO. DOMELIKE CONE (STÜBEL)

lava may flow rapidly, but it gradually cools, hardens, slackens in speed, and finally stops.

Columnar Structure.—The lava that cools and slowly solidifies under great pressure contracts more or less symmetrically around a central core, breaking into columns. This characteristic *colum-*

FIG. 219.—RUMINAHUI, WITH GREAT SIDE CRATER (STÜBEL)

nar structure is exemplified in the Palisades of the Hudson, in Fingall's Cave, Giant's Causeway, and at Regla.

History of the Cone.—A volcanic cone, like all land forms, passes through a cycle of growth and decline, and we easily recognize the stages of youth, maturity and old age.

In *youth*, the cone retains its symmetry unobscured by erosion. It is little dissected, though it may be scarred by stream and glacial valleys, as Mount Shasta in northern California.

In *maturity*, the destructive forces of erosion have reduced the cone to an unsymmetrical and dissected mass.

In *old age*, erosion has so destroyed the cone that only the core of the volcano remains. The volcanic ash and cinders have been for the most part removed and there remains, standing out prominently, the *plug* of hardened lava that once filled the vent. This plug, known as a *volcanic neck*, is the last remnant of the cone

FIG. 220.—PULULAGUA, ECUADOR. CALDERA, WITH INNER CONE (STÜBEL)
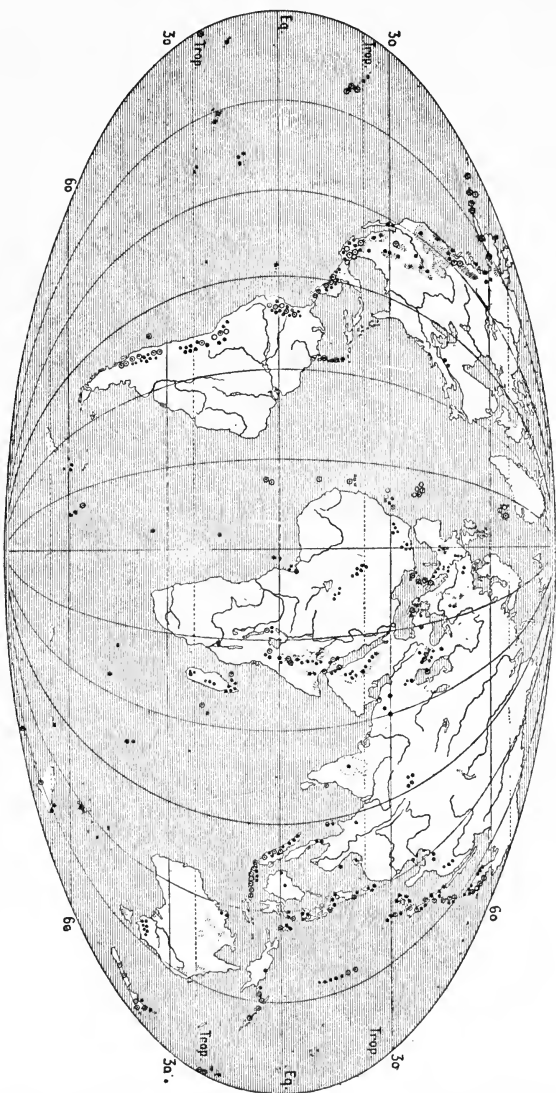
Fig. 221.—Distribution of Volcanoes. ⊙active. ○dormant. ●extinct.
From Martoune's Géographie Physique, Librarie Armand Colin, Paris.

to disappear. Mount Royal, which gives its name to Montreal, is an example of a volcanic neck.

Distribution of Volcanoes.—Active volcanoes are found *where the crust is weakest*, that is in or near the sea and in young and growing mountains. Most volcanoes lie in one of two belts. The best marked belt surrounds the Pacific Ocean. The other belt is an irregular one, passing through the Hawaiian Islands, the Mediterranean Sea region, and intersecting the first belt in the East Indies and in the West Indies.

Products of Volcanic Eruptions.—At the instant that they are ejected, nearly all of the products are in either the liquid or the gaseous state, the only exception being the rock fragments torn from the sides of the crater or blown from the overlying rocks. With the cooling of the products the steam condenses to water and only the sulphur dioxide, carbon dioxide, hydrogen sulphide,

FIG. 222.—COLUMNAR STRUCTURE OF COOLED LAVAS
Regla, Mexico. (Kindness of Prof. J. F. Kemp.)

chlorine and related substances remain as gases. Lava that is free from bubbles of gas and solidifies quickly forms *obsidian.*

When the lava is projected high into the air and solidifies before reaching the earth, it may be so filled with bubbles of the expanding gases contained in it that it becomes frothy or spongy and is called *pumice.*

If the ejected materials cool before falling to the ground, they are known by various names, depending upon the size of the particles: volcanic dust, ashes, lapilli, and bombs. Materials of all sizes up to " the size of an ox " are ejected. Volcanic bombs, if their contained gases have expanded them, as does bread in baking, are called bread cake bombs.

Economic Products.—A Scotch firm purchased the cone of Vulcano, a small Mediterranean volcano, because of the alum, boracic acid, and sulphur that could be obtained from it.

Pumice, sulphur, and *borax* are important volcanic products.

Trap rock was used to pave the streets of Rome and the famous Appian Way; similar blocks from old volcanoes in Germany are floated down the Rhine to face the dykes of Holland; and from the Palisades comes much of the material to pave the streets and parks of New York City. Volcanic dust and ashes when consolidated form *tuff,* a soft stone easy to work in the quarry, but hardening in air and becoming a very durable building stone, much used in Naples and Rome. Some of the oldest sewers in Rome, built of tuff 2,500 years ago, are still in good condition.

Volcanic dust and ashes exposed to plentiful rainfall rapidly weather and form a very fertile *soil.* Some of the finest orchards of New Jersey, some of the best farms of Oregon, and some of the most fruitful vineyards of Germany are on soils of volcanic origin.
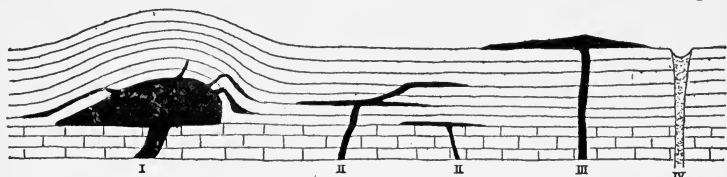
FIG. 223.—I, LACCOLITE. II, INTRUSIONS WITH DIKES. III, EXTRUSION WITH DIKE. IV, VENT FOR ASHES, ETC. (PENCK)

Stromboli.—An irregular cone of volcanic material rises from the floor of the Mediterranean some 36 miles north of Sicily, to a height of about 6,000 feet, one-half of which is above sea level. For more than 2,000 years this volcano has been in a state of mild activity, emitting clouds of steam and showers of stones, and at night illuminating the cloud, which usually hangs over it, with flashes of light. This "Lighthouse of the Mediterranean" has guided sailors for centuries. Light, curling columns of steam rise from fissures in the crater at all times. At intervals, without the slightest warning, a sound is heard "like that produced when a locomotive blows off steam," and a great volume of watery vapor, carrying many small masses of lava, is thrown violently into the air. The lava bombs are often in a semi-molten condition when they fall to the earth. Such outbursts occur at frequent intervals, and are due to the escape of great bubbles of steam through the chilled and tenacious surface of the molten lava that fills the cracks.

Etna.—The giant cone of Etna was known to the Romans as the " Forge of Vulcan." It is two miles high and about forty miles in diameter at its base. There are some 200 minor cones on its slopes. Its eruptions are preceded by earthquakes and loud explosions. Smoke, ashes, and cinders are discharged, and finally lava flows from the new cone formed. The large proportion of lava accounts for the gentle slope of the cone of Etna.

Vesuvius.—The ancients knew Vesuvius as a mountain rather than as a volcano. At the beginning of the Christian era its crater, then about three miles in diameter, was covered with vegetation. Its slopes were cultivated and towns were located at its base; and there was no record of previous volcanic activity of the mountain.

During the summer of the year 79 A.D., a series of earthquakes of increasing severity occurred, and a new and strange cloud formed above its summit. Explosion after explosion occurred within the mountain and the black cloud spread, shutting out the light of the sun. Tacitus gives us two letters from the younger Pliny, who was an eyewitness of this eruption. One of these letters describes the experiences of his uncle, the elder Pliny, who lost his

life near the foot of Vesuvius during an eruption. It seems that his party sought shelter from the shower of cinders and stones in a villa which " shook from side to side " from frequent earthquakes. When the accumulation of stones and ashes made it
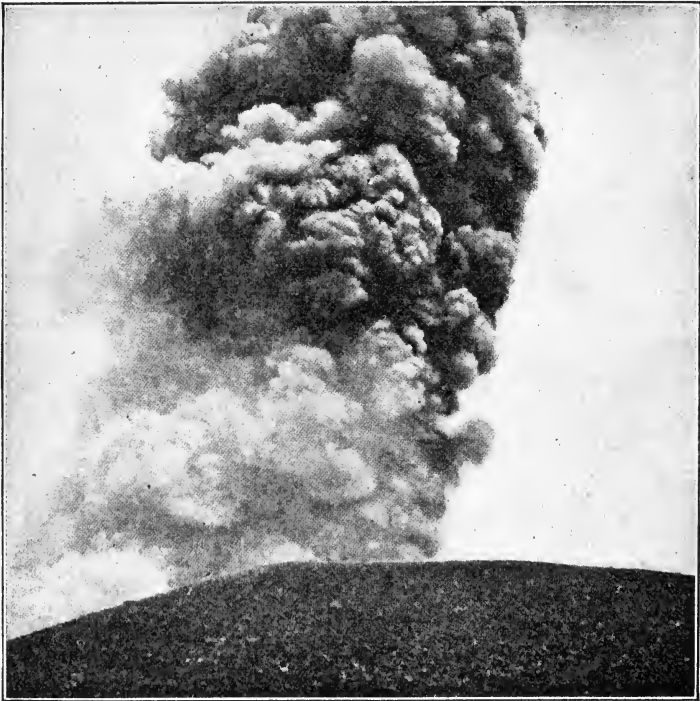
Fig. 224.—Explosive Eruption of Vesuvius in 1900
Steam with ashes, cinders, and bombs. (Matteucci.)

apparent that the villa would be buried, the party took to the fields, " with pillows tied about their heads with napkins " to protect them from the falling stones.

The second letter relates the younger Pliny's experiences at Misenum, across the Bay of Naples from Vesuvius. He describes chariots standing on level ground without horses, which would not stand still even when the wheels were blocked with great

stones, but "kept running backward and forward" with each
earthquake; and says, " Besides this, we saw the sea sucked
down and, as it were, driven back again by the earthquake."
Across the bay above Vesuvius " was a dark and dreadful cloud,
which was broken by zigzag and rapidly vibrating flashes of fire,
and, yawning, showed long shapes of flame. These were like light-
nings, only of greater extent. . . . Soon the cloud began to de-
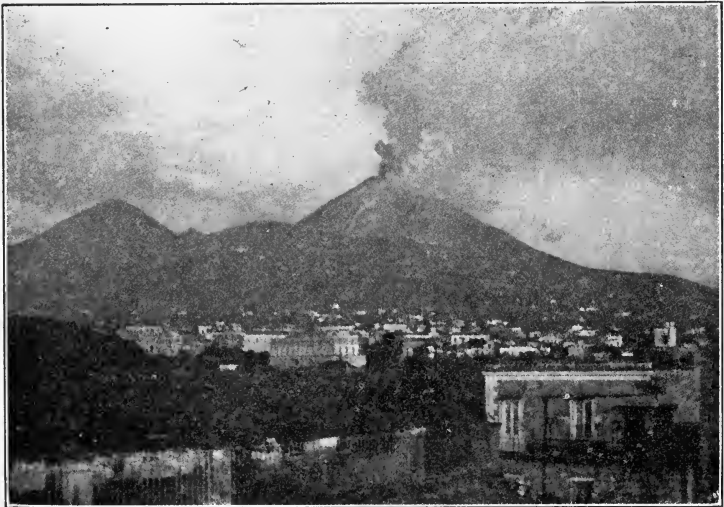
FIG. 225.—ERUPTION OF VESUVIUS IN APRIL, 1906
As seen from Portici.

scend over the earth and cover the sea. . . . Ashes now fell, yet
still in small amount. I looked back. A thick mist was close at
our heels, which followed us, spreading over the country like an
inundation. . . . Hardly had we sat down when night was upon
us—not such a night as when there is no moon and clouds cover
the sky, but such darkness as one finds in close-shut rooms. . . .
Little by little it grew light again. We did not think it the light
of day, but proof that fire was coming nearer. It was indeed
fire, but it stopped afar off; and again a rain of ashes, abundant
and heavy; and again we rose and shook them off, else we had

been covered and even crushed by the weight. . . . Soon the real daylight appeared; the sun shone out, of a lurid hue, to be sure, as in an eclipse. The whole world which met our frightened eyes was transformed. It was covered with ashes white as snow."

No lava flow accompanied this eruption, but the enormous quantity of ash buried Pompeii and, mixed with rain, formed a mud stream which overwhelmed Herculaneum. There have been frequent eruptions of Vesuvius since this one, those of 1631 and
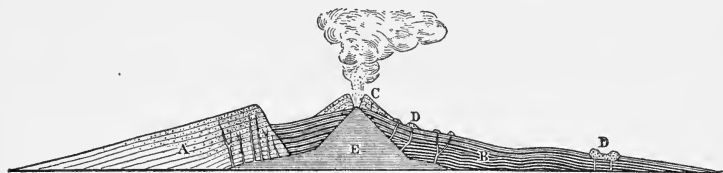
FIG. 226.—IDEALIZED PROFILE OF VESUVIUS
A, prehistoric ashes of Monte Somma; B, lava flows of Vesuvius; C, ash cone of Vesuvius; D, parasitic cones; E, molten lava of interior. (Penck.)

1906 being especially destructive. In these later eruptions the explosive action has been followed by lava flows.

The eruptions of Vesuvius are unlike the mild, continuous action at Stromboli, and consist of paroxysms of great violence separated by long intervals of quiet. During these intervals of rest the volcano is said to be *dormant*.

Mont Pelée.—An eruption of this volcano on May 8, 1902, destroyed the city of St. Pierre on the island of Martinique, one of the Lesser Antilles. Previous to this date it had been dormant for fifty years, but for days before the eruption it had shown signs of activity. Great columns of steam and ash were ejected, boiling mud flowed from the sides of the volcano, and repeated explosions occurred in its interior. Lightning flashed from the ascending cloud, and the frequent earthquakes broke all ocean cables leading to the island.

On the morning of May 8th, a dull red reflection was seen on the trade-wind cloud that covered the mountain summit. This became brighter and brighter, and soon red-hot stones were ejected from the crater and bowled down the mountain sides,

giving off glowing sparks. Suddenly a hot blast of gases shot from the crater, and two minutes later engulfed the city of St. Pierre, five miles distant, in an atmosphere that was fatal to all who breathed it. It wiped out all vegetation and every living creature in its path. Buildings of the city and ships in the harbor instantly burst into flames; 30,000 persons lost their lives. There was no lava flow, but the lava in the throat solidified and was forced upward by the pressure from below until it stood 1,200 feet above the crater at its maximum.

Krakatoa.—In 1883 the most violent explosive eruption of historic times occurred on the East Indian island of Krakatoa. The island was some five miles long and three miles wide, with an altitude of 2,623 feet at its highest point.

Nearly the whole of the lower part of the island and half of the highest peak were blown away. Dust was thrown into the air to a height of about twenty miles, and was carried several times around the earth. Beautiful sunrise and sunset effects were caused for many months by this dust. The concussion of the explosion broke windows in Batavia, 100 miles away, and the report was heard 2,267 miles. A mighty wave flooded the surrounding coasts to a depth of fifty feet, stranding ocean steamers, causing great loss of property, and drowning more than 36,000 people. For many weeks navigation was impeded by floating pumice that covered the surface of the sea.

Hawaiian Islands.—Hawaii is one of a group of islands in which are many volcanoes, and which in the main owe their existence to eruptions at the bottom of the ocean. This island is 80 miles long, and rises 30,000 feet above the ocean floor. There are four craters on the island, of which Mauna Loa is the highest. The eruptions of the volcanoes in the Hawaiian Islands are in sharp contrast with that of the island of Krakatoa. In these *oozing eruptions* there are no explosions, no showers of dust or ash, and no great volume of steam is ejected, and earthquakes are rare. The lava flows sometimes continue for months, whereas eruptions of the explosive type last but a few days. Before an eruption the lava rises quietly in the crater until the great pressure fissures the side

of the mountain, when a river of molten rock flows to the sea. The slopes of the volcano subject to oozing eruptions are very gentle, but this must not be understood to mean that the cone is small. Mauna Loa is many times as large as Vesuvius, and its crater is a typical *caldera*, nearly three miles long, two miles wide, and 1,000 feet deep. Icelandic volcanoes are of this type. Caldera
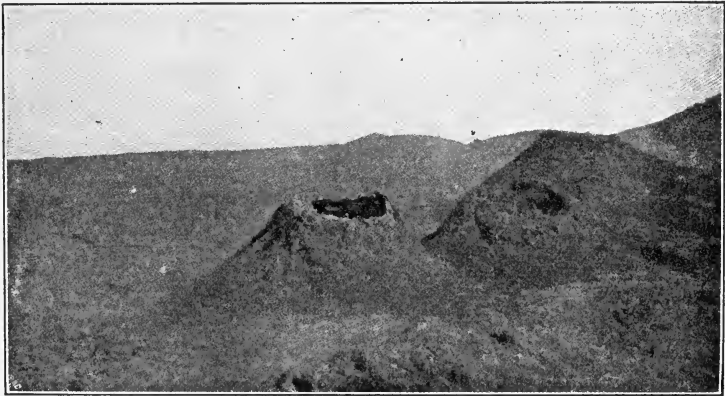
FIG. 227.—CINDER BUTTES IN IDAHO (PENCK)

is a Spanish word meaning caldron. The term is applied to large craters believed to have been formed by the sinking of the top of a volcanic mountain.

Volcanoes of North America.—Active volcanoes are numerous in Central America and Mexico, and some of the Alaskan volcanoes have been in eruption within a few years; but we have no reliable description of an eruption within the limits of the United States proper. There are, however, many evidences of former great volcanic activity.

San Francisco Mountain.—This mountain in Arizona is much eroded and no signs of a crater remain, but it is surrounded by lava flows and beds of cinders, and several hundred cinder cones, formed by volcanic eruptions, are found in the immediate vicinity. Some of these cones were formed so recently that erosion has not modified the original form of the cone. (Fig. 227.)

Mount Taylor.—On one of the large mesas of western New Mexico, Mount Taylor, rises to an altitude of 11,000 feet. The mountain is almost entirely composed of lava, and the mesa is covered by a cap of lava. This cone is also much eroded, and in the lowland about the mesa are many volcanic *necks*, each one a mass of lava which cooled in the throat of a volcano that has disappeared.

Mount Shasta.—This extinct volcano of northern California is in some respects like Etna. It towers 11,000 feet above a base seventeen miles in diameter, is snow clad even in summer, and its eruptions were explosive, followed by great lava flows. There are two great craters, the younger being near the top of one side of the older cone. Some twenty smaller cones are found near the base of the mountain, and from one of these a lava flow may be followed more than fifty miles. The cone is much dissected by glaciers and streams, but is still in its youth.

Mount Hood, on the crest of the Cascade Range in Oregon, is noted for its graceful outlines and for the *fumaroles* and steaming rifts which still emit sulphurous fumes and indicate comparatively recent activity, although there has been no eruption within the memory of man.

Mount Rainier.—This stately cone rises from near sea level to an altitude of 14,500 feet, and so appears much higher than most of those that reach a greater altitude. It has a bowl-shaped crater, below which on the sides of the mountain the rims of former craters may be seen. Jets of steam and gas still issue from small holes in its snow-clad summit, showing that its heat has not entirely disappeared.

Other Indications of Volcanic Activity.—The Columbian lava plateau covers a large part of Washington, Oregon, and Idaho with successive layers of lava, which in places reach a total thickness of 5,000 feet. The section of this plateau suggests stratified rock, but each layer represents a distinct flow of lava, and is sometimes separated from the next by layers of soil in which the roots and trunks of large trees are preserved. This proves that a long interval of time elapsed between the flows. Because of the
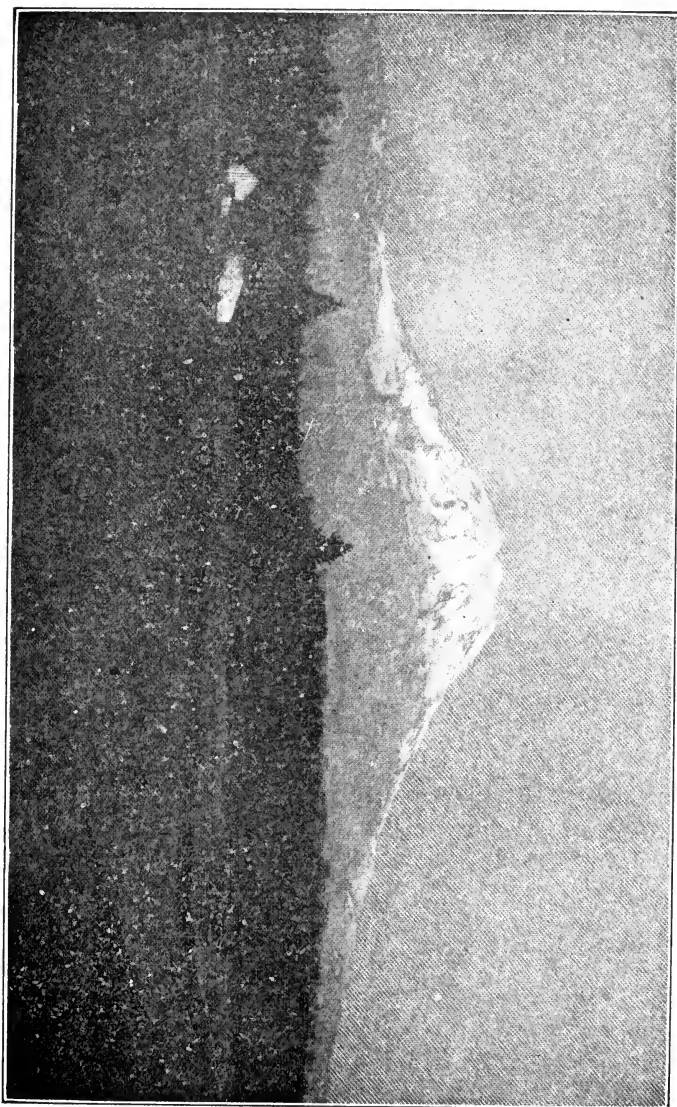
FIG. 228.—MOUNT RAINIER, NEAR TACOMA, WASHINGTON
A dormant, dome-shaped volcanic cone.

absence of cones in this region, it is thought that the lava came through fissures. The surface is covered with residual soil of great fertility. This plateau is cut by many deep cañons in which the structure of the plateau is shown.

There are few indications of volcanic activity east of the Rocky Mountains. Erosion has destroyed such volcanic cones as may have existed, but it has exposed numerous *sheets* of lava which were intruded between the layers of sedimentary rocks. The Palisades of the Hudson, the lava sheets of the Connecticut Valley, and the Watchung Mountains of New Jersey are examples of such sheets.

EARTHQUAKES

Definition.—The lithosphere is constantly in a state of tremor. Sometimes the vibrations are so slight as to pass unnoticed except as recorded by the most sensitive instruments, and at other times so violent as to destroy whole cities. Some of the tremors are due to human activities, such as the movement of railway trains or the explosion of dynamite; others are due to natural causes.

The vibrations travel through the lithosphere and may be detected at greater or less distances from their source, as the violence of the shock which causes them is greater or less.

An earthquake is a tremor of a part of the lithosphere produced by natural causes.

The Ischian Earthquake.—On July 24, 1883, the island of Ischia, near Naples, Italy, was shaken by an earthquake which was not preceded by warning shocks, and which lasted but 15 seconds. Violent detonations accompanied the tremors, 1,200 houses were destroyed, 2,300 persons were killed, fissures were opened, and landslips occurred. Survivors tell us that the whole town seemed " to jump into the air " and fall in ruins.

On this island is the great crater of Epomeo, which was in eruption in 1302, after at least 1,000 years of slumber. No eruption of Epomeo accompanied this earthquake, but it is believed that the underground explosions which caused the earthquake were of volcanic origin and indicate future activity of Epomeo.

The Charleston Earthquake.—During the last week of August, 1886, slight earthquake shocks occurred at intervals at Charleston, S. C. Their violence gradually increased, and culminated at 10 P.M. on August 31, in one of the great earthquakes of the last century. There was first noticed a distant rumble, which increased in intensity as though an enormous railway train was approaching through a tunnel passing beneath the city. As this rumble became a roar the ground seemed to rise and fall in visible waves. The disturbance lasted about 70 seconds and was repeated with equal violence eight minutes later.

During these tremors men could not stand, chimneys were thrown down, and every building in the city was damaged. Great cracks were opened in the earth and both underground and surface drainage were disturbed; railroad tracks were twisted and bent, and 27 persons were killed. The shock was felt as far north as Canada.

This earthquake is notable for the information concerning earthquakes derived from the study of its phenomena. The location of the origin of the disturbance was determined, and the velocity with which the earthquake wave traveled in this case was shown to be 150 miles per minute.

The earthquake was succeeded by several less severe shocks during the night, and slight shocks were observed in the region for several months.

The San Francisco Earthquake.—About 5 A.M., April 18, 1906, an earthquake occurred on the California coast which lasted 67 seconds. During this short interval many buildings in San Francisco were wrecked and the water supply was cut off, so that the fire which followed destroyed a large part of the city. Figs. 230 and 231. Many landslides occurred at the same instant in the mountains of the district affected, cracks were opened in the earth, and some regions settled several feet.

The earthquake was due to slipping along an old fault plane, which has been traced nearly 400 miles. Fig. 229. The average vertical displacement was slight, but the horizontal displacement was in places as much as 20 feet.

The Messina Earthquake.—At 5.23 A.M., December 28, 1908, the region about the Strait of Messina, in Southern Italy, experienced one of the most disastrous earthquakes in the history of the world. The cities of Messina and Reggio were reduced to a shapeless mass of ruins, several smaller towns were more or less

FIG. 229.—THE FAULT TRACE. SAN FRANCISCO EARTHQUAKE

damaged, and upwards of 200,000 persons were instantly killed or imprisoned in the ruins, so that rescue was impossible.

The ground seems to have been suddenly raised and then dropped, causing the buildings to collapse; great fissures opened; the wharf sank to the level of the sea, and a sea wave from six to ten feet high swept over the lower portions of the region.

The earthquake was preceded by several slight shocks, and the *seismic* activity continued for several weeks.

Extensive breaking of telegraph cables in the vicinity indicates a submarine disturbance, and the center of the disturbance was a

FIG. 230.—RUIN OF THE $7,000,000 CITY HALL BY THE SAN FRANCISCO EARTHQUAKE AND FIRE

FIG. 231.—MISSION STREET, SAN FRANCISCO, AFTER THE EARTHQUAKE

line through the Strait of Messina. These two facts make it probable that the earthquake was due to slipping along the old fault plane which runs through the Strait. This fault plane has probably been the seat of many earthquakes. The total vertical displacement of one side of this old fault is known to be several thousand feet.

Distribution of Earthquakes.—No portion of the earth is entirely free from earthquakes, although most of them occur either in the vicinity of active volcanoes or near growing mountains.

It will be observed that the borders of the Pacific Ocean are particularly subject to earthquakes, and that a belt of seismic activity crosses Eurasia, beginning at Gibraltar and following the general direction of the Mediterranean Sea.

There have been in recent times relatively few earthquakes among the older mountains which border our eastern coast. Professor Shaler has called attention to the fact that in New England there can have been no violent earthquake since glacial times, for such an earthquake would have displaced the numerous balanced rocks to be found there.

Cause of Earthquakes.—All great earthquakes are vibrations established by *the sudden yielding of the earth's crust (the lithosphere) to the stresses set up within it by lateral pressure.* Such earthquakes are steps in the natural process by which our plateaus and mountains have been uplifted. All of the earthquakes described above, except the Ischian, were of this class. In some instances the strains due to lateral pressure are relieved by fracture of the lithosphere, which is accompanied by faulting, and at others by lateral displacement of one side of the fissure, without faulting. In some instances the strains are relieved by slipping along an old fault plane.

Many earthquakes are caused by *explosions which accompany volcanic eruptions.* The Ischian earthquake was probably of this type, and like others of its class was a minor disaster.

Any natural phenomenon which results in a heavy blow to the lithosphere might throw a portion of it into a vibration which
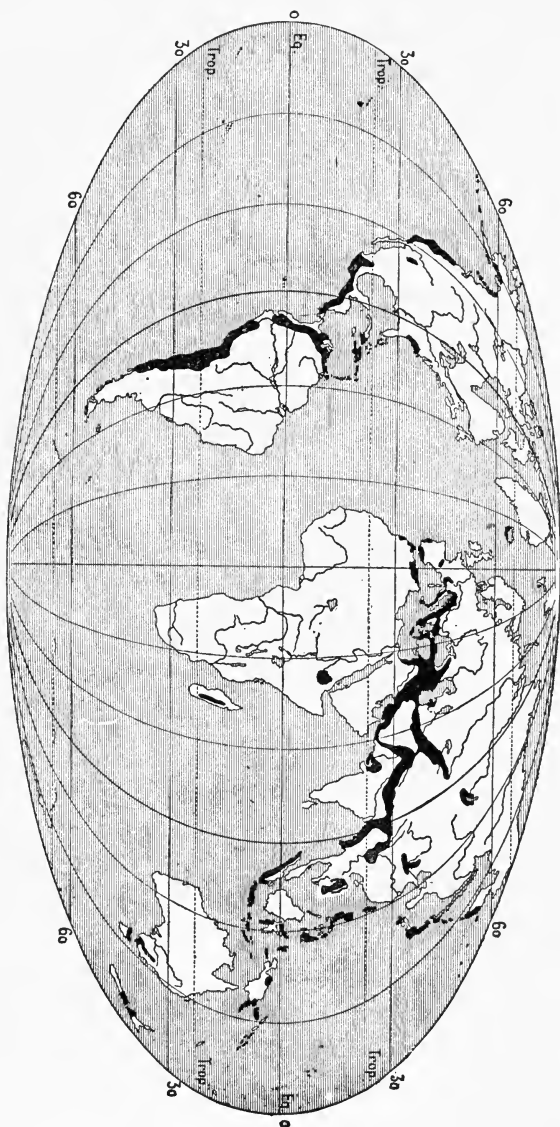
FIG. 232.—EARTHQUAKE REGIONS
After Montessus de Ballore, Tremblements de Terre, Librarie Armand Colin, Paris

would be classed as an earthquake, if the action occurred below the surface. Slight tremors may have been caused by great landslides, by the fall of the roof of a large cave, or by similar accidents.

Sea Waves.—When an earthquake occurs near the sea, great sea waves often increase the disaster. The water at first recedes from the land, sometimes leaving vessels stranded on the exposed sea bottom; this is followed by the advance of a great wave, which has in some instances swept the vessels over the tops of houses and has stranded them far inland. In the earthquake at Lisbon, Portugal, in 1755, some 30,000 people who had sought safety on the wharves were drowned by the sea wave. These waves have been called " tidal waves," an obvious misnomer.

QUESTIONS

1. Criticise the definition "A volcano is a burning mountain, belching forth fire, smoke and lava."

2. How can people near a volcano tell that an eruption is probably about to take place?

3. Contrast eruptions of Vesuvius, Pelée, and Hawaiian volcanoes.

4. Give, in their natural sequence, the phenomena of an ordinary explosive eruption.

5. State and account for the distribution of volcanoes.

6. Which is the most valuable volcanic product? Why?

7. What quakings of the earth are not properly called earthquakes? Why?

8. Contrast the two great classes of earthquake phenomena.

9. Define *seismic* and *seismograph*.

10. State and account for the general distribution of earthquake regions.

11. Why, after an earthquake near the seashore, does the water first recede?

12. Where would there be more danger of earthquakes—along a mountainous, or along a coastal plain shore? Why?

CHAPTER XXVII

SHORE LINES AND HARBORS

Definitions.—The *shore line* is the line along which land and water meet. The *shore* is the margin of land next to any large body of water, whereas the *coast* is the margin of land next to the sea. The *beach* is that portion of the shore that lies between high and low water levels. The *continental shelf* is the submerged portion of the continental mass adjoining the shore and extending seawards with gentle slopes. The depth of about 600 feet is generally taken as the outer limit of the shelf.

Migration of Shore Lines.—The fossil remains of sea shells and the character and arrangement of the rocks of the Atlantic Coastal Plain in the southeastern part of the United States indicate that in comparatively recent geologic time this plain was a continental shelf, and that the shore line of the Atlantic was near the inner border of the plain. This is shown in No. 1 of Fig. 233.

The deep channels across the continental shelf opposite the mouths of the Hudson and other rivers indicate that what is now continental shelf was once a coastal plain, with its shore line near the outer border of the present continental shelf. This is shown in No. 2 of Fig. 233.

Next the coastal plain was again almost entirely submerged, as is shown in No. 3 of Fig. 233.

At present the shore line is between the two. No. 4, Fig. 233.

These facts prove that the shore line has changed its position. Many other examples of migrations of shore lines could be given, to show that there have been in various parts of the world great *transgressions* of the sea over what had been dry land, and many exposures of sea bottom, changing it to land.

Explanations of Migrations.—The cause of the migration of shore lines is probably the cooling and contracting of the crust of the earth; the resulting folds and breaks in the crust produce great blocks, the rising or sinking of which disturb the relative levels of sea and land. There are two explanations of how this disturbance is brought about. According to one explanation, the *land* rises and sinks with reference to an *unchanging sea level*. The other explanation, without excluding minor and local risings and sinkings of the coast, emphasizes the idea of a *changing sea level*. Thus a settling of a great portion of the bed of an ocean would withdraw the sea from its shores without any real rise of the land with reference to the center of the earth, although there might be an apparent rise of the land. On the other hand, great deposits of sediment in the sea, or the uplift of a portion of the bed of the sea, would cause the sea to overflow its borders without any sinking of the land.

Classes of Shore Lines.—As the result of migrations, there are two great classes of shore lines—*regular* and *irregular*.

The surface of the land is characteristically irregular; hence, when the sea is made to cover a portion of the land, causing the shore line to migrate landward, the shore line is *irregular*. Such shore lines are found along the northeastern and the northwestern coasts of North America.

The ocean floor is characteristically smooth as the result of long-continued deposition and of slowly moving water; hence, when the shore line migrates seaward, exposing smooth land, a *regular* shore line is formed. The western coast of the United States is an example.

Waves, currents, and tides corrade weak rocks and sometimes make a shore line temporarily irregular; but they ultimately make the shore line regular by wearing away projecting portions of the coast, by filling bays, and by building sand reefs off shore.

At many places between Long Island and the Rio Grande, shore line migration has resulted in an *inner irregular* shore line along the mainland, in front of which the waves have built sand reefs forming an *outer regular* shore line facing the sea.

FIG. 233.—SHORE LINE MIGRATIONS IN SOUTHEASTERN UNITED STATES
No. 1. Shore line at inner border of coastal plain.
No. 2. Shore line next at outer border of continental shelf.
No. 3. Shore line again near inner border of coastal plain.
No. 4. Shore line at present. An. Rept. U. S. Geol. Survey, Vol. XI.

Regular Shore Lines.—Where the shore line migrates seaward over a wide continental shelf, a coastal *plain* is formed with a regular shore line. Shallow water extends so far from shore that vessels run aground before danger is suspected. The islands are low sand reefs, built parallel to the shore by the waves, currents, and tides. Openings through the reefs are numerous where the tides are high. A few shallow harbors supply a *hinterland* devoted to agriculture, as in the southeastern States along the Atlantic and the Gulf of Mexico.

Where the shore line migrates seaward, as the result of the rise of a *mountain* range, the shore line is generally regular. The coast is exposed to wave action and tends to become precipitous, with harbors few and unprotected. The western coast of the United States, Peru, and northern Chili are examples.

Africa and India are *plateaus*, with shore lines that have remained regular since they were shaped by the great faults in the earth's crust that permitted bordering regions to sink under the sea.

Kinds of Irregular Shore Lines.—When the shore line migrates landwards, so many bays are formed that the coast is called an *embayed* coast. An embayed *mountain* region differs so much from an embayed coastal *plain* that it is convenient to consider them separately.

Pacific Type of Coast.—Ranges of *mountains parallel the shores* of the Pacific Ocean. From northwestern United States southward to central Chili the coast is regular, except for a few passages through the coast ranges into rather *long bays paralleling* the coast, San Francisco Bay and Puget Sound, for example. But in higher latitudes the shore line is irregular; this is, because along the northwest coast of North America and the southwest coast of South America the encroachment of the sea has changed some ranges of mountains into chains of high, *rocky islands paralleling the mainland*, and separated from it by tortuous inner passages. The eastern coast of Asia has wide *bordering seas*, separated from the Pacific Ocean by great *festoons of islands* paralleling the mainland.

Ria Coast or Atlantic Type.—In northwestern Spain, in Nova Scotia and in Maine, the mountain ranges, instead of being parallel to the sea, advance to meet it at an angle and at the shore end abruptly, as if broken off. This enables the sea to enter the mountain valleys and to form long bays that merge into rivers. Such bays are called *rias*.

The Fiord Coast.—This is found in glaciated regions, such as Norway and Labrador, where glaciers have modified the valleys.
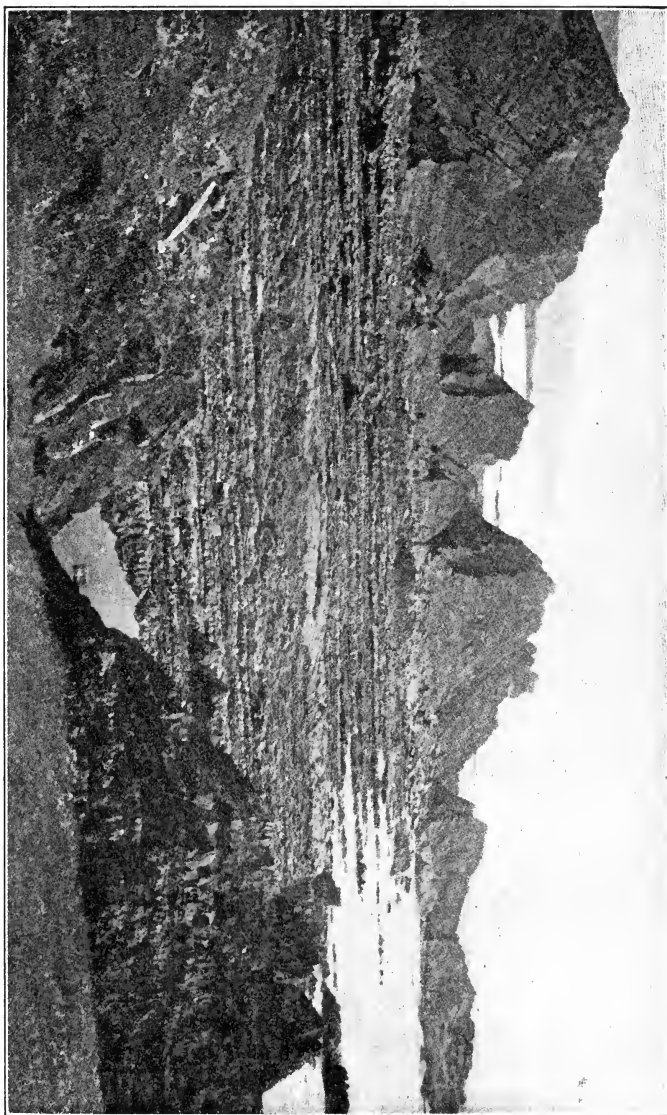
Fig. 234.—A Typical Irregular Rocky Shore Line
Rocky beach with cliffs, Hartland Quay in Devonshire (Penck).

Fiords are long, narrow, deep bays, with high precipitous sides, that were occupied by ice long enough for the glaciers to change the V-shaped valleys to U-shaped. Although the Maine coast has been called a fiord coast, its bays lack the length, depth, and high sides of the true fiord.

Economic Importance.—The value of an embayed mountain region depends in part upon the products, the climate, and the accessibility of the mountainous hinterland; and in part upon the products of the sea. The harbors are good, and fishing and commerce thrive. The people are seafaring, self-reliant, and hardy.

Embayed Coastal Plains.—When a shore line migrates landward, covering a coastal plain, stream valleys are drowned and become bays. Such an embayed coastal plain will have a more or less irregular shore line as the valleys were more or less numerous. As time elapses, sand reefs with regular outer shore lines may border the region. The currents along shore move the sand with them, extending capes in the direction of motion and reducing the capes facing the currents. Note the length of Cape May peninsula and the shortness of Cape Henlopen.

Economic Importance.—Embayed coastal plains combine with the advantages of coastal plains the additional advantages of numerous harbors and of greater accessibility from the sea. This accessibility made it easy for the colonists to settle Virginia and to market their heavy crops of tobacco, and has made Baltimore an important port.

The Dutch have built great dikes around large tracts of land covered with rather shallow water, and have by means of windmills pumped the water off, leaving *polders*. A large portion of the Zuyder Zee is being so reclaimed at great expense. Much tidal marsh land in and near New York City has been filled in, but thousands of acres more will be reclaimed.

Coral Reefs—Southern Florida, the Hawaiian Islands, and the shores of all oceans of the Torrid Zone, except the eastern shores of the Atlantic and the Pacific, are fringed with jagged coral reefs.

The *reef-building coral* is a small animal living in colonies at-tached to the ocean floor. It requires clear, warm, salt water currents to bring it food, and light, which it cannot get much below a depth of 120 feet. It extracts limestone from sea water and deposits it in the lower part of its body. By the growth and decay of countless corals, the rocky base may be built up nearly to the surface of the sea. The waves break off branches of the coral and grind them to coral sand which finally consolidates to a granular limestone. The waves and the wind may build up a low *reef*, not over 20 feet above the level of the sea.

Where the reef is close to the shore, as along eastern equatorial Africa, Brazil, Cuba and the Hawaiian Islands, it is called a *fringing reef*. The outer border, better supplied with food, grows more rapidly than within. Within the corals die, and the rock is dissolved until a lagoon may develop inside the *barrier reef*, as it is now called. The Great Barrier Reef of the northeast coast of Australia is about 1,000 miles long.

An *atoll*, or ring of coral around a central lagoon, may be formed where the coral has grown on the top of a shoal that comes to within 120 feet of the surface. Or, according to Darwin's theory, the atoll is a coral reef around a *sunken* island, as for example a volcano. The growth of the coral equalled the rate of sinking. When the rate of sinking, or rise of water, exceeds the rate of growth, the coral polyps are drowned. The Chagos Islands in the Indian Ocean are the unsubmerged portions of a very exten-sive coral region.

Coral islands are naturally very low, though some few show that they have been elevated. Plant life may be abundant, though of few varieties. The cocoanut palm furnishes food, clothing, and utensils to the unambitious natives.

HARBORS

Historic Importance.—There has been a close relation between harbors, trade and the spread of civilization ever since the Phœni-cians carried their own alphabet and the products of the civiliza-

tions of both Egypt and Asia from Tyre and Sidon into Greece, Carthage, and the western Mediterranean world.

Rome was the most convenient harbor on the borderland between Greek civilization and Etruscan civilization in Italy. After she had destroyed the harbor of her great rival, Carthage, Rome became the mistress of the Mediterranean world.

During the Middle Ages and the Renaissance, the products of the civilizations of the East and West were distributed largely by those cities that had good harbors, the Italian cities of Venice and Genoa, and the Hansa cities of Germany.

In modern times Holland, Spain, England, the United States, and Germany have owed no small part of their rapid advance in power and wealth to their numerous good harbors.

Requirements.—A *harbor* is a place affording anchorage and safety to shipping. A place from which vessels sail and to which they return is a *port;* if it has a custom house for the legal entry of merchandise, it is called a *port of entry*. A good harbor has the following *requirements:* a good entrance, good anchorage, room for many ships, freedom from ice in winter, good docking facilities, and a productive country tributary to it constituting its *hinterland*.

Classes of Harbors.—There are three great classes of natural harbors, with several varieties of each: *river* harbors, including deltas and estuaries; *bay* harbors, including fiords and craters; and *lagoon* harbors, both sand reef and coral.

River Harbors.—Hamburg, in northwestern Germany on the Elbe, is and has long been one of the great ports of the world. There is easy anchorage for vessels of deep draught, and river, canal, and railroad transportation to all Germany as a hinterland. Antwerp on the Scheld, in Belgium, although sixty miles from the sea, is one of the principal ports of the world. New Orleans, over 100 miles from the mouth of the Mississippi, with the central part of the United States as hinterland, is a delta port. One objection to some river ports is illustrated here—the ease with which a bar is formed at the mouth of the river, imped-

ing navigation. This is prevented in the Mississippi by building jetties.

Some *estuary ports*—Quebec, Canada, and Bristol, England, for example—have to contend with excessive tides. At Liverpool the bar that prevented the passage of large vessels except at high tide has been removed, and the difficulty of loading and unloading from vessels that are raised and lowered twenty feet by the tides, has been overcome by building an immense floating landing-stage with movable bridge approaches.

Bay Harbors.—Bay harbors vary widely in size and importance. Along shore lines of the Pacific type they are few; but when present they may be spacious, and within the inlet are more or less parallel to the outer shore line. Excellent examples are San Francisco Bay, Puget Sound, with its several ports, and the Bay of Rio de Janeiro.

The typical Norwegian *fiord*, although well protected, has steep, wall-like sides that render docking difficult. The hinterland is also poor and inaccessible.

Crater harbors, as St. Thomas, West Indies, are deep and well protected.

Lagoon Harbors.—Coral reef and sand reef harbors are better protected from waves than from winds which sweep over the low reefs. Both are generally shallow and difficult to enter. Through coral reefs the inlets are tortuous and bordered by jagged coral rocks. Key West, Florida, Pearl Harbor, in the Sandwich Islands, and the Island of Guam, are the principal coral reef harbors belonging to the United States.

Many of the harbors from New York City to the Rio Grande are protected by sand reefs. The sand shifted by currents along shore tends to close the entrances, so that it is necessary to keep dredging them. There is an almost continuous inner passage behind these reefs from Cape Cod Bay to northern Florida.

Island Harbors.—Islands help to form the harbors of Boston, Bombay, and Hong Kong.

Harbor Improvements.—Artificial harbors are building at both ends of the Panama Canal, and on the Pacific side of the Isthmus of Tehuantepec. A well protected harbor has been created at La Plata, near Buenos Aires, by building great breakwaters in the open roadstead of the La Plata River.

At New York City deeper channels have been dredged, new docks and piers built at right angles to the shore lines, and old ones lengthened.

Destruction of Harbors.—*Rivers* silt up shallow coastal plain harbors, and *currents* along shore close harbor entrances. *Mangrove* and other forms of plant life, and *corals* and other forms of animal life, fill or obstruct them.

Her climate is such that for usefulness practically every Russian port is destroyed by *ice* during the winter; and the desire for an ice-free harbor has been one great motive for the Russian advances toward Constantinople, Persia, India, and the Pacific Ocean.

The destruction of the harbors of an enemy is one of the most effective *war measures*. Alexander the Great destroyed the harbor of Tyre; the Romans that of Carthage; and the Dutch long kept closed the entrance to Antwerp. During the Napoleonic wars, England endeavored to blockade the ports of France and all her allies.

QUESTIONS

1. Obtain from Washington, D. C., the last annual report of the Lighthouse Board and state the number of men, lights, ships, and amount of money used in this way to lessen the dangers that lurk along our shores. Compare the number of lights along two different coasts, New Jersey and Maine for example, or Puget's Sound and California.

2. Obtain and study some one Pilot Chart, as for example, that of New York City—U. S. Coast and Geodetic Survey Chart No. 121— and note the numerous soundings off shore, the buoys along the channels, and the arrangement of the lighthouses to enable vessels to enter the harbor after dark. The channel outside Sandy Hook, etc.

3. Give reasons for believing that the shorelines migrate and state what may cause this migration.

4. Assign to the different members of the class the examination of

large scale maps of the coasts of the principal states and nations and have individual reports made by them in class, with reproductions on the blackboard or on manila paper of some of the most characteristic.

5. In the same way assign the principal harbors and ports of the world for careful study in the light of climate, land forms, and shore-lines. This work, which is in a sense library laboratory work, makes an excellent review and conclusion of the subject.

6. Compare in a table the effects of (1) elevation, (2) depression and (3) the action of waves, currents and tides at shoreline.

7. Account for branched appearance of Chesapeake Bay, the even shoreline of Peru, the deltas of the Mediterranean Sea, the tide ascending the Hudson to Albany.

8. By what means can one locate former shorelines of extinct lakes, such as Bonneville and Passaic?

APPENDIX

Physiography Reference Library for All High Schools

Bartholomew: Meteorological Atlas. J. B. Lippincott Co. $10.50.
  Atlas of Commerce. J. B. Lippincott Co. $8.00.
Brigham: Geographical Influences in American History. Ginn & Co.
  $1.25.
Chamberlain and Salisbury: Geology. Holt & Co. 3 vols. $12.00.
Davis: Elementary Meteorology. Ginn & Co. $2.50.
  Geographical Essays. Ginn & Co.
Diller: Educational Series of Rocks. U. S. Geological Survey. (Free.)
Dryer: Studies in Indiana Geography. Inland Publishing Co., Terre
  Haute. $1.25.
Gregory, Keller and Bishop: Physical and Commercial Geography.
  Ginn & Co. $3.00.
Halligan: Fundamentals of Agriculture. D. C. Heath & Co. $1.20.
Hickson: Story of Life in the Sea. Appleton & Co. 35 cents.
Hildebrandsson, etc.: International Cloud Atlas. Villars et Fils. 55
  Quai des Grands-Augustins, Paris. (13 francs.) $2.52.
Laboratory Work: Chamberlain, Darling, Davis, Emerson, Everly, Gil-
  bert and Brigham, New York State Handbook, No. 26, Simmons
  and Richardson, Trafton.
Mill: International Geography. Appleton & Co. $3.50.
Moore: Meteorology. Appleton & Co. $3.50.
Robinson: Commercial Geography. Rand, McNally & Co. $1.25.
Romanes: Scientific Evidences of Organic Evolution. Macmillan Co.
  50 cents.
Salisbury: Topographic Maps. Paper. No. 60, U. S. Geological Sur-
  vey. (Free.)
Semple: American History and Its Geographic Conditions. Houghton,
  Mifflin Co. $3.00.
Smithsonian Institution: Washington, D. C. Send for catalogue of free
  pamphlets.
State Geologist: Address for lists of maps and publications.
Teaching: See Bibliography of Science Teaching. Bulletin 446, U. S.
  Bureau of Education.
Todd: New Astronomy. American Book Co. $1.30.

United States: Washington, D. C.   Ask for catalogues, information,
     etc.:

Agricultural Department.   Lighthouse Board.
Coast and Geodetic Survey.   Post Office Department.
Forest Service.   Public Land Office.
Geological Survey.   Weather Bureau.

Ward: Climatology.   Putnams. $2.00.

Additional Books on Physiography for City or Large School Library

Avebury, Lord: (Sir John Lubbock.)   Scenery of England.   Macmillan
     Co. $2.50.
   Scenery of Switzerland.   Dyrssen and Pfeifter, N. Y. $1.00.
Baedeker: United States, Great Britain, etc.   Scribner, N. Y.
Ball: Ice Age.   Appleton & Co. $1.50.
Bonney: Volcanoes.   Putnams. $2.00.
Cowhane: Graphic Lessons in Geography.   Westminster School Book
     Depot, London, S.W.
Croll: Climate and Time.   Appleton & Co. $2.50.
Crosby: Common Minerals and Rocks.   D. C. Heath & Co.   60 cents.
Dana: Manual of Geology.   American Book Co. $5.00.
   Manual of Mineralogy.   Wiley, N. Y. $1.50.
Dodge: Readings in Physical Geography.   Longmans.   70 cents.
Geike: Scenery of Scotland.   Macmillan Co. $3.25.
Heilprin: Mt. Pelee.   J. B. Lippincott Co. $3.00.
Hobbs: Earthquakes.   Appleton & Co. $2.00.
Huxley: Physiography.   Macmillan Co. $1.80.
Hogarth: Nearer East.   Appleton & Co. $2.00.
Mackinder: British Isles.   Appleton & Co. $2.00.
Marr: Study of Scenery.   New Amsterdam Co., N. Y. $1.50.
New Jersey Geological Report: Vol. V, Glacial Geology.
Partsch: Central Europe.   Appleton & Co. $2.00.
Perry: Spinning Tops.   Young, London. $1.00.
Rotch: Sounding the Ocean of Air.   Young. $1.00.
Russell: Lakes of North America.   Ginn & Co. $1.50.
   Rivers of North America.   Putnams. $2.00.
   Volcanoes of North America.   Macmillan Co. $4.00.
Shaler: Sea and Land.   Scribner. $2.50.
   First Book in Geology.   D. C. Heath & Co.   60 cents.
   Nature and Man.   Scribner. $1.50.
Suess: Face of the Earth.   Oxford University Press, N. Y.   4 vols.
     $28.00.
Tarr: Physical Geography of New York State.   Macmillan Co. $3.50.

Tyndall: Forms of Water. Appleton & Co. $1.50.
  Hours of Exercise. Appleton & Co. $2.00.
Wallace: Distribution of Animal and Plant Life. Humboldt. 15 cents.
  Island Life. Macmillan Co. $1.75.
  Tropical Nature. Macmillan Co. $1.75.
Winchell: World Life. Scott. $2.50.
Wright: Ice Age in North America. Appleton & Co. $5.00.

Equipment in Physiography

The most important equipment is a well-trained, up-to-date teacher. He will know how to select from the following lists, and how to utilize and to supplement the local, State, and National equipments.

1. MAPS.—*Large hall maps of continents. These should show depth of the sea. (Habenich-Sydow are good.)
    *Public Land Office Map of United States. (Free or $1.25.)
    *State Geological, County, and Railroad Maps.
    *County or City Maps.
    *Grouped United States Topographic Maps of your neighborhood.
    Mississippi River Commission. (Address Secretary, St. Louis, Mo.)
    United States Geological Survey—Physiographic Folios 1 (q.s.) and 2 (q.s.). Chicago and New York Special Folios.
    Coast and Geodetic Survey Charts, *120, *121, 11, 21, 30, 123, 143, 145, 154, 204, 314, 337, 359, 408, 419, 469, 1007, 5500, 5532.
    Hydrographic Office: *Pilot Charts of various oceans.
2. GLOBES.—Joscelyn 18-inch globe is one of the best.
    *12-inch slated globe.
    * 6-inch globe ($.25), q.s.
3. MODELS.—*Harvard Geographical Models, (Mountains and Coasts).
    Consult Edwin E. Howell, 612 17th St., Washington, D. C.
        Ward's Natural Science Establishment, Rochester, N. Y.
        Knott Apparatus Co., Boston, Mass.
        Central Scientific Co., 14 Michigan St., Chicago.
4. PICTURES AND LANTERN SLIDES.—Detroit Photographic Co., Detroit
    American Bureau of Geography, Winona, Minn.
    W. H. Rau, Philadelphia.
    T. H. McAllister, 49 Nassau St., New York.
    Chicago Geographical Society, Chicago.
    *Department of Visual Instruction, Capitol, Albany, N. Y.
    E. Steiger & Co., New York.

*Very valuable.
q. s.—Quantity sufficient to supply every member of a class.

5. MINERALS, ROCKS AND FOSSILS.—Foote Mineral Co., 1317 Arch St., Philadelphia.

Ward's Natural Science Establishment, Rochester, N. Y.

Central Scientific Co., Chicago.

6. INSTRUMENTS.—Standard Thermometer.

Maximum and Minimum Thermometer.

*Thermograph.

Mercurial Barometer.

Aneroid Barometer.

*Barograph.

Hygrometer.

*Hygrodeik.

Hygrograph.

Rain Gauge.

Wind Vane (with connection with class room).

Anemometer.

B-K Solar **Calculator**

*Solar Compasses.

*Protractors (6-inch zylonite to $\frac{1}{2}°$ arc is very convenient)

*Very valuable.

INDEX