UNIVERSAL
LIBRARY

OU_160097

UNIVERSAL
LIBRARY

THE EARTH
AND ITS RESOURCES

The quality of the materials used in the manufacture of this book is governed by continued postwar shortages.

THE EARTH

AND ITS RESOURCES

A Modern Physical Geography

By

VERNOR C. FINCH
Professor of Geography, University of Wisconsin

GLENN T. TREWARTHA
Professor of Geography, University of Wisconsin

and

M. H. SHEARER
Westport High School, Kansas City, Missouri

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON

THE EARTH AND ITS RESOURCES

COPYRIGHT, 1941, BY THE
McGRAW-HILL BOOK COMPANY, INC.

PRINTED IN THE UNITED STATES OF AMERICA

All rights reserved. This book, or parts thereof, may not be reproduced in any form without permission of the publishers.

V

[Printed in August, 1947]

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

Many of the world's pressing economic and social problems originate partly at least in the differences in environment and natural resources over the regions of the earth. A clear understanding of the physical environment, therefore, immeasurably enriches the study of economic, social, and political problems. For the American student particularly, because of the striking differences in natural endowment among different parts of the United States, an intelligent consideration of many national problems presumes a knowledge of the contrasts in climate, land surface, soils, minerals, and other resources between East and West, between North and South.

In recent years, for example, the all-important subject of conservation of its natural resources has commanded the attention of the nation. Basic to a discussion of the problem of conservation is a knowledge of the nature and occurrence of such resources as soils, waters, and minerals. These facts are a vital part of the study of the physical earth, so that the subject of conservation has a logical and important place in a treatment of the earth and its resources.

It is the purpose of this book, therefore, to present the basic facts concerning the earth as the home of man so that the student may realize their importance and understand their relationship to the problems of his own time and place. To this end the major features of the physical earth are primarily considered as separate topics and secondarily in connection with the different regions of the earth. These features of our environment

are discussed under the following main headings: (1) the atmosphere: weather and climate; (2) landforms: plains, plateaus, hill country and mountains; (3) the oceans and their shores; (4) earth resources: waters, vegetation, soils and minerals. This treatment is supplemented by an analysis of the various types of regions—climatic regions and landform regions, for example. The elements of the environment are further considered in their regional combinations and are viewed in the light of their value for man's economic and social use.

Serious effort has been made to keep both the content of the book and its language and vocabulary at a level that will be understandable to the beginning student in a subject which may be and often is treated in a highly technical manner. Technical terms are used sparingly, and, when they are employed, are carefully explained. Over four hundred maps, diagrams, and photographs have been included in order to illustrate the text material and to assist the student in visualizing the phenomena of the physical environment.

The factual materials for this text have been drawn from the most accurate and recent sources available. The content and organization have come largely from *Elements of Geography*, a college text by two of the authors. The third author, having found *Elements of Geography* to have many features desirable in high-school classes, recruited the cooperation of the authors of this book in the development of a simplified text. With the background of an extended teaching experience in the secondary schools, he has largely restated the subject matter for use at that level of instruction.

A laboratory manual has been written to accompany this text so that the classwork can be presented in the manner used in other laboratory sciences. There is sufficient laboratory work for a two-semester course. If the work must be confined to one semester, some of the laboratory work may be omitted. The use of the exercises in the laboratory manual contributes much to the interest and comprehensiveness of the course.

The authors wish to make grateful acknowledgment to the many individuals who have assisted them in the preparation of this text and in particular to Mrs. M. H. Shearer, for her critical and clerical assistance during the preparation of the manuscript;

to R. S. Harris of Westport High School, who read part of the text critically, and to M. W. Bishop of Southwest High School (both of Kansas City, Mo.), who read the chapter on soils. The manuscript was tried out chapter by chapter with groups of high-school pupils, and their comments and helpful suggestions have aided the authors considerably in improving the manuscript. The cooperation of Miss Virginia Holbert, in charge of the library of the Department of Geology and Geography at the University of Colorado, has also been most helpful.

V. C. F.
G. T. T.
M. H. S.

CONTENTS

		Page
Preface		v
Chapter		
I.	The Earth and Its Planetary Relations	3
II.	Temperature of the Atmosphere	24
III.	Atmospheric Pressure and Winds	48
IV.	Atmospheric Moisture and Precipitation	78
V.	Storms and Their Weather Types	102
VI.	Climates of the Tropics and the Dry Middle Latitudes	133
VII.	Climates of Middle and High Latitudes	164
VIII.	Composition and Changes of the Earth's Crust	197
IX.	Wearing Away and Building Up of the Land	227
X.	River-made Plains	258
XI.	Glaciated Plains	288
XII.	Plateaus and Hill Country	314
XIII.	Mountains	340
XIV.	Oceans and Their Shores	367
XV.	Water Resources of the Land	404
XVI.	Native Vegetation and Animal Life	441
XVII.	Soils	479

CHAPTER PAGE

XVIII. Mineral Fuels, Ores, and Other Economic Minerals. 501

XIX. Major Physical Regions and Resources of the United States 537

APPENDIX

A. The Seasons 581

B. Supplementary Climatic Data for Selected Stations. 585

C. Meteorological Instruments and the Weather Map . 587

D. Interpretation of Maps 596

E. A Selected List of United States Topographic Quadrangles 604

F. Rocks and Minerals 608

G. Principal Subdivisions of Earth History 612

H. Useful Data and Tables 613

I. Maps 615

INDEX 623

THE EARTH AND ITS RESOURCES

Chapter I. The Earth and Its Planetary Relations

The importance of science in modern life is recognized by nearly everyone. We can all think of numberless ways in which physics, mathematics, chemistry, biology, and other fields of scientific study have contributed to the richness and comfort of our surroundings and to the broadening of our general knowledge.

There was a time, in the early days of science, when the amount of scientific knowledge was so small that one well-educated man could profess to be master of all of it. That time is past. The growth of knowledge has added so much of special detail in each of the scientific fields that no one mind can understand the total. Today, to obtain a good knowledge of even one of the sciences may take more time than the average student has to give. Such detailed and technical knowledge is more useful in a professional career than in the general business of living.

However, some study of science is important for the understanding of life about us and for the kind of training that it gives. Science deals both with general ideas and with definite facts and their relation to one another. The mastery of any body of facts in the field of natural science requires the learning of many new terms and principles. Much more important, however, for the education of the student, is that it requires the constant use of reason. Facts in any field of learning cannot be fully understood by themselves. They can be understood only as they are related to other things. Reasoning helps us to appreciate that relationship.

Because modern science tends to be specialized, it is desirable that an introductory course in science involve at least some of the principles of several of the sciences. To be sure, each of the

scientific studies does this to some degree. Students of physics and chemistry cannot progress far without using mathematics. Neither can biologists nor geologists advance greatly in their fields of learning without applying the principles of chemistry and physics.

But there is one general field of scientific study in which, more than in any other, important principles from several of the sciences may be brought together and studied in their relationship to one another. That field may be called *earth science.* In it are combined facts from several related fields. There are the simple mathematical ideas relating to the earth as a planet and the means of picturing it in maps. There are the physical principles governing the climates of the earth's atmosphere. There are the processes by which the surface forms of the land are molded. There is the chemistry of rocks and soils. There are the biological relationships of the plants and animals that man uses in the process of getting a living.

Recent years have witnessed a considerable improvement in methods of transportation, which, together with the completion of thousands of miles of good roads, has resulted in increased travel by larger numbers of people. Their travels lead them to many interesting places, such as the ocean shore, the north woods, or regions of hills and mountains. In these various localities they observe the great variety of features of the earth's surface. One region may have many beautiful lakes; another may have none. One shoreline may be smooth and sandy; another, rocky and dangerous. Certain mountains may be rounded, smooth, and not difficult to climb, while others are rugged, steep, and so high that they are covered with snow and glaciers. A clear, sparkling mountain stream tumbling over numerous rapids and waterfalls contrasts sharply with the slow-moving, muddy creek of level lowlands. From place to place climatic conditions may vary considerably. A West-coast locality may have a fairly uniform, cool, foggy, rainy climate, while another region much farther inland may experience a great variety of weather changes, such as blizzards, hot waves, and droughts. A common topic of conversation is the condition of local weather, a knowledge of which is especially valuable to the farmer, the orchardist, the airplane pilot, and many others. Most of us have noticed

these variations in earth phenomena and have already become interested in the way in which they are related to land use and man's mode of living. Certainly a knowledge of at least some of them would contribute greatly to man's understanding of environmental conditions in different parts of the world. This book on earth science is an attempt to make such a contribution.

The Earth

Many familiar conditions, both in the realm of nature and in our everyday lives, have their origins in the shape and size of the earth and its relation to other heavenly bodies, especially the sun. Our common ideas of distance, area, direction, time, and weight depend upon these conditions of earth size and relation.

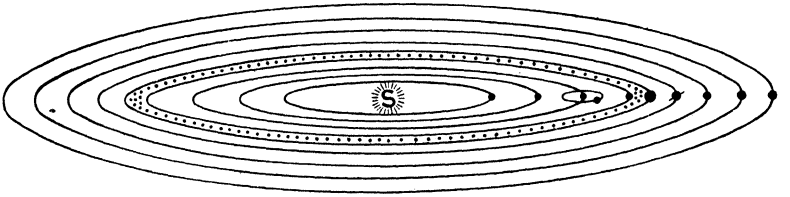


FIG. 1.—The planets move about the sun in orbits nearly spherical in shape. Mercury is nearest the sun; Venus comes second; then the earth, around which is shown the orbit of the moon. Next in order are Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. Revolving around the sun between the orbits of Mars and Jupiter are several hundred asteroids.

Such phenomena as day and night, the seasons, the tides of the ocean, and indeed the very existence of the oceans and the atmosphere depend upon them also. Knowledge of the external relations of the earth is important to an understanding of the nature of earth environment and of the ways in which natural features are related to those created by man.

The Earth in Space. The earth is a planet. It is a member of the solar system which consists of (1) the sun, which is a star and the center of the system; (2) nine planets and their satellites, all of which revolve around the sun; (3) several hundred asteroids, which are small planets; and (4) a few comets.

The planets in order from the sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. It should be remembered that the sun shines by its own light but the planets reflect the light of the sun (Fig. 1).

The earth's satellite, the moon, revolves around the earth about once a month (Fig. 2). Earth and moon travel together, making a complete trip around the sun once a year. Eclipses occur when the three bodies—sun, earth, and moon—are in a straight line. When the moon comes between the earth and the sun, an eclipse of the sun results. This can occur only at the new moon. When the earth is between the sun and the moon, an eclipse of the moon results. This can occur only at full moon. The distance from the earth to the moon is much less than the radius of the sun.

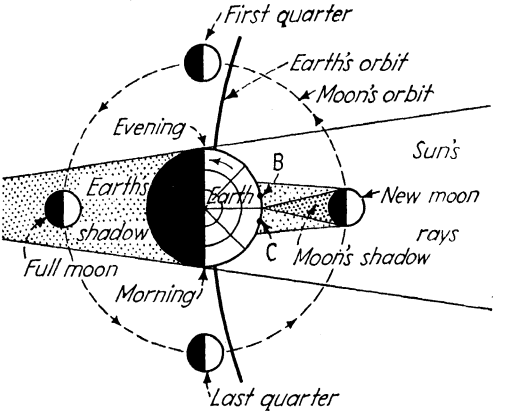


FIG. 2.—This diagram shows the phases of the moon and the eclipses. At the right the moon is in position for total eclipse of the sun, visible at the point where the moon's darker shadow reaches the earth. A partial eclipse would be observed at other points such as *B* and *C*. At the left of the diagram the moon is in the earth's shadow. When this occurs, an eclipse of the moon is observed from the earth.

Shape of the Earth. The earth is almost a sphere. A slight flattening at each earth pole causes the radius from the earth center to the pole to be about 13.5 miles shorter than the distance from the center to any point on the equator. That is the earth's greatest departure from being a true sphere. Great ocean deeps (6 miles or more below sea level) and high mountain peaks (5.5 miles above sea level) exist, but the height of the highest mountain above the lowest point on the ocean floor is not more than the amount of the polar flattening. If the circumference of the earth is represented by a true chalk circle of the largest size that can be drawn on an ordinary blackboard, the chalk line will have more than enough thickness to include all the earth's

departures from being a true sphere, if they could be represented properly at that scale.

Size of the Earth. The earth has a polar diameter of about 7,900 miles and an equatorial diameter about 27 miles greater. At the equator it lacks only 100 miles of being 25,000 miles in circumference. Its surface area is nearly 197 million square miles. The size of the earth is, therefore, great but not vast in comparison with some other heavenly bodies. The planet Jupiter, for example, has a diameter of over 80,000 miles.

Force of Gravity. Because of its great size and density (weight per unit volume) the earth has a strong attraction for objects on or near its surface. This attraction is called the *force of gravity*. It holds the atmosphere and hydrosphere (waters of the earth) on the earth's surface. It determines the weight of all objects. The force of gravity in fact holds the earth together and attracts all objects to it. Its constant presence is taken for granted by everyone. The pull of gravity enables builders to establish a vertical line (necessary in constructing walls of buildings) by means of a *plumb line* (a string to which a weight is attached). Such a line is perpendicular to a tangent to the earth's surface at the point where it touches. A line drawn perpendicularly to the tangent at some other point is not vertical (Fig. 3). The shadow of the plumb line at noon (sun time) establishes a true north-south direction.

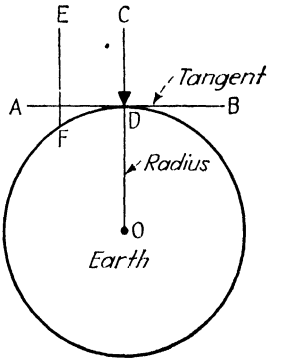


FIG. 3.—The line *CD* is the plumb line referred to in the text. Only such a line can be called vertical. The line *EF*, for example, although parallel to *CD*, is not vertical, for it does not form, with a radius, a straight line to the center of the earth.

Land, Water, and Air. The solid mass of the earth (the lithosphere) is covered in part by water (the hydrosphere). Both are surrounded by an envelope of gas (the atmosphere) which has a thickness of at least several scores of miles. Each of these "spheres" touches upon the life of man in many ways, and their many different features or phases combine and recombine in hundreds of ways to make up the sets of natural features that characterize different regions of the world.

Some of the combinations of hydrosphere and atmosphere form regions that are eminently suited to the habitation of man and to intensive use by modern human society. Others form regions that are very unsuited. In the latter group are the depressed parts of the earth crust which are occupied by oceans and the great seas. These together occupy about 71 per cent of the surface of the sphere, leaving the smaller part, about 29 per cent, as the exposed continental surfaces. Only these are in any degree suited to permanent human abode.

The total area of the land surface of the earth, about 51 million square miles, is equal to about seventeen times the area of the United States. Upon this rather restricted surface the entire human population of the earth resides and tries to secure a living. However, large parts of the land, for one reason or another, are poorly suited to human occupation or use. The primary purpose of this book is to direct attention to the many different phases of the major elements, land, water, and air, which combine to create the great variety of conditions under which men live.

Earth Motions

Earth Rotation and Its Consequences. The two principal motions of the earth are (1) rotation on its axis and (2) revolution around the sun. The earth rotates upon an imaginary axis which, because of the polar flattening, is its shortest diameter. The ends of the axis of rotation are at the earth poles. The time required for the earth to rotate once upon its axis is called a *day* and is divided into 24 hours.

During the period of one day each place on the sphere is turned alternately toward and away from the sun. Each experiences a period of light and a period of darkness. Each also has been swept over twice by the circle of illumination (the dividing line between day and night), once at dawn and again at twilight.

The direction of earth rotation is toward the east. This fact has broad significance. Not only does it determine the direction in which the sun, moon, and stars appear to rise and set. It is also related to other earth phenomena of far-reaching consequence, such as the prevailing directions of winds and ocean currents, which will be studied later.

Earth Revolution. The rotating earth revolves in a slightly elliptical orbit, or path, about the sun. It keeps an average distance from the sun of about 93 million miles (Fig. 4). It is held in its orbit by two forces, *viz.*, (1) the attraction of gravitation of the sun and (2) centrifugal force.

All heavenly bodies attract each other. The larger the body the stronger is its attraction. The sun is an enormous body, having a diameter of about 860,000 miles. The great size of the sun is largely responsible for its tremendous "attraction of

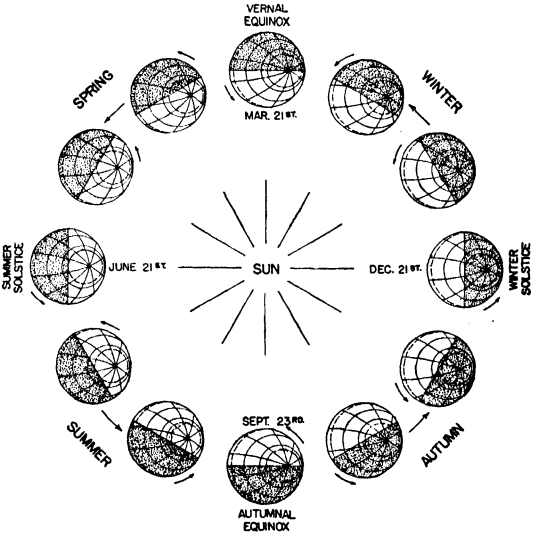


FIG. 4.—The relation of the inclination of the earth's axis to the change of seasons in the Northern Hemisphere (see Appendix A).

gravitation," which holds the various planets in their orbits. The attraction of gravitation of the earth holds the moon in its orbit and attracts meteors toward the earth. The meteors, wrongly called "shooting stars," burn because of friction with the earth's atmosphere caused by the terrific speed at which they are traveling (Fig. 5).

The speed of the earth as it travels through space is indeed great, being over 60,000 miles per hour. This speed tends to pull the earth away from the sun, like mud flying off a rotating wheel. The outward pull exerted by a rotating body is called *centrifugal force.* This force opposes the sun's attraction of gravitation. Here there is a continual struggle between two

great forces. The balance between them establishes the orbit over which the earth travels year after year.

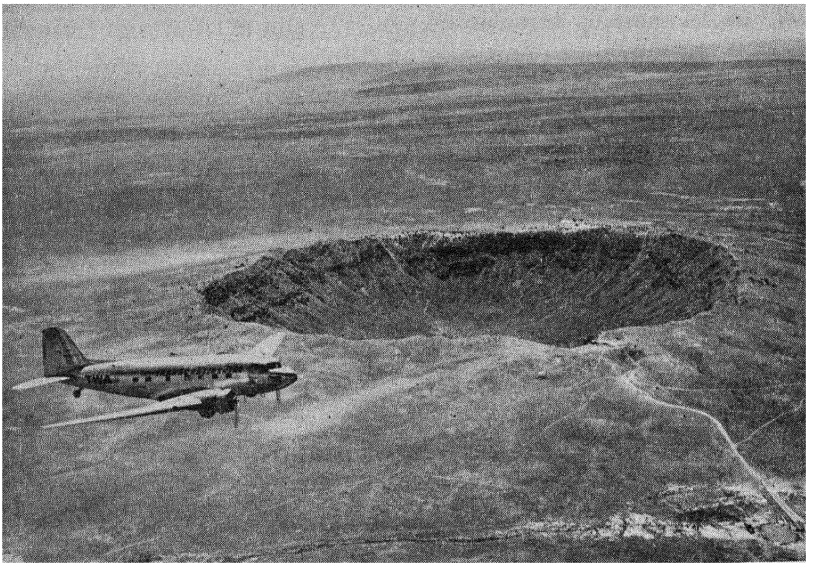


FIG. 5.—A meteor made this basin near Winslow, Ariz. The basin is nearly a mile in diameter and about 600 feet deep. (*Courtesy of Transcontinental and Western Air, Inc.*)

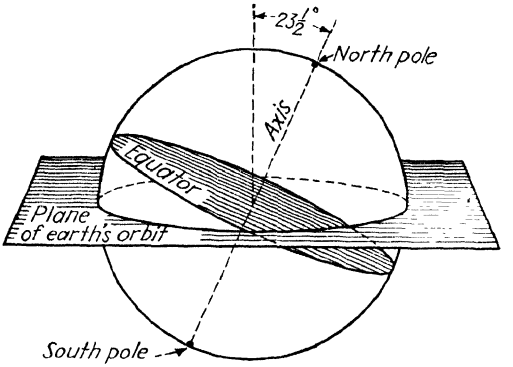


FIG. 6.—The earth's axis is inclined 23½° from a line perpendicular to the plane of the earth's orbit.

The time required for the earth to pass once completely around its orbit fixes the length of the year. During the time of one revolution the spinning earth rotates on its axis approximately 365¼ times, thus determining the number of days in the year.

An imaginary plane passed through the sun and extended outward through all points in the earth's orbit is called the *plane of the orbit.* The earth's axis has a fixed inclination of about $23\frac{1}{2}°$ from a line perpendicular to the plane of the orbit (Figs. 6, 7). This position is constant, with the North Pole always pointing toward the North Star. Therefore, the axis at any time during the yearly revolution is parallel to the position it occupied at any previous time. This is called the *parallelism of the axis.*

The degree of inclination of the earth's axis and its parallelism, together with the earth's shape, its rotation on its axis, and its revolution about the sun, combine to produce several earth phenomena which are of vital importance among the

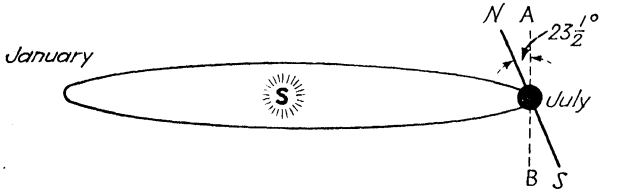


FIG. 7.—The sun, somewhat off center in the earth's orbit, is about 3 million miles closer to the earth in January than it is in July. Winter and summer climates are due to the inclination of the earth's axis *NS* and not to distance from the sun.

conditions that surround us. Some of these are (1) the primary distribution of the sun's heat and light over the earth, (2) the changing of the seasons, and (3) the changing lengths of day and night. These matters and others related to them will be discussed more fully in their connection with climate.

Location on the Earth

Earth Grid. The location of the North and South poles of the earth is established by rotation of the earth on its axis. With the poles as starting points, a system of lines can be drawn upon a globe. These lines, called *parallels* and *meridians,* make possible the location of places on the earth's surface. The complete system or network of parallels and meridians is called the *earth grid.*

The *equator,* zero latitude, is a line that passes around the earth halfway between the poles. It is a Great Circle. A Great Circle is (1) the largest circle that can be drawn on the globe and (2) the shortest distance between two points on the earth's

surface, and (3) its plane always passes through the center of the earth. If a wire hoop is made to fit snugly around the equator, it can be adjusted so as to pass through any two points on the earth's surface, indicating the shortest, or Great Circle, distance between these points. Ocean liners and airplanes follow Great Circle routes whenever possible.

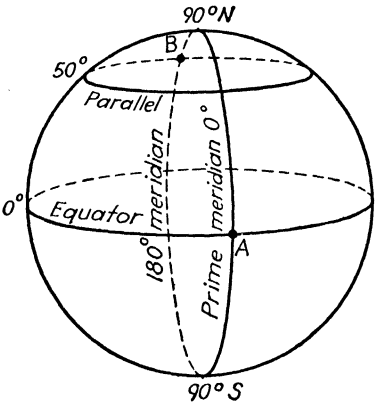


FIG. 8.—In this simplified diagram of the globe are shown one of the parallels and a Great Circle, made up of two meridians. Point *A* on this diagram could be located on any map by the direction "0° Long., 0° Lat."; point *B*, by the direction "180° Long., 50°N. Lat."

A *parallel* is an east-west line, drawn completely around the earth, with all points equidistant from the equator. Parallels are called *Small Circles* because each one is smaller than the equator, the size decreasing as the poles are approached (Fig. 8). The Great Circle distance between two points on the same parallel is shorter than that along the parallel itself (Fig. 9).

Latitude is distance measured in degrees north and south of the equator. From the equator to either pole is 90°. Parallels of latitude on a map or globe may be drawn 1, 5, 10, or any other convenient number of degrees apart. All points on the same parallel have the same latitude. One degree of latitude is always about 69 miles. Philadelphia is on the 40th parallel of north latitude. Its distance from the equator is, therefore, about 2,760 miles. Latitude is determined by a sextant, an instrument that measures the angle between the sun's rays and a tangent to the earth's surface. This angle is called the *sun altitude* (Fig. 10). The altitude of the North Star is made use of in calculating latitude at night. On board ship, latitude is usually determined

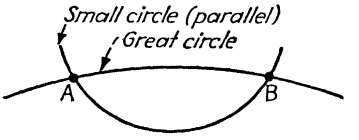


FIG. 9.—The distance between two points on a parallel (a small circle) may be covered more quickly by following a Great Circle route than by following the arc of the parallel. The Great Circle path on a globe may be observed by stretching a string tightly between any two places. The arc of the larger circle more nearly approaches a straight line.

at noon, provided the sun is not hidden by clouds. One degree of latitude (or longitude) is divided into 60 minutes (′), and 1 minute into 60 seconds (″). Thus the exact latitude of a given point may be 49°56′14″N.

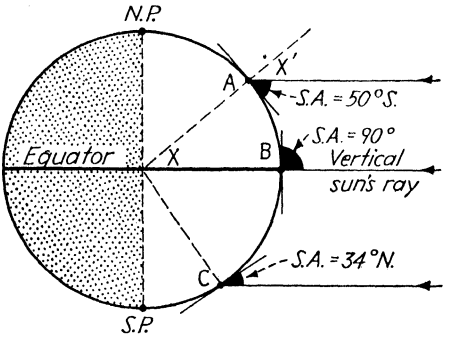


FIG. 10.—Point *B* represents any point on the equator at noon at the time of an equinox. The sun is directly overhead, with its rays striking the equator at an angle of 90°. At Philadelphia (*A*) the angle is 50°S. At Cape Horn (*C*) the angle is 34°N. Since angle $X = X'$ it is evident that the latitude of $A = 90° - S.A.$

Four parallels of latitude are of special importance. Because of the $23\frac{1}{2}°$ inclination of the earth's axis, the vertical rays of the

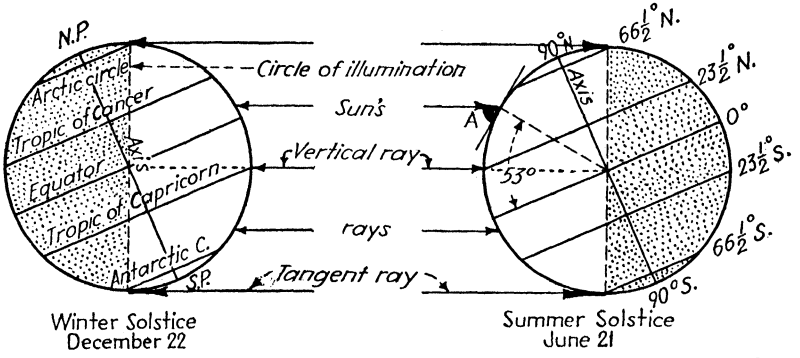


FIG. 11.—These studies of the distribution of light on the earth in winter and summer present in detail two of the positions illustrated in Fig. 4. The sun's rays are shown by parallel lines. Note the shifting of the vertical ray. Angle *A* is the noon sun altitude at a point 53°N. Lat. On the June 21 diagram, what is the sun altitude of the Tropic of Cancer? The Antarctic Circle at noon? The Arctic Circle at midnight?

sun move $23\frac{1}{2}°$ north and south of the equator (Fig. 11). The *Tropic of Cancer* is the parallel $23\frac{1}{2}°$N. and is the farthest north reached by the vertical rays of the sun at the time of the *summer solstice*, about *June* 21 (Northern Hemisphere). The *Tropic of Capricorn* is the parallel $23\frac{1}{2}°$S. and is the farthest south reached

by the vertical rays of the sun at the time of the *winter solstice*, about *December* 22. The *Arctic Circle* is the parallel 66½°N. and is determined by the point where the sun's noon rays are tangent to the earth's surface at the time of winter solstice. The *Antarctic Circle* is the parallel 66½°S. and is determined by the point where the noon sun's rays are tangent to the earth's surface at the time of summer solstice. These four parallels are often considered as the boundary lines between the tropical, intermediate, and polar zones of the earth. The vertical rays of the sun cross the equator twice each year. The time of their first crossing, about

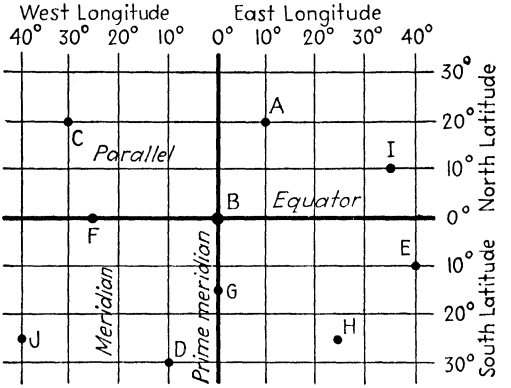


FIG. 12.—Point *A* is 10°E. Long. and 20°N. Lat. Give the longitude and latitude of the other points.

March 21, is called the *vernal equinox*. Their second, about *September* 21, is called the *autumnal equinox*. On these dates, day and night are equal everywhere on the earth, each being 12 hours.

A *meridian* is a north-south line drawn on a globe from pole to pole. Each meridian is one-half a Great Circle. All places on the same meridian have the same longitude. Meridians may be spaced any convenient number of degrees apart on a map or globe. The prime meridian is zero longitude and passes through Greenwich, near London, England.

Longitude is distance measured in degrees east and west of the prime meridian. The only point on the earth's surface having zero longitude and zero latitude is in the Gulf of Guinea on the west coast of Africa where the equator crosses the prime meridian (Fig. 12). Longitude extends 180° east and 180° west from the prime meridian.

Opposite the prime meridian is the *international date line* which roughly follows the 180th meridian near the center of the Pacific Ocean (Fig. 13). This is the line "where day begins and ends." Travelers crossing the date line going west add a day and going east subtract a day. When it is noon on the prime meridian, it is midnight on the 180th meridian. Likewise, when it is noon on the meridian of 90°W. Long. (near St. Louis, Mo.), it is midnight on the meridian of 90°E. Long. (near Calcutta, India).

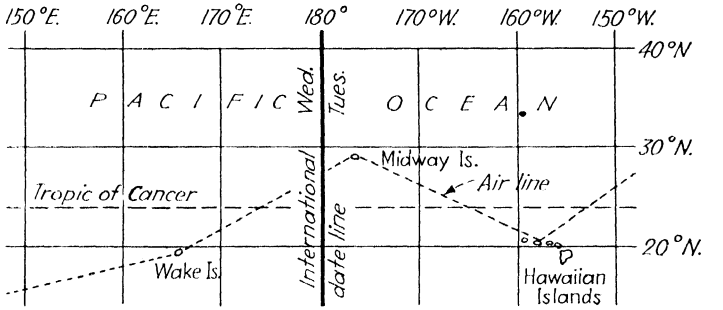


FIG. 13.—When crossing the international date line going west, travelers add a day; going east, they subtract a day. Only when it is midnight on the date line is the whole world living in the same day.

Degrees of Longitude Vary in Length. All the parallels of latitude, except the equator, are smaller than a Great Circle. Since each parallel, regardless of its circumference, is divided into 360°, it follows that the length of 1° of longitude, in miles, must decrease toward the poles. One degree on the equator, a Great Circle, has about the same length as an average degree of latitude (about 69 miles).

The following table gives the approximate mileage per degree of longitude along certain parallels:

Latitude, Degrees	*Miles per Degree of Longitude*	*Latitude, Degrees*	*Miles per Degree of Longitude*
0	69	50	44
10	68	60	34.5
20	65	70	23
30	59	80	12
40	53	90	0

The longitude of an unmapped place east or west of the prime meridian or of a ship at sea can be determined only by finding the *difference in time* between that place and the prime meridian. This was first accomplished by means of accurate timepieces (chronometers) carried on board ship and set at Greenwich, or prime meridian, time. Observation of the sun at the instant when it reached the highest point (zenith) in its daily course across the sky gave local noon time which could then be compared directly with the chronometer, and the difference in time translated into degrees and minutes of longitude (Fig. 14). Now, instantaneous communication by telegraph and radio makes accurate time comparison possible almost everywhere and, therefore, makes possible greatly improved determinations of longitude. This is of particular aid in geographical exploration, aviation, and ocean transportation.

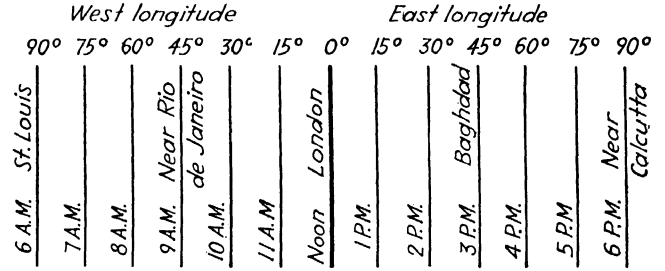


FIG. 14.—Fifteen degrees of longitude equal 1 hour of time. When it is noon in London, it is 6 A.M. in St. Louis, Mo., and 6 P.M. near Calcutta, India. Suppose that on board ship the sun time is noon (sun due south) and London time (by radio) is 3 P.M. The ship is 45°W. Long. What would be the longitude of a ship that at noon received London time as 9 A.M.? 6 A.M.? Midnight?

Accurate Location. The intersection of any two lines is a point. Consequently, any point on the earth's surface may be located by determining that it lies at the intersection of a certain meridian with a certain parallel. By exact determination of its latitude and longitude the location of any place may be expressed briefly and with great accuracy. Thus, when we say that the dome of the national Capitol at Washington, D.C., is located at 38°53′23″N. Lat. and 77°00′33″ Long. west of Greenwich, we have stated its exact position on the earth to within 10 paces.

Longitude and Time. The earth rotates eastward through its entire circumference of 360° of longitude in 24 hours, therefore through 15° in 1 hour. When noon arrives at any meridian, it is already 1 hour later (1 P.M.) on the meridian 15° east of that one, and it lacks 1 hour of noon (11 A.M.) on the meridian 15° to the west. When the sun is directly over a given meridian, it is noon at all points on that meridian from North Pole to South Pole. Four minutes later it is noon on the meridian 1 degree farther west.

In a generation past, each town kept the time of its own meridian which was called *apparent solar time* or, in common American parlance, *sun time.* When rail transportation permitted rapid travel, it became awkward or impossible to change one's time a few minutes with every village passed. To avoid this necessity, each railroad adopted an arbitrary time scheme which differed from that of most of the places it passed through but was the same for considerable distances on the rail line. Unfortunately, several railroads in a region often adopted different times for their own use. Consequently, it sometimes happened that a town reached by different railways found itself required to use or distinguish between several different kinds of time: its own solar time and one for each of its railways.

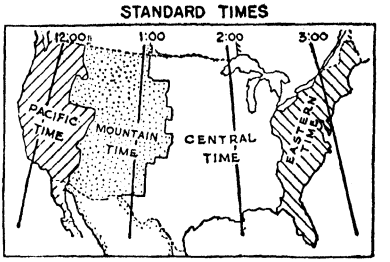


FIG. 15.

The awkwardness and confusion of this situation led to the adoption by American railways, in 1883, of a system of standard time. This system, in theory, supposes that all parts of a north-south zone 15° of longitude in width adopt the solar time of the central meridian of that zone. Places within the zone that are east or west of the central meridian, instead of differing in time by a few minutes from it and from each other, all have the same time. Changes of time are then necessary only in crossing the boundary of the zone, and each change is exactly 1 hour. The timepiece is set forward (as from 12 to 1) in traveling east and is set back (as from 12 to 11) in traveling west. In practice,

these zones are not bounded by meridians but by irregular lines, the location of which is dictated by railway convenience and political consideration. Figure 15 shows the present standard time zones of the United States.

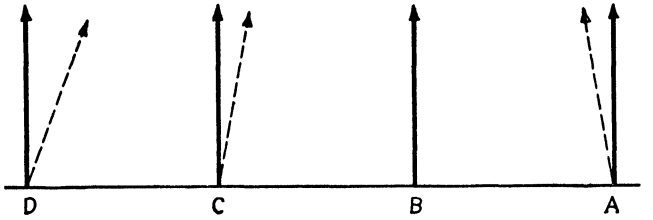


FIG. 16.—The solid lines represent true north as indicated by meridians. The dotted lines show magnetic north as indicated by a magnetic compass. The magnetic variation at *A* (in New York) is 10°W.; at *D* (in Washington), 20°E.; at *C* (in Kansas), 10°E.; and at *B* (western Michigan), zero. At *B*, on the agonic line, the compass points both true and magnetic north.

On the whole earth there should be 24 standard time zones, each extending from pole to pole and each differing from Greenwich time by a definite number of hours. In practice, the arrange-

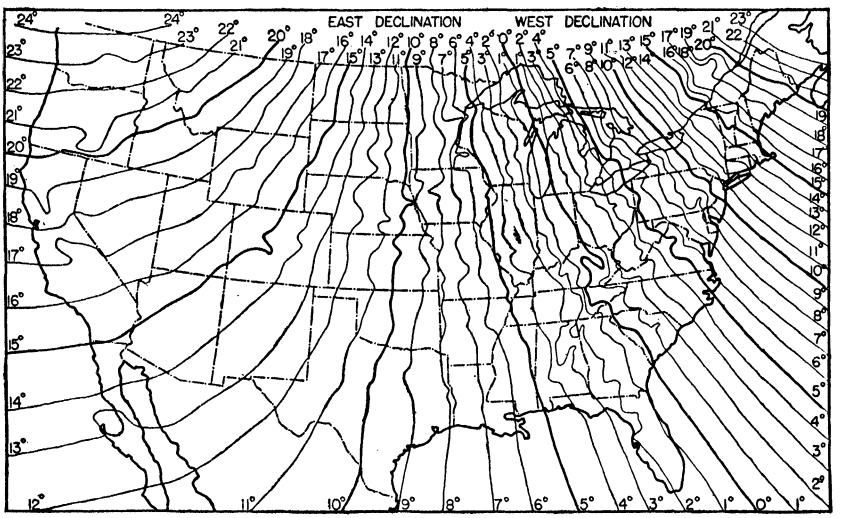


FIG. 17.—Lines of equal magnetic variation or declination (isogonic lines) in the United States. Only at points on the agonic line (0° declination) does the magnetic compass point true north. (*Generalized from a map by U.S. Coast and Geodetic Survey.*)

ment is not quite so simple. Although most countries follow the plan, certain isolated countries employ standard meridians that are not multiples of 15 and, therefore, do not differ from Greenwich time by exact hours. For example, Netherlands time is 19

minutes faster, and Bolivian time is 4 hours and 33 minutes (instead of 5 hours) slower than Greenwich time.

Direction. Places may be located in terms of direction such as northeast (45°), east (90°), southeast (135°).

Much direction finding, especially in land surveys, still is accomplished by means of the magnetic compass. The needle of this instrument aligns itself with the magnetic lines of force that surround the earth. The magnetic north and south poles of the earth happen not to be located at the geographical poles, are not exactly opposite each other, and even are subject to slight changes of position. In consequence, there are few places on the earth where the magnetic needle points true geographical north.

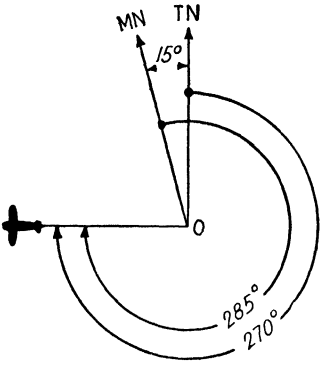


FIG. 18.—The magnetic variation at Boston, Mass., is 15°W. The heading of an airplane from the starting point *O* is west, or 270°. Because of the variation, the compass will read 285° instead of 270°. *TN* is true north (a meridian). *MN* is magnetic north as shown by a magnetic compass. The angle measured clockwise from true north to the heading of the plane (270°) is called the *true course;* from magnetic north to the heading of the plane is the *magnetic course.* What would the magnetic course be if the starting point was in southern California where variation is 15°E.?

The *agonic line* connects those places where the magnetic compass points true north as well as magnetic north. In the United States this line follows a very irregular course from Michigan to South Carolina (Figs. 16, 17). East of the agonic line, as in New York, the magnetic compass points a few degrees west of true north. West of the agonic line, as in Colorado, magnetic north (indicated by the compass) is east of true north (indicated by a meridian). *Magnetic variation,* or *declination,* is the angle between true north and magnetic north (Fig. 16).

An *isogonic line* connects places of *equal* magnetic variation. In flying across country an airplane pilot must be familiar with changes in magnetic variation and know how to calculate true directions from compass readings (Fig. 18). True north is indicated by the shadow of a vertical rod, or plumb line, at noon, sun time; or by the North Star at night. Recent improvements in the radio compass and directional radio-beam navigation

make pilots and navigators less dependent on the magnetic compass than in past years. A good navigator, however, seldom relies entirely on one system of navigation.

Summary

In this chapter we have considered a few facts concerning the earth in space. The size, shape, and motions of the earth greatly influence our daily lives. The system of longitude and latitude (1) helps us in locating places and (2) provides a method of measuring distances on the earth. Longitude is useful in establishing time belts. The earth's magnetism is useful in the navigation of aircraft and ocean liners.

We have learned the meaning of the lithosphere, the hydrosphere, and the atmosphere. The next few chapters deal with the atmosphere and include mainly a study of weather and climate.

Questions

1. What are the members of the solar system?
2. What is a planet? A satellite?
3. In what order do the planets range from the sun?
4. How do planets differ from stars?
5. About how long does it take the moon to revolve once about the earth? What causes an eclipse of the sun? Of the moon?
6. What is the shape of the earth?
7. What is the greatest ocean depth? The height of the highest mountain?
8. The average depth of the oceans is $2\frac{1}{2}$ miles. How much would this be on a globe 4 feet in diameter and having surface features molded to scale?
9. What is the probable reason for the polar flattening of the earth?
10. The polar diameter of the earth is how many miles? The equatorial diameter? What is the difference between these two diameters? How does the earth's diameter compare with that of Jupiter?
11. What are some effects of the force of gravity? What is a vertical line?
12. What is one method of establishing a true north-south line?
13. What is the lithosphere? The hydrosphere? The atmosphere?
14. What percentage of the earth's surface is water? What percentage land?
15. Why is much of the land surface sparsely populated?

16. What are the two principal motions of the earth?

17. What is the earth's axis? The poles? The circle of illumination?

18. What are some results of rotation of the earth on its axis?

19. What is the average distance from earth to sun?

20. The earth makes one revolution around the sun in how many days? (Find out the periods of revolution of the other planets.)

21. What is the earth's orbit? What is the shape of the earth's orbit? What holds the earth in its orbit?

22. What is the difference between gravity and attraction of gravitation?

23. What is a meteor?

24. What is the plane of the orbit?

25. How much is the earth's axis inclined?

26. What is meant by the parallelism of the axis?

27. What are three results of the combined effects of inclination, parallelism, rotation, and revolution?

28. What is the earth grid? The equator?

29. What are three characteristics of a Great Circle?

30. Why do airplanes and steamships follow Great Circle routes?

31. What is a parallel? Latitude? What is the latitude of the equator? The poles? Why are parallels called *Small Circles?*

32. Why is the Small Circle distance between two points greater than the Great Circle distance?

33. One degree of latitude is about how many miles? What is the latitude of New Orleans? How many miles is it from the equator?

34. What is meant by sun altitude? With what instrument is it measured?

35. In what two ways may latitude be calculated?

36. What is the Tropic of Cancer? The Tropic of Capricorn? The Arctic Circle? The Antarctic Circle?

37. What is the summer solstice? Winter solstice? Vernal equinox? Autumnal equinox?

38. What is a meridian? The prime meridian? Longitude?

39. What point has zero latitude and zero longitude?

40. Where is the international date line? What is the purpose of this line?

41. When it is noon 60°E., at what longitude is it midnight?

42. What is the length in miles of 1° of longitude on the equator? On the 30th parallel? On the 80th parallel?

43. By what method is longitude determined?

44. How is the exact location of a point on the earth's surface expressed?

45. What are the longitude and latitude of New York, London, Peiping, Cape Town, Buenos Aires, Melbourne, Honolulu, and Manila? (Use maps.)

46. How many degrees of longitude equal 1 hour of time?

47. Why was the system of standard time adopted?

48. What determines the standard time of any belt?

49. What are the standard time belts of the United States? When it is 11.00 P.M. in Denver, what is the time in Los Angeles? New York? Chicago?

50. The prime meridian, 0, determines the standard time of London and Paris. When it is noon in St. Louis, Mo., what time is it in London?

51. Where, by longitude and latitude, are the earth's magnetic poles? (Use maps.)

52. Why does a magnetic compass not point true north at most places?

53. What is the agonic line? Magnetic variation? Isogonic line?

54. What is the magnetic variation in your locality? (Magnetic variation is usually shown on topographic maps and always on airway maps.) What is the variation at Pittsburgh? Muskegon, Mich.? St. Louis? San Francisco?

55. In what two ways can you determine true north?

Suggested Activities

1. Construct a homemade sextant. Keep a daily record of the sun altitude at noon for several months. At the time of equinox, the sun altitude substracted from 90° will give your latitude.

2. On a clear night, locate the North Star by means of the Big Dipper. The direction of the North Star is true north.

3. Erect a vertical rod or plumb line, and mark the positions of its shadow at various hours of the day.

4. Practice pointing in the direction of large cities.

5. Observe and record the direction of sunrise and sunset on the twenty-first of June, September, December, and March. Record the sun altitude at noon on these dates and the number of hours of sunlight. Suppose you lived on the Strait of Magellan. How would these observations differ from those made in your own locality?

6. Some people are lost when they enter strange cities. To avoid this, practice reading the maps of cities that you expect to visit. Learn directions from place to place. Maps of cities are found in connection with automobile highway maps. Place your map so that north on the map is really in the direction of north.

7. Make a list of 25 large cities scattered over the various continents. By using maps, determine as closely as possible the longitude and latitude of each.

8. If possible, visit an airport. Observe the magnetic compass, radio compass, and directional radio-beam apparatus.

9. Find out the magnetic variation in your local community.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. The Solar System
2. Proofs that the Earth Is Spherical in Shape
3. The Royal Astronomical Observatory at Greenwich
4. The Locations of Great Circle Routes between Important Cities
5. Standard Time Belts of Europe
6. The International Date Line
7. The Earth as a Huge Magnet
8. Magnetic Variation in Different Parts of North America

REFERENCES

BAKER, R. H.: *Astronomy*, D. Van Nostrand Company, Inc., New York, 1933.

HARRISON, LUCIA: *Daylight, Twilight, Darkness, and Time*, Silver, Burdett & Company, New York, 1936.

KILLEN, ARTHUR H.: *Physiography* (Oxford Series), Oxford Book Company, Inc., New York, 1937.

MOULTON, F. R.: *An Introduction to Astronomy*, The Macmillan Company, New York, 1931.

Regents Bluebook in Physiography, Regents Publishing Company, New York, 1925.

Chapter II. Temperature of the Atmosphere

Man lives on the solid portion of the earth's surface but in, and at the bottom of, a sea of air which is many times deeper than any ocean. This sea of air, or the atmosphere, has certain characteristics that greatly influence man's life. Of the various elements of natural environment that affect the usefulness of the earth's regions for human beings, such as climate, landforms, minerals, soils, and native vegetation, climate probably is the most important single item. This is because climate affects a region's usefulness not only directly but also indirectly through its influence upon native vegetation, soils, and landforms. Thus large areas with similar climates are likely to have strong resemblances also in vegetation and soils.

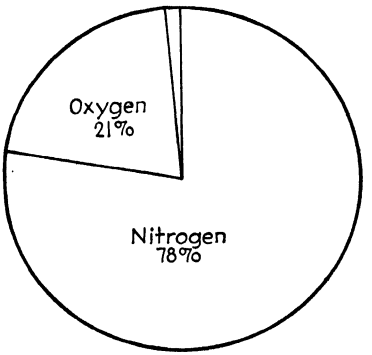


FIG. 19.—The atmosphere is composed mainly of nitrogen and oxygen. Both are colorless, odorless gases.

Pure, dry air near sea level is a mechanical mixture of a number of gases. Two of them, nitrogen (78 per cent) and oxygen (nearly 21 per cent), together comprise 99 per cent of the total by volume (Fig. 19). At higher elevations, certain lighter gases, especially hydrogen, predominate. In the atmosphere also are smaller amounts of carbon dioxide, argon, ozone, and others. In addition to these gases the lower layers of air contain variable amounts of water vapor (up to nearly 5 per cent on hot, humid days) and numerous impurities classed as dust.

As far as climate and weather are concerned, certain of the minor gases of the air are far more important than nitrogen and

oxygen. Subtract the single item, water vapor, from the air, and rainfall would cease. This invisible vapor condenses to form clouds, fog, dew, frost, rain, snow, sleet, and hail. Water vapor acts as a sort of blanket in helping to regulate the temperature of the air, because it readily permits sun energy to reach the earth but tends to retard the radiation of heat from the earth.

Certain kinds of dust particles serve as nucleuses upon which water vapor condenses to form raindrops. Dust in the air is largely responsible for the colors of sunrise and sunset, the blue of the sky, and the occurrence of twilight and dawn. Abundant smoke and dust over large cities act as a screen to incoming sunlight and greatly hinder visibility. A combination of smoke and fog is known as *smog* and at times, especially near cities, is a severe hindrance to aviation.

Elements of Weather and Climate. The principal elements of the atmosphere that largely determine the weather or climate at any given time or place are temperature and precipitation (including humidity and clouds). In addition to these are such elements as atmospheric pressure, winds, storms, and visibility. Weather is the sum total of these elements for a short period of time. Two friends meet on the street and speak of the weather for today or of last week. Climate is the generalization of the great variety of weather conditions over a long period of time.

The Controls of Weather and Climate. Variations in weather and climate are due to the climatic controls, which are (1) latitude, which largely determines (*a*) the angle of the sun's rays and thus their effectiveness and (*b*) the duration of sunlight; (2) distribution of land and water; (3) winds; (4) elevation; (5) mountain barriers; (6) the great semipermanent high- and low-pressure centers; (7) ocean currents; and (8) storms of various kinds. These controls, acting with various intensities and in different combinations, produce changes in temperature, which in turn give rise to varieties of weather and climate. It is well to remember that climatic controls acting upon climatic elements produce various types of weather and climate.

Temperature

Sources of Atmospheric Heat. The sun is the most important source of heat for the earth's atmosphere. Out into space

from this gigantic body, whose diameter is more than one hundred times that of the earth and whose surface temperature is estimated to be more than 10,000°F., streams a tremendous amount of energy. The earth, nearly 93 million miles distant, intercepts only a tiny part of this output. The radiant energy received from the sun, transmitted in the form of short waves and traveling at the rate of 186,000 miles per second, is called *solar radiation*, or *insolation*. To the small amount of insolation received at the earth's surface most of the physical and all the biological phenomena of the earth owe their existence. The distribution of insolation over the earth's surface is of outstanding significance in understanding weather and climate. Certainly the sun, or insolation, is the greatest single control of climate.

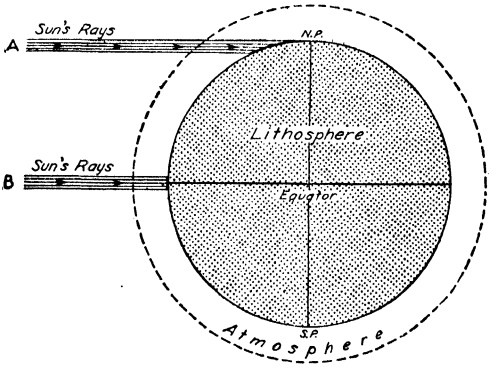


FIG. 20.—Rays that are slanting (*A*) as they reach the earth deliver less energy at the earth's surface than vertical rays (*B*), for two reasons: They must pass through a thicker layer of atmosphere, and they spread their energy over a wider area.

Effectiveness of Insolation. The amount of insolation received at any given place depends mainly upon (1) the length of day (number of hours of sunlight) and (2) sun altitude, or the angle at which the sun's rays strike the earth. For two reasons oblique solar rays deliver less energy to the earth's surface than direct rays: (1) Oblique rays are spread over a larger area than are direct rays; (2) oblique rays pass through much more air than direct rays, and the air tends to absorb, scatter, and reflect some of the solar energy (Fig. 20). Winter sunlight, therefore, is much weaker than that of summer. At Kansas City, Mo., 39° N.Lat., for example, the noon sun altitude around December 21 is about 28°; in the latter part of June it is about 74°. Added

to this great difference in the angle of the sun's rays is the fact that there are many more hours of sunlight in June than in December.

LENGTH OF THE LONGEST DAY (ALSO OF THE LONGEST NIGHT IN THE OPPOSITE HEMISPHERE) AT CERTAIN LATITUDES

Latitude	Equator	17°	41°	49°	63°	66½°	67°21′	69°51′	78°11′	90°
Duration (hr.)	12	13	15	16	20	24	1 mo.	2 mo.	4 mo.	6 mo.

The earth is some 3 million miles closer to the sun in January than in July. That there is a cold season in the Northern Hemisphere at the time when the earth is nearest the sun and a warm season when it is farthest from the sun tends to emphasize the fact that this item of distance is minor compared with length of day and the angle of the sun's rays. In general, it is well to remember that the higher the sun altitude and the longer the days the higher the temperature; and the lower the sun altitude and the shorter the days the lower the temperature.

Much sun energy that reaches the earth's outer atmosphere is prevented from heating the earth's surface. A considerable percentage is lost by reflection from clouds, small dust particles, molecules of air, and the earth's surface. Some 10 to 15 per cent is absorbed directly by the atmosphere. About 50 per cent reaches the earth's surface, heats it, and eventually heats the atmosphere as well.

Seasons. An explanation of the change of seasons as regards temperature is given in Appendix A and should be studied carefully at this point. The inclination and parallelism of the earth's axis are responsible for the day-to-day change in sun altitude and length of day resulting in the change of seasons. One should constantly bear in mind that the *time* of seasons in the north and south intermediate zones is reversed. When it is summer in the United States, it is winter in Argentina. The change of seasons in the intermediate zones is much more pronounced in the interiors of large continents than along windward coasts where ocean influence is felt.

Heating and Cooling of Land and Water Surfaces

Land and Water Contrasts. Sun energy is of such a nature that only relatively small amounts (10 to 15 per cent) of it can be absorbed by the earth's atmosphere. In order to be absorbed by

the air, it must first be converted into heat energy given off by the earth. This conversion takes place principally at the earth's surface. Thus the atmosphere receives most of its heat directly from the earth's surface and only indirectly from the sun.

For the following reasons land surfaces heat and cool more rapidly than water surfaces:

1. Much more heat is required to raise the temperature of 1 cubic foot of water 1° than is required for 1 cubic foot of soil or rock.[1]

2. The sun's rays penetrate to considerable depths in water and are thus required to heat a greater mass than is the case with land. Since land is opaque, only the surface layers of soil and rock are heated to any extent.

3. Water, being a fluid, has movements in the form of waves, drifts, currents, and tides that tend to distribute the absorbed solar energy throughout the whole mass. Obviously, no such distribution and mixing can take place in landmasses, and the land surface, therefore, attains a higher temperature. Moreover, when a water surface begins to cool, convectional currents are set up, the cooler, heavier surface layers sinking and being replaced by warmer waters from underneath. Therefore, water bodies cool much more slowly than do land bodies and tend to act as regulators of air temperature.

From the foregoing comparisons it becomes evident that, with the same amount of solar energy falling upon each, a land surface will reach a higher temperature, and reach it more quickly, than a water surface. Conversely, a land surface also cools more rapidly. Land-controlled, or *continental*, climates, therefore, should be characterized by large daily and seasonal extremes of temperature; on the other hand, ocean-controlled, or *marine*, climates should be more moderate.

How the Atmosphere Is Warmed

We are now acquainted, as a result of our earlier discussion, with the distribution of solar energy over the earth and the

[1] *Specific heat* is the term applied to the amount of heat (calories) required to raise the temperature of 1 gram of a substance 1°C.

contrasting reactions of land and water surfaces to this solar energy. We are also aware that the air receives most of its energy directly from the surface upon which it rests and only indirectly from the sun. This is sufficient background for an analysis of the processes involved in heating and cooling the atmosphere.

Absorption of Sun Energy. As previously stated, the atmosphere absorbs directly only about 10 to 15 per cent of the solar energy that comes to it. Such absorption takes place mainly in the upper layers of the air. This process, therefore, is not very effective in heating the layers of air close to the earth. Often on a clear winter day, when snow covers the ground, air temperatures may remain bitterly cold in spite of a bright sun. At the same time, on the south side of a brick building, the temperature may be much more comfortable. This is because the brick wall absorbs sun energy and converts it into a form of heat energy that is effective in warming the surrounding air.

Conduction from the Warm Earth. *Conduction* refers to the transfer of heat (1) through a substance, such as a metal rod, and (2) from a warm substance to a cooler one, provided they are in contact. During the daylight hours the solid earth (without a snow cover) absorbs much solar energy and becomes warmer than the surrounding atmosphere. By conduction, therefore, the layer of air resting upon the warmer earth becomes heated. Air, however, is a poor conductor. As a result, the transfer of heat from the lower, warmed layers of air to those above is very slow. It is a well-known fact that, ordinarily, as one goes up in the air the temperature drops.

The Air Absorbs Heat Radiated from the Earth. Since the earth absorbs solar energy, it becomes warm and therefore radiates heat just as the sun does. This heat radiated from the earth is readily absorbed by the air. It is estimated that, although only 10 to 15 per cent of the solar energy is absorbed by the atmosphere, some 90 per cent of the radiated earth energy is absorbed. As stated before, water vapor and, to a lesser extent, carbon dioxide and ozone are the principal absorbing gases. One reason for the rapid night cooling in deserts is that the dry air and clear sky permit a more rapid escape of the heat that is radiated from the earth. One may think of the atmosphere as being somewhat like a pane of glass which lets through most of the incoming

solar energy but greatly retards the outgoing heat, or earth radiation. This is the so-called *greenhouse effect* of the atmosphere.

Through the first three heating processes described above, there is actually an addition of energy to the atmosphere. Through the three processes whose description follows, there is no addition of energy but only a transfer from one place to another, or from one air mass to another, of that which already has been acquired.

Convectional Currents from the Warm Earth. The surface air after being heated by conduction and radiation expands in volume and consequently decreases in density.[1] Because of expansion, a portion of the warmer, lighter column of air overflows aloft, thereby decreasing its own pressure at the surface and at the same time increasing that of the adjacent cooler air. This causes a lifting of the warmer, lighter air column by the heavier, cooler, settling air which flows in at the surface to displace it. Such a circulation as described above and illustrated in Fig. 21 is called a *convectional system.* Warm surface air, expanded and therefore less dense, is like a cork that is held under water, *i.e.*, it is unstable and inclined to rise. This convectional principle (which applies to liquids and gases only) is employed in the ordinary hot-air and hot-water heating systems. On a hot summer day "bumpy" air is experienced when an airplane alternately crosses rising and sinking air currents.

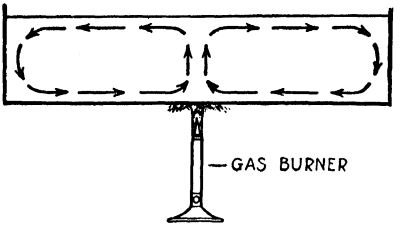


FIG. 21.—Representation of a convectional circulation.

Conduction and radiation are especially effective in heating the lower layers of atmosphere, but convection, on the other hand, is capable of carrying heat to the upper air strata as well.

Importation by Air Masses or Winds. "It will be warmer today because there is a south wind." Such a remark is common in many parts of North America and Europe. The south wind may be an air mass of tropical origin which is advancing northward. In so doing, it conveys the temperature conditions acquired in its source region where high temperatures are normal.

[1] Density means weight per unit volume.

Such an importation of southerly warmth in winter results in mild weather, with melting snow and sloppy streets. In summer several days of south wind may result in a "hot wave" with maximum temperatures of 90° to 100° or above.

Heating by Compression. A mass of air generally becomes warmer as it descends from higher to lower altitudes, *e.g.*, when it moves down a mountain slope. At lower altitudes, a thicker layer of air is pressing down upon the descending air mass, which gradually is being compressed in volume. Work is being done upon the descending air, and as a result of compression its temperature is increased.

How the Atmosphere Is Cooled

Radiation to the Cooler Ground and to Space. During the night the earth's surface may radiate heat so rapidly that it becomes cooler than the air above it. When this condition prevails, the lower layers of atmosphere lose heat by radiation to the colder ground as well as upward toward space. This process is particularly effective during the long nights of winter when, if the skies are clear and the air is dry and calm, very rapid and long-continued radiation takes place. If snow covers the ground, cooling is even more pronounced. This causes a greater decrease in the temperature of the lower layers of air.

Water, like land, is a good radiator, but the cooled surface waters keep constantly sinking to be replaced by warmer currents from below. Extremely low air temperatures over large water bodies are impossible, therefore, until they are frozen over, after which they act like a snow-covered land surface. Humid air or a cloudy sky tends to prevent rapid earth radiation, so that air temperatures remain higher. Thus frosts are less likely to occur on humid nights and especially when a cloud cover prevails. There are authentic cases in the dry air and under the cloudless skies of the Sahara Desert in northern Africa, where day temperatures of 90° have been followed by night temperatures slightly below freezing.

Conduction to the Cold Earth. As previously stated, conduction is the transfer of heat between two substances that are in contact. As the earth's surface cools during the night, conduction of heat from air to earth causes a lowering of air temper-

ature. Often on a calm clear winter or summer night, the layers of air close to the earth actually become colder than those at some distance above the earth's surface.

Importation by Air Masses or Winds. Just as warm air masses carry warmth northward (south wind in the Northern Hemisphere), so likewise do cold air masses convey low temperatures from one place to another. Especially in North America and Eurasia, cold polar air masses from the far north may move southward for considerable distances. Such movement (north wind) and resulting importation of low temperatures are particularly effective where there are no mountain barriers to block the passage of air. In eastern North America where lowlands prevail, great masses of cold polar air periodically pour down over the Mississippi Valley, occasionally carrying severe frosts even to the Gulf states.

Cooling by Expansion. Just as descending air heats as a result of compression, so rising air cools as a result of expansion. A cubic foot of air at low altitudes is subject to greater atmospheric pressure than at high altitudes. As this cubic foot of air rises, it expands because the weight of the atmosphere upon it becomes less. Work is done in pushing aside other air in order to make room for itself. This work done by the rising and expanding air consumes energy, which is subtracted from the ascending currents in the form of heat, resulting in a lowering of their temperature. On the average, rising air cools about 5°F. for each 1,000 feet.

Daily and Seasonal March of Temperature

All average temperatures for a month, season, year, or even a long period of years are built upon the mean (average) daily temperature as the basic unit. The daily mean is thus the individual brick out of which the general temperature structure is composed. The U.S. Weather Bureau at present uses the following formula to determine the mean daily temperature:

$$\frac{\text{Maximum} + \text{minimum}}{2}$$

In other words, the daily mean is the average of the highest and the lowest temperatures recorded during the 24-hour period.

Daily Temperatures. The daily march of temperature refers to the hourly changes in the thermometer readings during the day (24 hours). From about sunrise until 2 to 4 P.M., when energy is being supplied by incoming solar radiation faster than it is being lost by earth radiation, the temperature curve usually continues to rise. Conversely, from about 3 P.M. to sunrise, when loss by earth radiation exceeds receipts of solar energy, the daily temperature curve usually falls. It is noticeable, however, that the time of highest temperatures (2 to 4 P.M.) does not exactly coincide with that of maximum insolation (12 M. sun time).

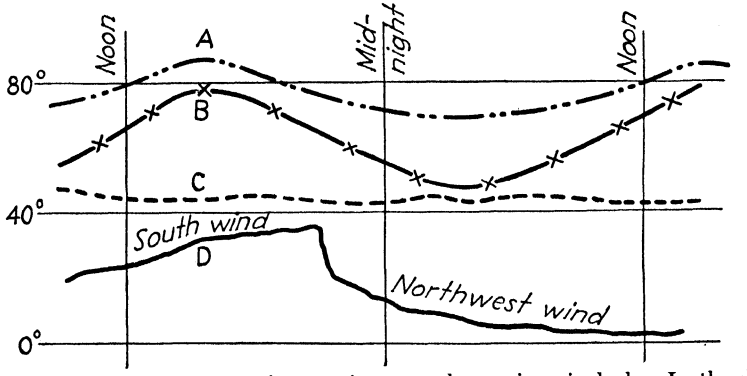


FIG. 22.—Temperature sometimes varies many degrees in a single day. In the chart above, *A* shows the temperature range for a fair day in summer; *B*, for a summer day in the mountains. Contrast these with *C*, a cloudy day in spring or fall, and *D*, a winter day on which the wind changed from south to northwest.

This is because incoming solar radiation continues to exceed outgoing earth radiation until midafternoon. The lowest temperatures of the night usually occur about 4 to 6 A.M. because the earth continues to radiate more heat than it receives until near sunup.

The *daily range of temperature* is the difference between the highest and lowest temperatures of the day. In clear weather, throughout most of central and eastern United States, this range is about 10° or 15°. In mountains it is much greater, because the less dense atmosphere at high elevations permits more rapid radiation of heat from the earth at night, and consequently lower temperatures result. Daily range is usually greater in deserts than in humid lands, because the low percentage of water vapor in the air over deserts and the general absence of a cloud cover permit rapid radiation of heat from the earth at night.

During a spell of cloudy weather the daily range may be as little as 5° or less. A cloud cover regulates air temperature, because clouds serve to obstruct incoming and outgoing radiation. However, in clear or cloudy weather, the daily march of temperature may be entirely upset by a shift in wind direction. Thus a strong northwest wind may cause a steady drop in temperature during the day so that midafternoon may be colder than early morning (Fig. 22).

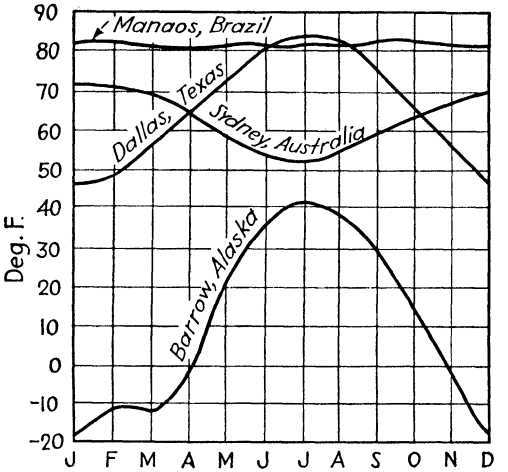


FIG. 23.—The seasonal range of temperature. Note that the coolest month at Sydney, Australia, is July.

The Seasonal March of Temperature. Using the mean daily temperatures, the average or mean temperature of a month may be calculated. This in turn may be used to compute the mean annual temperature. Mean monthly temperatures make it possible to obtain some idea of seasonal changes in temperature in different parts of the world. It is well to remember, however, that in some localities the mean monthly temperature may cover a considerable range. For example, although the mean January temperature at Kansas City, Mo., is 28°, the temperature may actually range from 10° below zero to 45° above during the month. Such extreme changes, however, do not occur on windward coasts (where wind generally blows from sea to land). In the middle latitudes of the Northern Hemisphere, July is usually the warmest month, and January the coldest. Conditions are

reversed in similar latitudes of the Southern Hemisphere (Fig. 23).

Vertical Distribution of Temperature

Temperature Decreases with Altitude. By means of airplanes and balloons, men have soared to considerable heights in the atmosphere. They have recorded temperature readings during such flights. Self-recording instruments, carried aloft by smaller balloons, have reached greater heights. All such observations and recordings show that under normal conditions there is a decrease in temperature as altitude increases. The amount of decrease, of course, varies somewhat from place to place and at different times of the year. On the average, however, the decrease in temperature as altitude *increases*, called the *lapse rate*, is about 3°F. per 1,000 feet. The fact that air temperature decreases as distance from the earth increases emphasizes the fact that the atmosphere receives most of its heat directly from the earth and only indirectly from the sun.

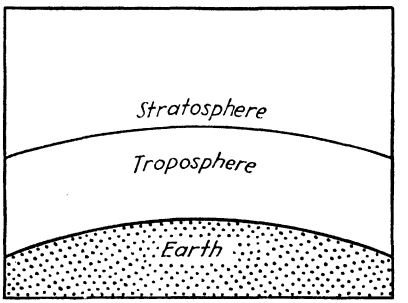


FIG. 24.—The atmosphere is composed of two principal layers, the troposphere and the stratosphere. The elevation of the lower side of the stratosphere in the United States is approximately 7 miles. It is higher at the equator and lower at the poles.

Stratosphere and Troposphere. The average lapse rate of 3°F. per 1,000 feet continues until an elevation of about 7 miles (about 37,000 feet) is reached. From this elevation upward for several miles there is little change in temperature, and to this region the name *stratosphere* has been applied. In it temperatures have been found to be in the neighborhood of −60° to −70°F., although above the equator −110°F. has been recorded. Thus it is possible to think of the earth's atmosphere as composed of two shells or layers. In the outer layer, or stratosphere, temperatures are very low, clouds are absent, dust and water vapor are at a minimum, convectional currents are lacking, and all air movement is horizontal. Below the stratosphere is the turbulent, dusty layer known as the *troposphere*, which contains much water vapor and also clouds, and in which temperature de-

creases with increasing altitude (Fig. 24). For reasons already mentioned, the stratosphere or substratosphere offers certain advantages for long-distance airplane flights.

Air Drainage. Cold air is heavier than warm air. As a result, cold air next to the earth's surface, because of its greater weight, tends to flow downhill and to collect in valleys and lowlands. This is called *air drainage* (Fig. 25). It is a well-known fact that the first frosts of autumn and the last in spring occur in bottom lands and that the lowest temperatures on calm, clear winter nights are found in similar locations. Citrus orchards in California, which might be damaged by frost, are located on hill slopes where air drainage causes a slipping off of the frosty air. Coffee in Brazil is prevailingly planted on the rolling uplands, and the frosty valleys are avoided. Resort hotels in the Swiss Alps shun the cold, foggy valleys and choose instead sites on the brighter and warmer slopes.

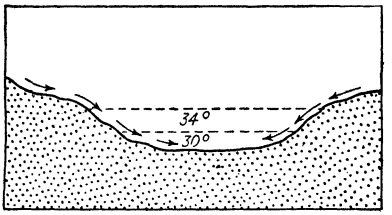


FIG. 25.—Cold air, because it is denser, tends to settle into the valley bottoms. For this reason frost is more prevalent and more severe in low places than it is on adjacent slopes.

On clear, cold nights when air drainage is prevalent, the atmosphere is very stable. The heaviest air is at the lowest elevation where, on the basis of density, it should be. There is no inclination for it to rise. This is quite opposite to the unstable condition of the atmosphere on a hot summer day, when the heated and expanded air near the earth's surface is like a cork held under water.

Conditions Favorable for Frost. The term *frost* may be applied either (1) to the white deposits of condensed water vapor in solid form or (2) to a temperature of 32°F. or below, even though there is no deposit of white frost. There are frosts of various degrees of severity, but it is the "killing frost" that is of principal interest. A killing frost may be defined as a temperature condition so low that the economic crops of a locality are damaged. Throughout much of North America, frosts are of chief significance in autumn and spring. The *growing season* is the number of frost-free days between the last killing frost in spring and the first in autumn (Fig. 26). The length of the growing

season has a considerable influence upon the types of economic crops that may be produced in any given region.

Ideal conditions for the occurrence of frost are those which are favorable to rapid and prolonged surface cooling, *viz.*, (1) a preliminary importation of a mass of chilly polar air, (2) followed by clear, dry, calm nights, during which the temperature of the surface air, because of radiation and conduction, may be reduced below freezing. The original importation provides the necessary mass of cool air whose temperature is already rela-

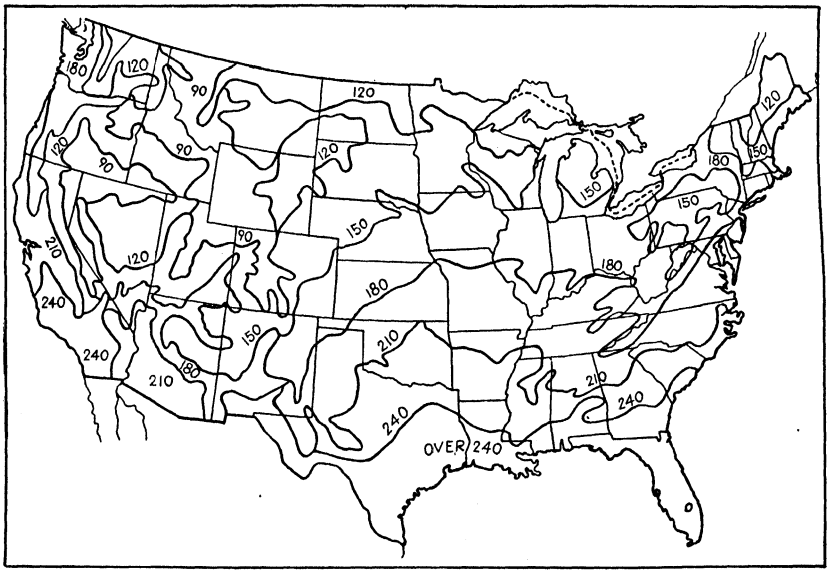


FIG. 26.—The average "frostless," or "growing," season throughout the United States is shown on this map. Figures indicate number of frost-free days. (*After map by U.S. Weather Bureau.*)

tively low, although still somewhat above freezing, but further rapid loss of heat by earth radiation during the following clear night is all that is necessary to reduce the temperature of the surface air below freezing. In central and eastern United States the dry, cold air mass usually arrives with northwest winds. If the daytime temperature of the cold air mass is in the neighborhood of 40°, frost may be expected the following night, especially if the sky is clear and the air calm.

Frost Protection. The problem of artificial protection from frost is of considerable importance, especially in the valuable citrus groves of California and Florida. In these regions, orchard

heaters are used in an attempt to prevent a bad freeze (Fig. 27). Large numbers of such heaters are spaced among the fruit trees and are kept burning for several hours during the time when freezing temperatures are expected. Sometimes the smoke from numerous heaters drifts into a near-by city where it may prove a considerable nuisance.



FIG. 27.—Orchard heaters are placed at regular intervals between rows of orange trees in a citrus grove when fruit is endangered by frost. These shown are of the oil-burning variety, most common in California groves. Coke heaters also are used. (*Courtesy of California Fruit Growers Exchange.*)

For small-scale vegetable gardeners or fruit growers, the simplest and most effective means of frost protection is to spread over the crop a nonmetallic covering such as paper, straw, or cloth. Such a covering tends to intercept the heat that is radiated from the ground and plants at night. The purpose of the cover, obviously, is not to keep the cold out but to keep the heat in. This inexpensive type of frost protection is the one resorted to by the housewife in saving her garden plants from freezing.

Temperature Distribution over the Earth

Isothermal Maps. An *isotherm* is a line connecting places of the same temperature. Thus all points of the earth's surface

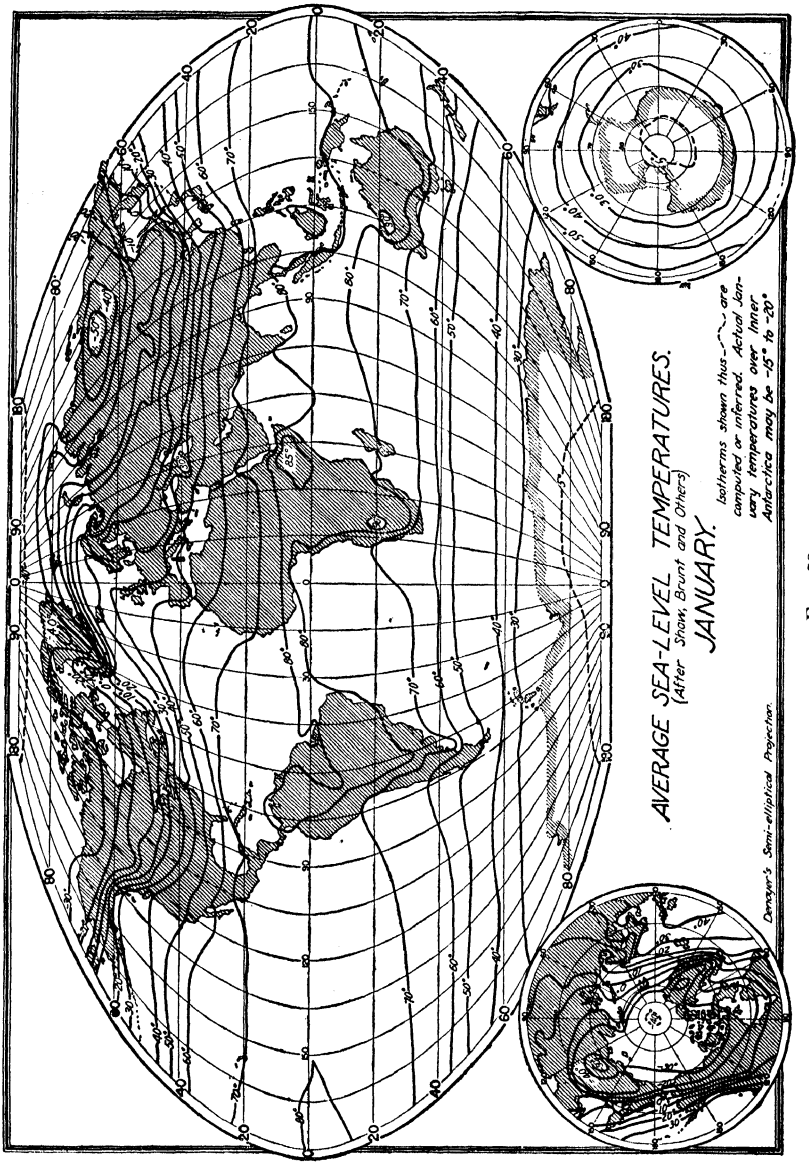

AVERAGE SEA-LEVEL TEMPERATURES.
(After Shaw, Brunt and Others)
JANUARY.
Isotherms shown thus ~ are computed or inferred. Actual January temperatures over inner Antarctica may be -15° to -20°.
Denoyer's Semi-elliptical Projection.

FIG. 28.

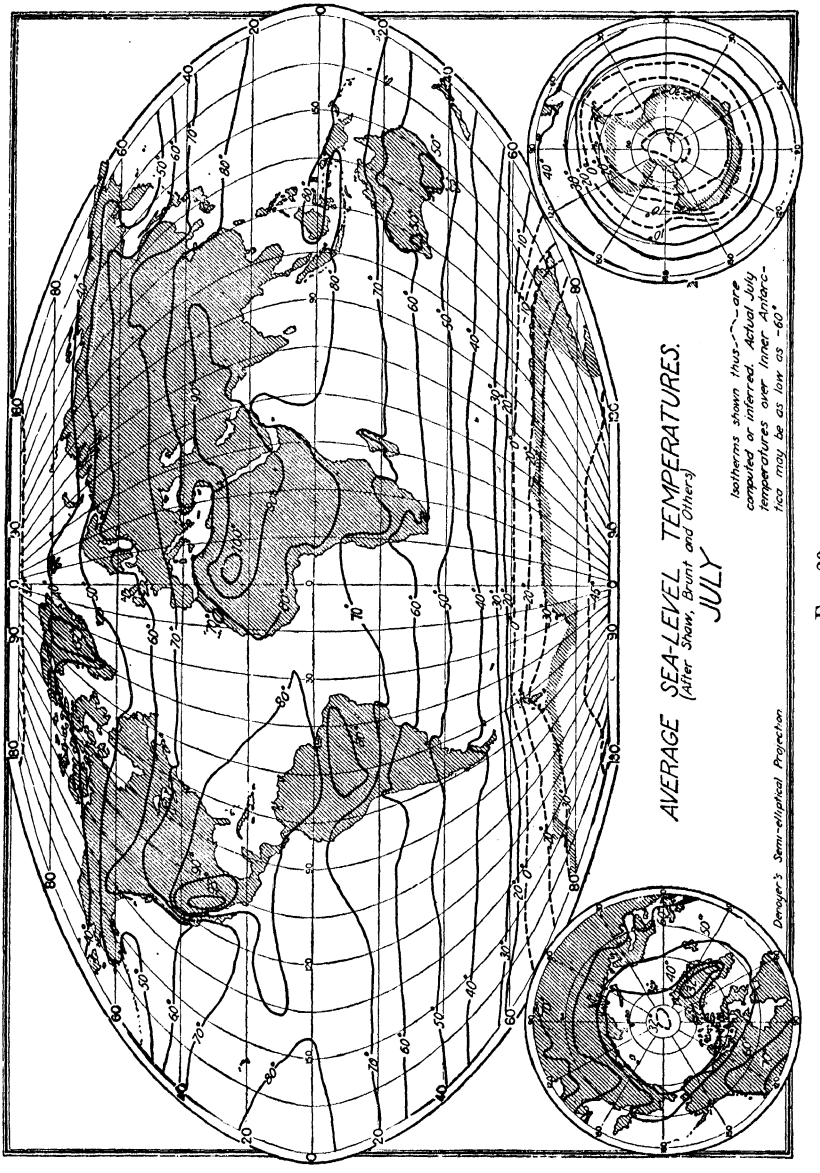

AVERAGE SEA-LEVEL TEMPERATURES.
(After Shaw, Brunt and Others)
JULY
Isotherms shown thus:—— are computed or inferred. Actual July temperatures over inner Antarctica may be as low as −60°
Denoyer's Semi-elliptical Projection

FIG. 29.

through which any one isotherm passes have identical average temperatures (Figs. 28, 29). On the maps here shown, all temperatures have been reduced to sea level so that the effects of altitude are eliminated. If this were not done, the complications and details caused by mountains and other lesser relief forms would make the maps so confusing that the general world-wide effects of latitude and land-and-water distribution would be difficult to perceive. It will be noted that the isotherms in general trend east and west, roughly following the parallels. This east-west trend indicates that latitude is the greatest single cause of temperature differences over the earth's surface.

General Features of Temperature Distribution. A study of the isothermal maps of the world reveals the following general features:

1. The highest average annual temperatures are in the low latitudes, where the largest amounts of insolation are received. The average lowest temperatures are in the vicinity of the poles, the regions of least annual insolation.

2. Isotherms tend to be straighter and are also more widely spaced in the Southern Hemisphere, where the surface is largely composed of water.

3. The greatest departures from east-west courses are in localities where isotherms pass from continents to oceans or vice versa. That is caused by the contrasting heating and cooling properties of land and water surfaces and the effects of ocean currents. The distribution of land and water bodies ranks next to latitude in the control of temperature distribution. Cold ocean currents off the coasts of Peru and northern Chile, southern California, and southwestern Africa make themselves conspicuous through the equatorward bending of the isotherms. Similarly, warm currents in higher latitudes cause isotherms to bend poleward. This condition is most marked off the coast of northwestern Europe owing to the effects of the Gulf Stream.

January and July Temperatures. For the earth in general, January and July represent the seasonal extremes of temperature. The following are some of the more significant features of temperature distribution as shown on the seasonal maps: (1) The isotherms and temperature belts move north and south, following the north-south migration of the sun's more vertical

rays. (2) The north-south shifting is greater over continents than over oceans, because of greater extremes of temperature over landmasses. (3) The highest temperatures on both the January and the July maps are over land areas. The lowest temperatures in January are over Asia and North America, the largest of the landmasses in middle latitudes. (4) In January in the Northern Hemisphere isotherms bend toward the equator over the colder continents and toward the poles over warmer oceans. In July the opposite conditions prevail. (5) Temperature differences between land and water are less pronounced in the Southern Hemisphere because of the absence of great landmasses. (6) The so-called *cold pole* of the earth is in Siberia, where temperatures of 90° below zero have been recorded.

The *annual range of temperature* is defined as the difference between the average temperatures of the warmest and coldest months. The approximate annual range at any given place can be learned from study of the isothermal maps. Notice, for example, Duluth, Minn. On the July map the nearest isotherm is 70°; on the January map it is zero, an annual range of about 70°. The greatest annual ranges are over the Northern Hemisphere continents, which alternately become hot in summer and cold in winter. Low annual range is observed (1) near the equator, where insolation varies little, and (2) over large bodies of water, which change temperature much more slowly than land areas. The predominance of water in the Southern Hemisphere results in much smaller annual ranges of temperature than in the Northern Hemisphere. Thus the change of seasons at any given place, as regards temperature, is clearly shown by these two maps.

Air Temperature and Sensible Temperature. Correct air temperature can be obtained only by an accurate thermometer properly exposed. One of the principal items of correct exposure is to see that the instrument is not in the sun; otherwise it receives energy not only from the surrounding air but from the absorption of insolation as well. It also should be protected from direct radiation from the ground and adjacent buildings.

Sensible temperature refers to the sensation of temperature which the human body *feels*, as distinguished from actual air temperature which is recorded by a properly exposed thermom-

eter. The human body is a heat engine, generating energy at a relatively fixed rate when at rest. Anything, therefore, that affects the rate of loss of heat from the body affects physical comfort. Air temperature, of course, is an important element, but so also are wind, humidity, and sunlight. Thus a humid, hot day is more uncomfortable than one of dry heat with the same temperature, since the loss of heat by evaporation is retarded more when the air is humid. A windy, cold day feels uncomfortable because the loss of heat is speeded up by greater evaporation. A sunny day in winter feels less cold than it actually may be, because of the body's absorption of direct insolation. Cold air containing moisture particles feels colder than dry cold air. This is because cold-water particles collect on the skin. By conduction, heat is transferred from the skin to the tiny water droplets. Evaporation of the water particles also contributes to a lowering of temperature. Because of its sensitiveness to factors other than air temperature, the human body is not a very accurate thermometer.

Summary

The atmosphere is warmed mainly by the earth, which absorbs sun energy. If the earth's surface is warm, the air above it is likely to be warm. A land surface heats and cools more rapidly than water. Convection currents carry warm air up and cool air down. Rising air cools about 5°F. per 1,000 feet. Roughly, the atmosphere may be divided into two layers called the troposphere and the stratosphere. A thermometer carried upward through the troposphere will show a drop of about 3° per 1,000 feet. This is called the lapse rate. Note that rising dry air, because of expansion, cools faster than the normal drop in temperature with elevation. In the stratosphere temperature is fairly constant. Seasonal changes in temperature are much greater in middle and high latitudes than in the vicinity of the equator.

Cold air is heavier than warm air. As air changes temperature, it also changes weight or pressure. Differences in atmospheric pressure over the earth's surface cause the air to move. Our next chapter, therefore, deals with the subject of atmospheric pressure and winds.

Questions

1. What are several elements of environment? Why is climate a most important one?
2. Name the principal constituents of the atmosphere.
3. Why is water vapor in the air so important?
4. How does water vapor influence air temperature?
5. What are a few effects of dust in the air?
6. What is smog? Where is it most likely to occur?
7. What are the weather elements? Which two are most important?
8. What is meant by weather? Climate?
9. What are the climatic controls?
10. What is the most important source of heat for the earth's atmosphere?
11. What is meant by insolation? Sun altitude?
12. What two factors determine the effectiveness of insolation?
13. Why are oblique sun's rays less effective than direct rays?
14. Winter occurs in the United States when the earth is nearest the sun. Why?
15. In general, what is the relation of sun altitude and length of day to temperature?
16. Approximately, what is the length of the longest day (duration of sunlight) at Singapore? Winnipeg? Point Barrow, Alaska? The North Pole?
17. Why does the atmosphere receive most of its heat indirectly from the sun?
18. How do land and water surfaces differ with regard to absorption of solar energy?
19. The sun's rays penetrate water. How does this influence the rate of heating of a water body?
20. What is the effect of reflection and evaporation on heating a body of water?
21. When water is heated, convection currents are set up. Why does this process retard the heating of a water body?
22. Why do water bodies act as regulators of air temperature?
23. Since land heats and cools faster than water, where should you expect extreme climates? Moderate climates?
24. On a clear, cold day, with snow on the ground, the temperature often remains low in spite of a bright sun. Why?
25. How is the atmosphere warmed by conduction?
26. What percentage of earth radiation is absorbed by the air? Mainly by what constituents of the air?

27. What is meant by the greenhouse effect of the atmosphere?

28. What is meant by convection? How does convection distribute temperature in the atmosphere?

29. What causes the "bumpy" air encountered by airplanes? Why is air more bumpy over land than over sea?

30. How does wind direction affect temperature?

31. Why does air become warmer when descending a mountain slope?

32. Why does the atmosphere usually cool at night?

33. What conditions promote rapid cooling of the atmosphere at night?

34. When is frost more likely to occur, on a clear or a cloudy night? Why?

35. What extreme day and night temperatures are sometimes experienced in the Sahara Desert? Why?

36. How is the atmosphere cooled by conduction? By winds?

37. Why does warm air cool as it rises? What is the rate of cooling?

38. How is mean daily temperature calculated? What is meant by daily range of temperature?

39. How is the daily range affected by mountains? Deserts? A cloud cover?

40. What is meant by the seasonal march of temperature?

41. What is meant by the lapse rate? What does it average?

42. What is the altitude of the stratosphere? What are its characteristics?

43. How does the troposphere differ from the stratosphere?

44. What is meant by air drainage?

45. What is one important result of air drainage?

46. Give an example of stable and unstable air.

47. What are the two meanings of the term *frost?*

48. What are the ideal conditions for frost formation?

49. What is one method of frost protection?

50. What is an isotherm?

51. Why are temperatures reduced to sea level on some world isothermal charts?

52. What are three general features of world-temperature distribution?

53. What are some significant features of temperature distribution shown by the isothermal charts for January and July?

54. What is meant by annual range of temperature? In what regions is the annual range greatest? Lowest?

55. Why should a thermometer not be placed in the sun when measuring air temperature?

56. Why is a hot, humid day so uncomfortable?

Suggested Activities

1. Record the sun altitude at noon daily for several months.

2. Secure from the Superintendent of Documents, Government Printing Office, Washington, D.C., a copy of the *Nautical Almanac* which, along with other interesting information, gives the declination of the sun (latitude of the vertical ray) for a year in advance. Keep a record of this declination alongside your record of sun altitude.

3. Keep daily records of outdoor temperatures, using both Fahrenheit and centigrade scales.

4. If possible, get a thermograph, and place it outside a north window where it will be easily visible from within. Try to explain temperature changes as shown by it.

5. Using weather-bureau data, plot curves to show the daily and annual march of temperature at a number of selected places.

6. In winter, test the rapidity of melting of clean snow as contrasted with that of dirty snow. Explain.

7. If possible, make inquiry of air transport companies or pilots concerning the effects of convectional air currents on airplanes. At many airports you can see the weather data of the upper atmosphere secured from balloon and airplane soundings. Make notes of any interesting and significant facts that you discover. Notice the maps or charts of the upper atmosphere that the weather-bureau men make and study. These upper air observations aid in advising aviators concerning flights and in more accurately forecasting the weather.

8. If you drive through the country in autumn or spring, note the prevalence of valley frosts caused by air drainage.

9. One member of the class may be appointed to write to the Government Printing Office in Washington for a list of publications dealing with weather and climate. Many of these can be purchased at relatively low cost, and it may be desirable to have several on hand.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. The Sun as a Source of Energy

2. The Stratosphere Balloon Flight from the Black Hills (See *National Geographic Magazine* for January, 1936)

3. Possibilities of Long-distance Airplane Flights in the Stratosphere

4. World's Records of High and Low Air Temperatures
5. Low Temperatures Recorded by Balloons at High Altitudes
6. Temperature Contrasts over Land and Water Areas in Similar Latitudes
7. Damage Done by Severe Frosts (See U.S. Weather Bureau publications)
8. Distribution of Temperature over North America in July and January

References

BLAIR, THOMAS A.: *Weather Elements*, Prentice-Hall, Inc., New York, 1937.

DUNCAN, RICHARD: *Air Navigation and Meteorology*, The Goodheart-Wilcox Company, Chicago, 1930.

GREGG, WILLIS R.: *Aeronautical Meteorology*, The Ronald Press Company, New York, 1930.

TREWARTHA, GLENN T.: *An Introduction to Weather and Climate*, McGraw-Hill Book Company, Inc., New York, 1937.

"Weather Forecasting," *Bulletin* 42 of the U.S. Weather Bureau, Government Printing Office, Washington, D.C.

Chapter III. Atmospheric Pressure and Winds

Compared with temperature and precipitation, atmospheric pressure and winds are relatively insignificant as elements of weather and climate. To be sure, winds of high velocity may be dangerous to man's crops and structures. There are, as well, certain physiological reactions to strong air movement. But the sum total of these direct effects of wind is not of first importance. Still less is human life directly affected by the slight changes in air pressure that occur at the earth's surface. Although imperceptible to our bodies, these pressure differences are the reason for the existence of winds. Therefore, although not directly of first importance as climatic elements, both pressure and winds are indirectly of outstanding significance in the effects that they have upon temperature and precipitation, the two genuinely important elements of weather and climate.

The sequence of events might be as follows: A minor change in pressure (of little consequence directly) acts to change the velocity and direction of wind (also not of major importance directly). This in turn brings about changes in temperature and precipitation, which together largely determine the character of weather and climate. Whether it is a south wind or a north wind is important because of the different temperature conditions induced by each. An onshore wind as compared with an offshore one is climatically significant because of differences in moisture and temperature. It is chiefly as controls of temperature and precipitation, then, rather than as elements of weather and climate that pressure and winds are worthy of attention. The most important single function of wind is the transportation of water vapor from the oceans to the lands, where that water vapor condenses and falls as rain.

Relation of Air Pressure to Temperature. A column of air 1 square inch in cross-sectional area extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds. This weight is balanced by a column of mercury nearly 30 inches tall and having the same cross-sectional area. Thus it is customary to measure air pressure in terms of its equivalent weight as expressed in inches of a column of mercury—in other words, by a mercurial barometer. But the weight of a given volume of air varies with temperature. Thus when air is heated it expands and occupies more space, so that a column of warm light air weighs less than a column of cold heavy air, both having the same height and cross-sectional area. In central Asia in January, when temperatures are very low, the air pressure is nearly 1 inch of mercury greater than it is in summer.

It may be accepted as a general rule, therefore, that regions with high temperatures are likely to have lower air pressures than other regions where temperatures are not so high. In other words, high temperature tends to produce low pressure, and low temperature is conducive to high pressure. There are, however, some notable exceptions to the rule.

Distribution of Atmospheric Pressure

Vertical Distribution. Since air is very compressible, there is a rapid decrease in air weight or pressure with increasing altitude. The lower layers of the atmosphere are the densest because the weight of all the layers above rests upon them. In general it may be said that a mercury barometer drops about 1 inch for each 900 feet increase in elevation. With higher altitudes the air rapidly becomes much thinner and lighter; so that at an elevation of 17,500 feet, one-half the atmosphere by weight is below the observer, although the whole air mass extends to a height of several hundred miles. The human body is not physiologically adjusted to the low pressures and associated small oxygen content of the air at high altitudes. Nausea, faintness, and nosebleed often result from a too rapid ascent. Oxygen tanks are a part of the normal equipment of aircraft operating at high altitudes.

Horizontal Distribution. Just as temperature distribution is represented by isotherms, so atmospheric pressure distribution

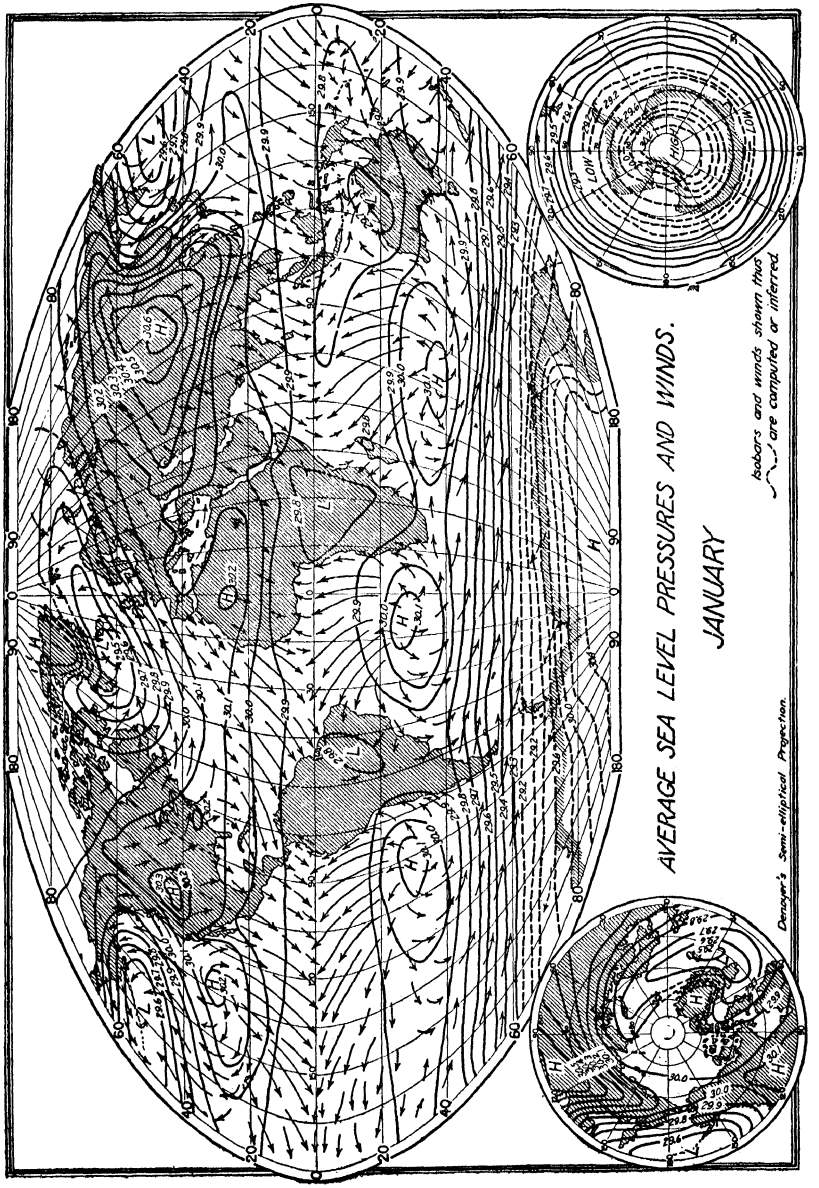

AVERAGE SEA LEVEL PRESSURES AND WINDS.
JANUARY
Isobars and winds shown thus
are computed or inferred.
Denoyer's Semi-elliptical Projection.

FIG. 30.

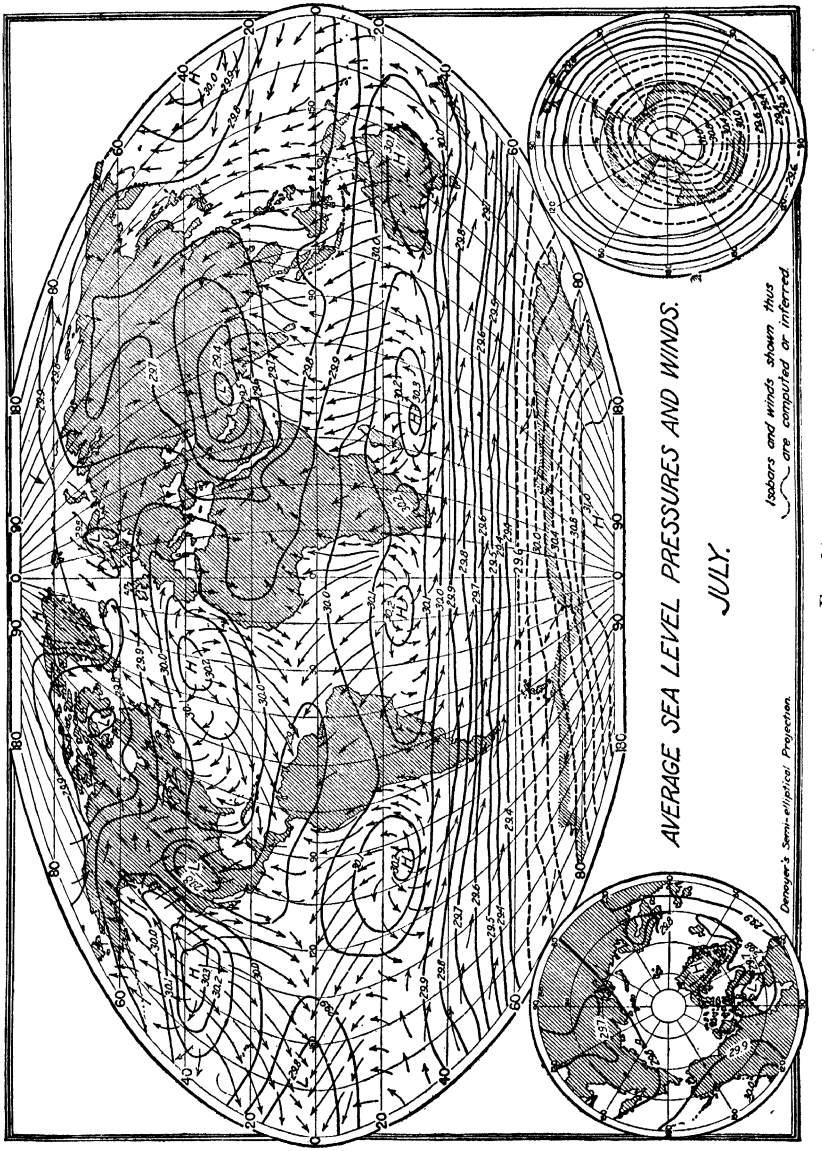

AVERAGE SEA LEVEL PRESSURES AND WINDS.
JULY.
Isobars and winds shown thus
are computed or inferred
Denoyer's Semi-elliptical Projection.

FIG. 31.

is represented by *isobars, i.e.*, lines connecting places having the same pressure. On the isobaric charts here shown (Figs. 30, 31), effects of elevation have been eliminated. All pressure readings have been reduced to sea level. This is necessary because pressure in high mountains and plateaus is always much less than at sea level. If these differences caused by elevation were not eliminated, it would be very difficult, if not impossible, to make world-wide comparisons of atmospheric pressure. Similar reduction to sea-level pressure is done also when drawing isobars on a daily weather map.

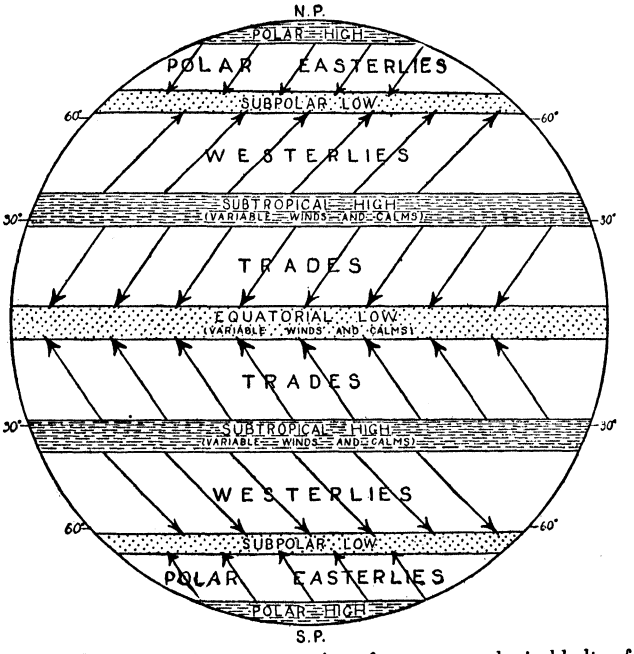


FIG. 32*A*.—A very diagrammatic representation of pressure and wind belts of the earth.

Figures 32*A* and 32*B* are diagrammatic sketches of pressure belts as they might exist on a globe composed of either all land or all water. This arrangement of pressure belts may be observed to some extent on the seasonal isobaric charts for January and July in the Southern Hemisphere where such a high percentage of the earth's surface is covered with water. In the Northern Hemisphere, great landmasses tend to disrupt the pressure belts.

The most noticeable features of average world-pressure conditions are as follows: (1) There is an equatorial belt of low

pressure (below 30 inches) which coincides rather closely with the belt of highest temperature. Within the belt the lowest pressures are over land, where the highest temperatures occur. (2) The subtropical highs (horse latitudes), a series of high-pressure centers, are located about 30° to 40°N. and S. Lat. (3) The subpolar troughs of low pressure are situated about 60° to 70°N. and S. Lat. This trough is much more continuous in the Southern than in the Northern Hemisphere. In the Northern Hemisphere it is represented by two distinct centers, the Iceland low in the North Atlantic and the Aleutian low in the North Pacific. (4) The polar highs in the vicinity of the North and South poles. It should be emphasized that equatorial low pressure is a result of high temperatures and that polar high pressure is a result of low temperatures.

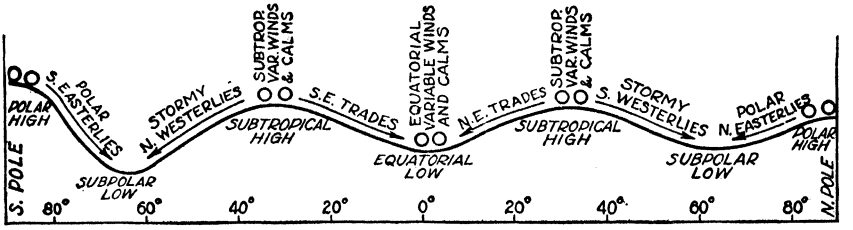


FIG. 32*B*.—A very diagrammatic representation of pressure and wind belts of the earth. Compare with Fig. 32*A*.

Profile of Average Pressure Distribution along a North-south Meridian. The general pressure conditions that have just been described are shown in a diagrammatic way in Fig. 32*B*. A line of "hills and valleys" drawn from pole to pole shows the points of high and low pressure. Above this line, by means of arrows which slope downhill, are shown the prevailing winds of the world. The curved line, or pressure profile, rises from the belt of low pressure near the equator to the subtropical highs at about 30° or 35°N. and S. Lat. Then it slopes downward to the subpolar lows in latitudes 60° to 70°, after which it rises again in the vicinity of the poles.

Isobars for January and July. Comparing the January and July maps, the following features may be noted: (1) The pressure belts, like those of temperature, move north with the sun's rays in July and south in January. They lag behind and do not migrate so far as do the insolation belts. Migration is greater

over continents than over oceans. (2) In winter the subtropical highs are strengthened by cold landmasses and are therefore more continuous; in summer they are weakened by the warm land areas. (3) Over landmasses, especially in Asia and North America, centers of low pressure develop in summer, and high pressure in winter. Pressure over adjacent oceans is just the reverse, huge low-pressure centers existing over the North Atlantic and North Pacific in winter.

Relation of Winds to Pressure

The Pressure Gradient. Air that moves essentially parallel to the earth's surface is referred to as *wind*. Vertical air movements are more properly designated as *currents*, although the name is often applied to horizontal movements as well. Wind is usually the result of horizontal differences in air pressure.

The *pressure gradient*, or *barometric slope*, refers to the rate and direction of the change in pressure. If pressure is low in Minnesota and high in Missouri, then the barometric slope is from south to north, and the wind will blow from south to north. If the difference in pressure between the two states is very great, then a steep barometric slope exists, and winds of high velocity will result.

Two fundamental rules concerned with the relationships existing between pressure and winds are: (1) The direction of air flow is from regions of higher pressure to regions of lower pressure, *i.e.*, down the barometric slope. This follows the law of gravitation and is just as natural as the well-known fact that water runs downhill. (2) The rate of air flow, or velocity of the wind, depends upon the steepness of the pressure gradient or the rate of pressure change. When the gradient is steep, air flow is rapid; and when it is weak, the wind is likewise weak. Just as the velocity of a river is determined largely by the slope of the land, or rate of change in elevation, so the velocity of wind is determined largely by the barometric slope, or the rate of change in air pressure.

One therefore can determine the steepness of the pressure gradient, and consequently the relative velocity of air movement, by noting the spacing or closeness of the isobars. Closely spaced isobars, like those in the vicinity of the subpolar trough

in the Southern Hemisphere, indicate relatively steep gradients, or marked pressure differences. Under these conditions winds of high velocity prevail. When isobars are far apart, gradients are weak, and winds are likewise. Calms prevail when pressure differences over extensive areas are very small. At such times there is nearly an absence of isobaric lines on the pressure map.

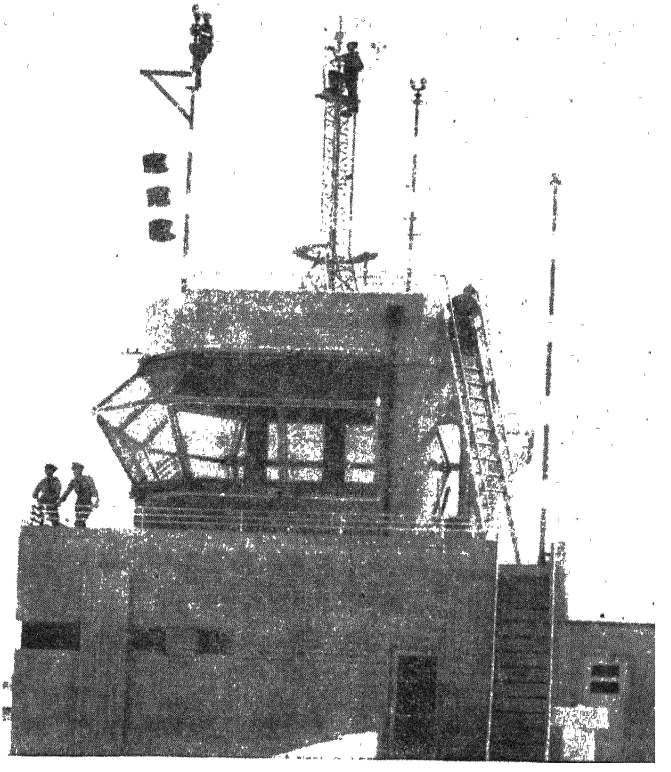


FIG. 33.—Navy personnel installing new aerological station on East Field Tower at Norfolk, Va. Anemometer cups appear to the right of the wind vane. (*Official photograph, U.S. Navy.*)

It should be borne in mind that winds are always named by the direction from which they come. Thus a wind from the south, blowing toward the north, is called a *south* wind. The wind vane points toward the direction from which the wind is coming (Fig. 33). It therefore points in a general way toward the high-pressure area down whose barometric slope the air is flowing. *Windward* refers to the direction from which a wind comes;

leeward, that toward which the wind blows. Thus a windward coast is one along which the air is moving onshore, and a leeward coast has winds offshore. When a wind blows more frequently from one direction than from any other, it is called a *prevailing* wind (Fig. 34). On the daily weather map, wind arrows fly with the wind.

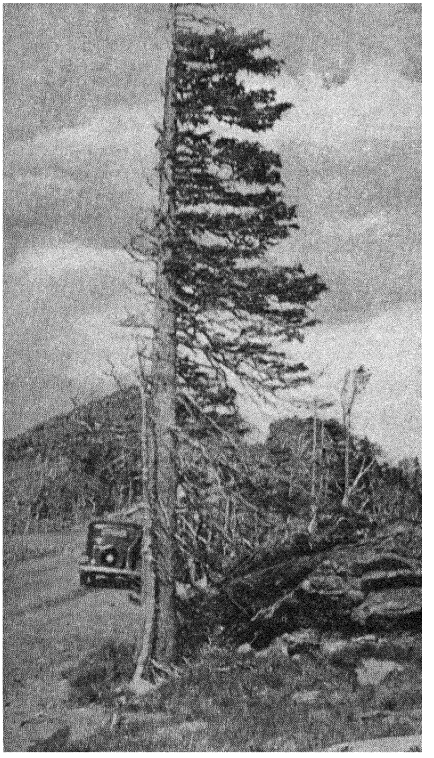


FIG. 34.—Prevailing winds often influence tree growth. Cold northwest winds in Rocky Mountain National Park, Colorado, have checked the growth of this tree on the side facing the wind. (*Photograph by Frank Banister.*)

Wind Direction and Velocity

Importance of Wind Direction. Wind directions as recorded by the weather bureau are usually limited to sixteen points of the compass at $22\frac{1}{2}°$ intervals beginning with north (Fig. 35). Ability to foretell wind direction a day ahead is a prime requisite of a good weather forecaster.

Suppose that a tropical air mass, moving as a south wind, is causing unusually warm weather in Des Moines, Iowa. The forecaster, by studying the weather map, foresees that on the following day a polar air mass, advancing from the northwest, will reach the city. Under such conditions he is certain to forecast colder weather. At another time, opposite conditions may exist.

Throughout the Central states, the prevailing wind direction in summer is south, owing to the prevalence of low pressure near the center of the North American continent; and in the winter northwest, owing to high pressure in the same locality. During January and February, 1936, a number of high-pressure areas with temperatures 40° to 50° below zero moved slowly over western Canada, Montana, and North Dakota, resulting in strong northwest winds over the Central states and the coldest winter in the history of many localities. Conversely, hot, dry air masses from the southwest often cause severe droughts in July and August, resulting in great damage to growing crops and causing much suffering among people and livestock. Wind direction foretells weather. Generally speaking, over much of central and eastern United States, easterly winds indicate the approach of foul weather; and westerly winds, fair weather.

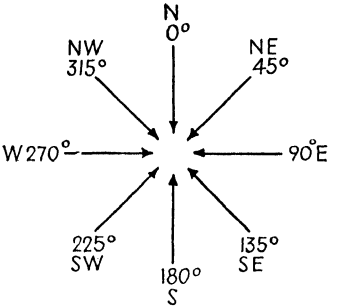


FIG. 35.—The eight principal wind directions.

Wind direction at high altitudes is ascertained by releasing rubber balloons filled with hydrogen and observing them through a small telescopic instrument (Fig. 36). Such balloon soundings also indicate velocity of winds aloft.

In the Central and Eastern states the upper winds are mainly from the southwest, west, and northwest and are usually much stronger, especially in winter, than surface winds (Figs. 37, 38). These upper winds partially account for the fast airplane flights from Los Angeles to New York.

Layers of air at different elevations often move in different directions. Thus an airplane pilot may find a strong head wind at 2,000 feet, whereas at 6,000 feet he might have a tail wind.

Two-way radio communication between airplane and airport often makes it possible for meteorologists to advise pilots in flight of the correct altitude at which to fly in order to take advantage of favorable wind direction. Obviously this service renders considerable savings in fuel consumption and in time.

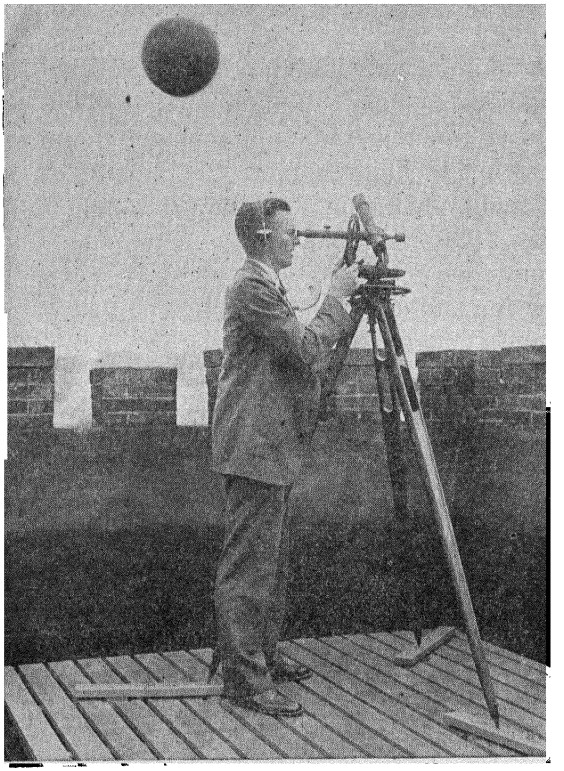


FIG. 36.—Weather observer watching pilot balloon through a theodolite. He telephones data to a computer at the plotting board in the office. The data enable the computer to calculate the wind direction and velocity aloft. (*Courtesy of U.S. Weather Bureau.*)

Airplanes take off and land against the wind. A head wind causes the take-off to be more rapid; in landing a head wind acts as a brake, considerably lowering the landing speed of the plane (Fig. 39).

Wind velocity is measured in miles per hour by an instrument called an *anemometer* (see Appendix C). In general, winds are steadier over water than over land. Gusty winds are characteristic of landmasses. The surface velocity throughout the

Central states averages about 10 to 15 miles per hour but may range from zero to 60 or more.

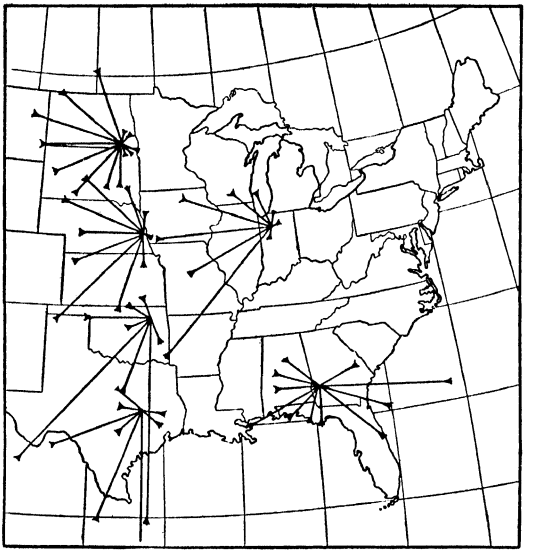


FIG. 37.—Prevailing directions of upper winds in summer. (*U.S. Weather Bureau.*)

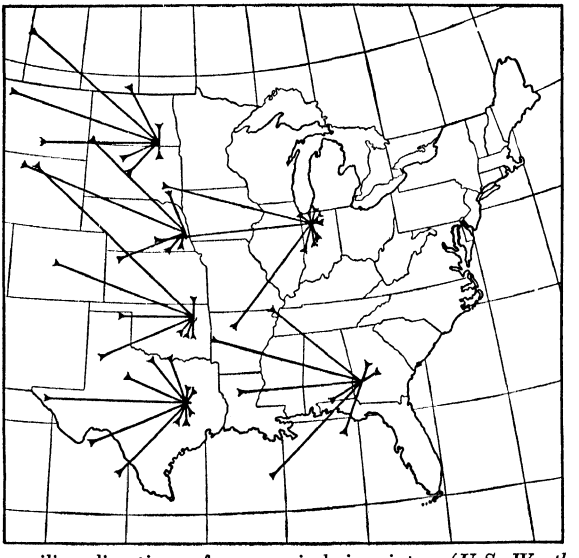


FIG. 38.—Prevailing directions of upper winds in winter. (*U.S. Weather Bureau.*)

Wind velocity is of tremendous importance in aviation. If an airplane has an air speed of 100 miles per hour and is going against a 100-mile wind, its speed over the earth's surface will

be zero, and from the ground it will appear stationary. If the wind increases to 110 miles per hour, the airplane will move backward at a speed of 10 miles per hour. If the pilot turns and goes with the wind, his speed over the earth will be 210 miles per hour. In many cases, however, the airplane encounters neither a direct head wind nor a tail wind. Instead, a side wind may be strong enough to carry the ship off its course. In such cases the pilot must head the nose of the ship into the wind in order to follow a given track over the earth's surface (Fig. 40). Taking advantage of strong upper winds, pilots have flown from California to New York at an average speed of over 250 miles per hour. Wind velocity is usually greater in high mountains than

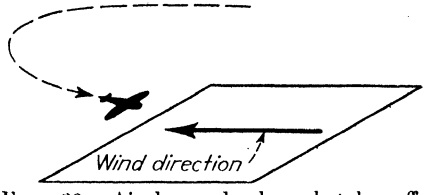


FIG. 39.—Airplanes land and take off against the wind. Why?

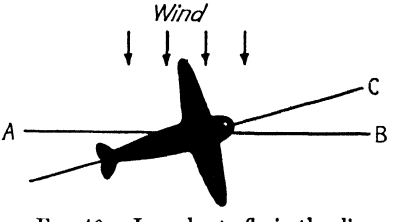


FIG. 40.—In order to fly in the direction represented by the line *AB*, the ship must head toward *C* to counteract wind drift. This is called *nosing into the wind*.

in lowlands. Low passes in the continental divide are well known for strong winds. One of the highest wind velocities ever recorded, 231 miles per hour, occurred atop Mt. Washington in northern New Hampshire in December, 1934.

The Earth's Wind Systems

PLANETARY SYSTEM OF WINDS

Planetary Winds. We have seen that, just as water flows from high to low elevations, so air flows from high to low pressure. Observe again Figs. 30, 31, and 33. From both subtropical high-pressure belts the air flows toward the equator. These are the *trade winds*. On the poleward side of the subtropical highs the air flows toward the subpolar troughs of low pressure. These winds are called the *stormy westerlies*. From the polar highs the *polar easterlies* blow toward the subpolar lows. Between the

trades, where pressure gradients are weak, is the equatorial belt of variable winds and calms called the *doldrums*. Between the trades and westerlies, at the tops of the subtropical highs, where pressure gradients are likewise weak, are the subtropical belts of variable winds and calms, sometimes called the *horse latitudes*.

Effects of Earth Rotation on Winds. The rotation of the earth on its axis causes the winds in the Northern Hemisphere to be deflected toward the right and in the Southern Hemisphere toward the left. Thus the trades become northeast winds *north* of the equator, and southeast winds *south* of the equator. The westerlies become mainly southwest winds in the Northern Hemisphere, and northwest winds in the Southern Hemisphere (Fig. 41).

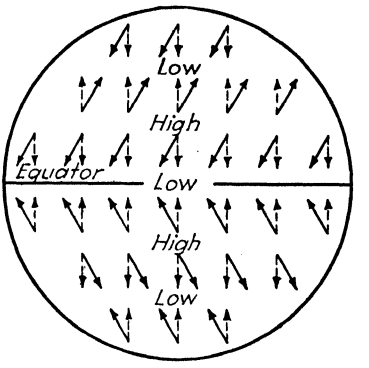


FIG. 41.—The solid arrows show the deflection of winds due to the earth's rotation. The rule is as follows: With one's back to the wind, deflection in the Northern Hemisphere is toward the right; in the Southern Hemisphere, toward the left.

THE SURFACE WINDS AND THEIR CHARACTERISTICS

Wind Belts and Centers of Action. It should be remembered that the system of world winds thus described holds true over oceans better than over landmasses. Heating and cooling of land and irregularities of the land surface tend to break up the generalized system of world wind belts. Isobaric charts of the world show certain centers of action, great semipermanent areas of high and low pressure over the oceans and continents with spiraling wind systems around them. Especially on the January chart the huge low-pressure area over the North Pacific Ocean (the Aleutian low) and another over the North Atlantic (the Iceland low) are clearly shown. On the same chart large areas of high pressure appear over North America and Asia. The "high" over Asia in January is intensified by the extreme cold of Siberia. In the Southern Hemisphere, on both the January and the July charts, centers of high pressure appear over the Indian, South Atlantic, and South Pacific oceans, and an unbroken belt

of low pressure extends around the world in the vicinity of the 70th parallel.

The centers of action are literally great wheels of atmospheric circulation, for it is they that generate the winds. Winds, in turn, largely determine the extent to which water vapor is carried from sea to land. Winds also influence the direction of ocean currents. It is evident that shifts in the position and intensity of these centers of action might have very marked effects upon the seasonal weather of any part of the earth. The study of these centers has been the basis of some attempts at long-distance weather forecasting.

Doldrums, or Equatorial Belt of Variable Winds and Calms. As the northeast and southeast trades converge toward the equator, they rise above the earth's surface, leaving between them at low elevations a condition of light and baffling breeze with much calm (Fig. 42). This doldrum belt therefore occupies the axis, or valley, of lowest pressure in the equatorial low-pressure trough where pressure gradients are weak and variable, resulting in winds of the same character. It needs to be emphasized that the nature of the winds is the result of the character of the barometric gradients. The condition of calms and variable winds is not clearly marked all round the equator, nor does it exist at all times of the year. In places and upon occasions it may be reduced to the vanishing point by the encroaching trades or by monsoons.[1]

The principal air movement in the doldrums is vertical rather than horizontal, ascending currents being indicated by the abundance of cumulus clouds,[2] numerous thunderstorms, and heavy convectional rainfall. Because this is a region of converging air currents that escape by upward movement, the doldrums are inclined to be turbulent and stormy, with calms, squalls, and light winds alternating. Within the doldrums, calms prevail 15 to 30 per cent of the time, and winds, chiefly light and gentle breezes, come from all points of the compass with about equal frequency (Fig. 42). Poor ventilation and sultry, oppressive weather are characteristic. In past times these regions were

[1] Monsoons are seasonal winds, blowing from sea to land in summer and from land to sea in winter. They are more fully explained in the latter part of this chapter.

[2] Cumulus clouds are described and illustrated in the next chapter.

rigorously avoided by sailing vessels. Owing to the fact that a sailing ship could very well be becalmed for days in the doldrums because of lack of wind, such boats often took longer routes and went far out of their courses in order to cross in the narrowest parts of the belt.

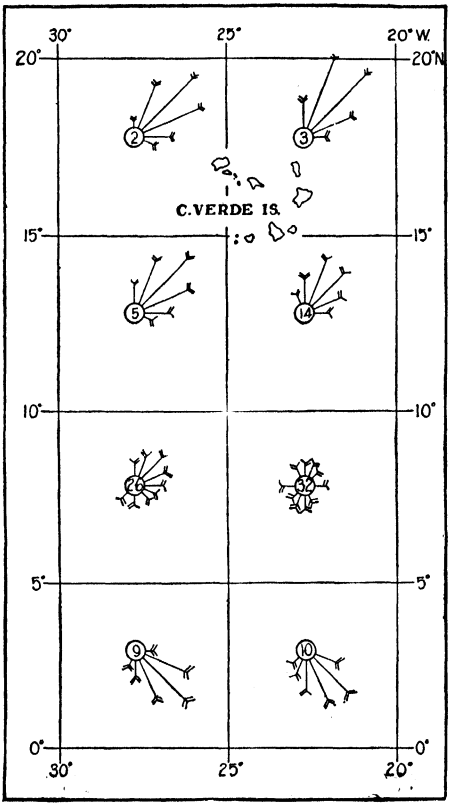


FIG. 42.—Northeast and southeast trades and doldrums over the Atlantic Ocean, June, 1922. The wind rose is given for each 5° square. Arrows fly with the wind. The length of the arrow is proportional to the frequency of winds from that direction. The number of feathers on the arrow indicates the average force of the wind. The numeral in the center gives the percentage of calms, light airs, and variable winds. (*U.S. Hydrographic Office Pilot Chart.*)

Although the doldrums are usually spoken of as a belt, it would be incorrect to conceive of this condition of variable winds and calms as having definite northern and southern boundaries. It merges imperceptibly with the trades on both margins over the oceans, so that its limits are often difficult to define. Irregular in width but averaging perhaps 200 to 300

miles, it extends in places for as much as 10° or more away from the equator. In other longitudes, especially where monsoons are well developed, as they are in the Indian Ocean, it may be wiped out entirely. Over the Atlantic Ocean in July, doldrums lie between latitudes 11°N. and 3°N., and in January between 3°N. and 0°. Most of the doldrum belt probably lies between parallels 5°N. and 5°S.

The Trade Winds. In each hemisphere these winds blow over the oceans approximately between latitudes 30° or 35° and 5° or 10°. They move obliquely downgradient from the subtropical high centers toward the equatorial low. Over the North Atlantic in summer the approximate limits of the northeast trades are 35°N. and 11°N.; in winter, 26°N. and 3°N. In parts of the low latitudes they reach, and even cross, the equator. Away from landmasses, trades blow rather constantly from an easterly direction (northeast in the Northern and southeast in the Southern Hemisphere). Over continents, and even adjacent to them, both steadiness and direction may be considerably modified. On the island of St. Helena, which lies in the heart of the southeast trades of the South Atlantic, the percentage of winds from various directions is as follows, according to Kendrew:[1]

	N.	*N.E.*	*E.*	*S.E.*	*S.*	*S.W.*	*Calm*
January ..	....		5	76	19		
July	1	2	9	62	20	1	5

Trades are the most regular and steady winds of the earth, particularly over the oceans. Their characteristic moderate to fresh breezes average 10 to 15 miles an hour. Calms are infrequent, usually prevailing less than 5 per cent of the time. Over landmasses and near their margins the surface trades are much less conspicuous. They blow with greater strength and constancy in winter than in summer, for in the hot season the belt of subtropical highs is broken by the heated continents, resulting in a much less continuous belt of trades at that season. Especially over eastern and southern Asia, and to a degree over the waters south and east of the United States as well, summer monsoons tend to weaken or even eliminate the trades. In

[1] KENDREW, W. G., *Climate*, p. 90, Oxford University Press, New York, 1938.

winter, on the other hand, outflowing continental winds tend to strengthen them. In general, the trades are regions of fine, clear weather with few storms. The most spectacular of these storms are the tropical hurricanes which infest their western equatorial margins over the oceans in the late summer and early fall.

The trades yield little precipitation when traveling over oceans or over landmasses of *low elevation*, so that they are often described as *desert makers*. But when these prevailingly "dry" winds are forced to rise abruptly, *e.g.*, along the elevated windward margin of a continent, they may yield copious rain. On one of the mountainous Hawaiian Islands, located in the northeast trades, annual rainfall on the windward side is over 200 inches, but on the leeward side it is less than 20 inches (Fig. 43).

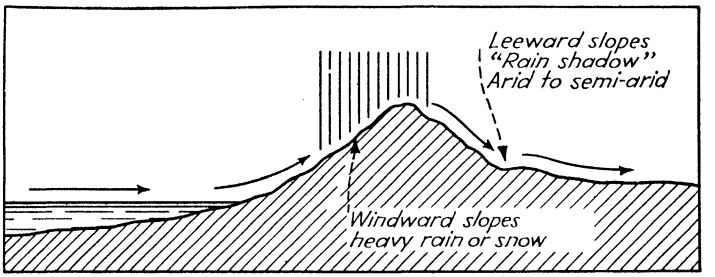


FIG. 43.—When moist winds are forced to cross mountain barriers, heavy precipitation falls on the windward slopes, but leeward slopes are relatively dry.

Trade-wind Belts as Sailing Routes. Because of the steady nature of the trades, as well as their fine, clear weather with few severe storms, they were thoroughfares for sailing vessels. The routes of ships powered with either steam or Diesel engines are, of course, but little influenced by wind belts. Just as sailing craft avoided the belts of calms and fickle winds, so they sought out the trades and plotted their courses in order to take advantage of them. Thus, the charted route for wind-driven boats traveling from Europe to the United States ran southward along the Atlantic Coast of Europe and Africa to about latitude 25° or 30°, then due westward in the trades, and finally northward again in the western Atlantic (trace on Figs. 30, 31). This is much farther in miles than the more direct steamship route of today; but sailing craft measured their trips in days rather than in miles, and better time could be made by sailing

with the trades over a longer course than by fighting against the westerlies over a shorter route.

Columbus in his first voyage to the New World sailed south from Spain to the Canary Islands and then westward in the trades. His journal of the voyage contains frequent remarks concerning the fine weather and the favorable winds experienced. One notation describes the weather as being like April in Andalusia. The almost constant following winds from the northeast worried the sailors, however, for they feared that the return trip to Spain might be impossible. Upon one occasion when a westerly wind was experienced, Columbus wrote: "This con-

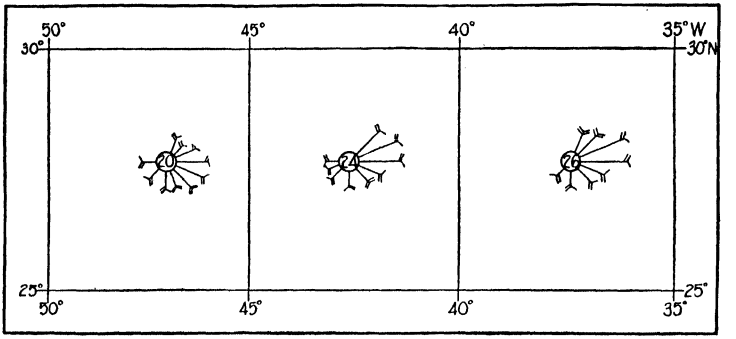


FIG. 44.—The subtropical "belt" of variable winds and calms, or horse latitudes, over the North Atlantic Ocean for June. Explanation of symbols is given below Fig. 42. (*U.S. Hydrographic Office Pilot Chart.*)

trary wind was very necessary to me, because my people were much excited at the thought that in these seas no wind ever blew in the direction of Spain."

The flying route from California to China via the Hawaiian and the Philippine Islands takes advantage of the fine weather of the trades. In flying west the trades are utilized as tail winds. On the return trip the ships fly at somewhat higher altitudes where the trades are weaker.

Subtropical Belts of Variable Winds and Calms, or the Horse Latitudes. Lying between the trades and stormy westerlies over the oceans are the horse latitudes. They occupy the crests of the high-pressure centers where pressure gradients are weak. Light, variable winds and calms therefore are the rule (Fig. 44). All regions with such wind characteristics must of necessity have weak pressure gradients. On the wind charts

(Figs. 30, 31) the horse latitudes are the centers of the great subtropical "whirls" of air, these whirls having opposite rotations in the Northern and Southern hemispheres. Although the horse latitudes are like the doldrums in their preponderance of light and fickle winds, blowing from any and all points of the compass, they are totally unlike them in their general weather conditions. Because they are regions of settling air and light, variable winds, the air is prevailingly dry. Skies are clear. The weather is fine much of the time. Sunshine is abundant and rainfall is relatively low. The centers or "ridges" of subtropical high pressure lie in the vicinity of latitudes 30° to 40°N. and S. These are sometimes known as the *Mediterranean latitudes*, because they correspond in location to that sea. The representative wind rose (Fig. 44) for these regions resembles that of the doldrums, calms prevailing 15 to 25 per cent of the time; and light and gentle breezes from all points of the compass, the remainder. The horse latitudes, like the doldrums, are avoided by sailing vessels.

Stormy Westerlies. Moving downgradient from the centers of subtropical high pressure to the subpolar lows (roughly 35° or 40° to 60° or 65°) are the stormy westerlies. Particularly is the poleward boundary of this wind belt a fluctuating one. It shifts with the seasons and over shorter periods of time as well.

The westerlies are distinctive among the wind belts in that they are neither uniformly strong nor weak but instead are composed of extremes. "Spells of weather" are one of their distinguishing characteristics. At times, and more especially in the winter, they blow with gale force; upon other occasions mild breezes prevail. Although designated as *westerlies* (westerly being the direction of most frequent and strongest winds), air does blow from all points of the compass (Fig. 45). The variability of winds, in both direction and strength, so characteristic of the westerlies, is largely the result of the procession of storms (cyclones and anticyclones) which travels from west to east in these latitudes. These storms tend to break up and modify the general westerly air movement. Moreover, on the eastern sides of Asia, and to a lesser degree North America, monsoon wind systems tend to disturb the westerlies, especially in summer.

It is in the Southern Hemisphere, where in latitudes 40° to 65° landmasses are largely absent, that the westerlies can be observed in their least interrupted development. Over these great expanses of oceans, winds of gale strength are common in summer as well as winter. These are the "roaring forties" of nautical jargon. In the vicinity of Cape Horn they are often

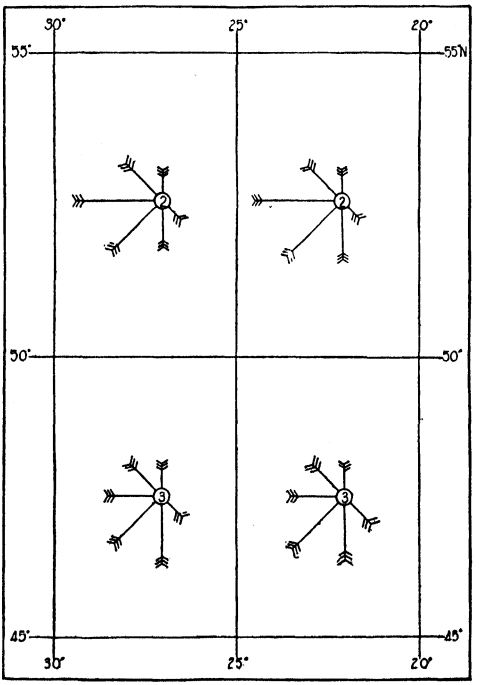


FIG. 45.—The westerlies over the North Atlantic Ocean in January. (*U.S. Hydrographic Office Pilot Chart.*)

so violent as to make east-west traffic around the Cape not only difficult but even dangerous. It is a wild region where gale follows gale with only brief intervening lulls; where raw chilly weather, cloudy skies, and mountainous seas prevail.

The westerlies of the Northern Hemisphere, where the great landmasses with their seasonal pressure reversals cause the wind systems to be much more complex, are considerably less violent in summer than in winter. In summer, gentle to fresh breezes prevail, and winds come from a great variety of directions with almost equal frequency. But winter winds are strong and boisterous, blowing mainly from westerly directions. In winter,

great masses of cold polar air occasionally move equatorward in the westerlies.

It is clear that the westerlies must be more difficult and strenuous sailing winds than are the trades, both because they are more stormy, and likewise because they are more variable in strength and direction. Although the winds are variable, they are strongest and most frequent from the west, so that sailing vessels plot their courses to take advantage of this condition. Thus sailing craft use the trades from Europe to America and the westerlies on the return trip. Similarly, in going from the United States or Europe to Australia, they go by the Cape of Good Hope, returning by Cape Horn.

Polar Winds. In the higher latitudes, beyond the belts of westerlies, the subpolar low-pressure troughs are extremely wild and stormy areas, for they are the routes followed by a large number of cyclonic storms of high latitudes. These storms, especially in the cool seasons, move southward into the paths of steamships plying the North Atlantic and North Pacific oceans. Winds of gale force together with huge waves often reduce the speed of an ocean liner. As a result, the ship's arrival at its destination may be delayed many hours.

Terrestrial Modifications of the Planetary Wind System

Causes of Terrestrial Modifications. Certain modifications of the idealized planetary wind system are due to (1) the inclination ($23\frac{1}{2}°$) and parallelism of the earth's axis, (2) the distribution of large landmasses in the Northern Hemisphere, and (3) shapes and elevations of landmasses.

Latitudinal Shifting of Wind Belts. The inclination and parallelism of the earth's axis as the earth revolves around the sun cause the sun's vertical ray to migrate from $23\frac{1}{2}°$N. (summer solstice, about June 21) to $23\frac{1}{2}°$S. (winter solstice, about December 21), a total of 47°. This in turn causes a north-south migration (of lesser extent) of the temperature, pressure, and wind belts. Some regions are thus influenced by two wind belts during the year. For example, between latitudes 5° and 15°N. and S., the doldrums may prevail during high sun, and the trades during low sun. Certain Mediterranean lands (latitudes 30° to 40°) experience the clear, dry weather of the horse lati-

tudes and trades in summer and the more stormy and wetter weather of the cyclonic westerlies in winter.

Monsoon Winds. Monsoon winds are the result of the earth's surface being composed of great land and water areas which have unequal heating and cooling qualities. Seasonal differences in temperature often give rise to seasonal contrasts in pressure; and, of course, contrasts in pressure give rise to changes in wind direction. The chain, or sequence, of events, then, is from temperature, through pressure, to winds.

In winter, for example, the interior of Asia becomes excessively cold, resulting in the development of a great stationary continental anticyclone or high-pressure center. Over the warmer seas to the east and south of Asia temperatures are higher, and the pressures consequently lower. As a result of this arrangement of the pressure areas, the surface gradient is from the continent toward the ocean. Consequently, cold surface winds move out from Asia toward the surrounding seas. This prevailing land wind constitutes the *winter monsoon* (January, Fig. 30). It is not always from the same direction in the various parts of eastern and southern Asia, for it blows from the west and northwest in Japan and North China and from the north and northeast in southern Asia, where it acts to strengthen the normal trade winds of those latitudes. But although not always from the same direction, it is, in almost all sections, a land wind, bringing cold, dry air down to the very sea margins and beyond. This condition is not conducive to rainfall, so that winter, or the period of low sun, is characteristically the driest season in monsoon lands. Winter monsoons, particularly of middle latitudes, are subject to interruptions by the passage of cyclonic storms which bring some precipitation even in the cool season.

Summer Monsoon. In summer the Asiatic continent becomes warmer than the adjacent oceans, and as a consequence a semipermanent seasonal low-pressure center develops over that landmass. Higher pressure prevails over the cooler oceans, so that the gradient is from sea to land, as are also the winds (July, Fig. 31). This mass of sea air moving in toward the heated continent is called the *summer monsoon*. Much of it originates in the trades south of the equator. Since it travels great distances

over bodies of tropical water, it brings with it abundant supplies of water vapor which are conducive to rainfall. Summer, therefore, is characteristically the wet season in monsoon lands. The summer monsoon is not always a wind from the same direction throughout southeastern Asia, but at least it is from the sea.

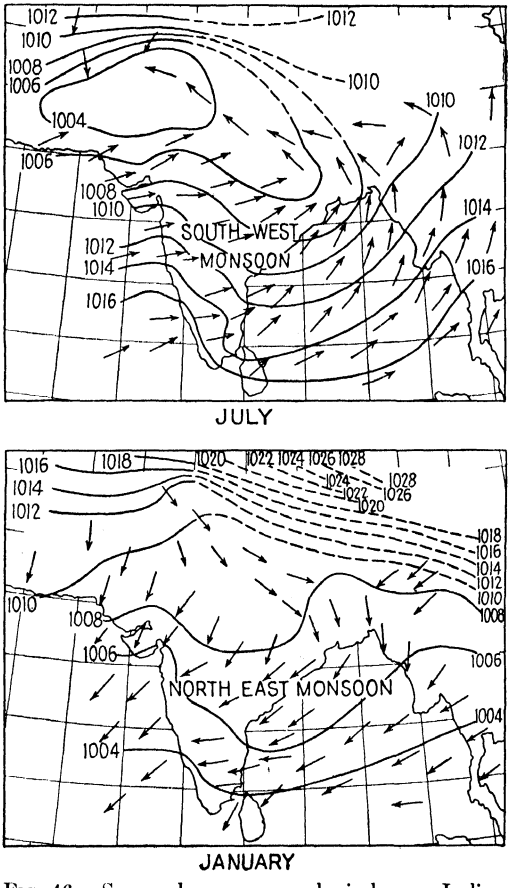


FIG. 46.—Seasonal pressures and winds over India.

Interruptions due to cyclonic storms are not infrequent. In monsoon regions continental-controlled winds tend to wipe out the planetary system of trades and westerlies, substituting in their places a terrestrial system. Hot, humid summers and relatively cold, dry winters are characteristic of most regions with continental wind systems in the middle latitudes. India, cut off as it is from the rest of Asia by high mountain ranges and

plateaus, has a monsoon system of local origin, quite distinct from that of the rest of the continent (Fig. 46). The following will help to fix the chain of events described above for a monsoon region:

Winter....Asia cold....high pressure.....winds toward sea.....dry season
Summer...Asia warm...low pressure.....winds toward land....wet season

Partly because of the great size of the continent, the monsoon system of winds is most perfectly developed over eastern and southern Asia, although monsoons in modified form, or monsoon tendencies, are characteristic of other regions as well (Fig. 47).

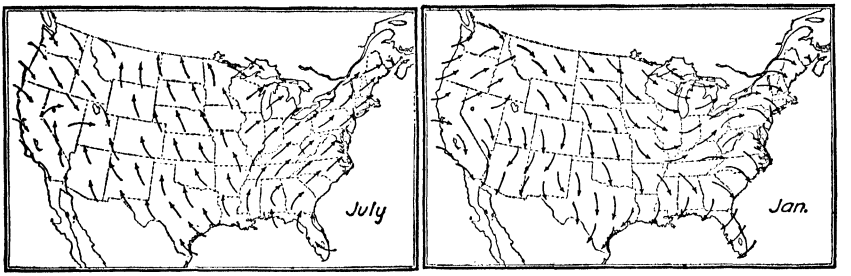


FIG. 47.—Seasonal winds over the United States. (*After Ward.*)

Southeastern United States, northern Australia, Spain, and South Africa all are regions with monsoon tendencies. These land areas may not always be sufficiently powerful to cause a complete seasonal reversal of winds as is Asia, but at least they create partial monsoons.

Land and Sea Breezes. Just as there are seasonal wind reversals (monsoons) resulting from seasonal temperature contrasts between land and water, so there are diurnal, or daily, monsoons resulting from similarly induced temperature contrasts within the 24-hour period. These are called *land and sea breezes*, or *diurnal monsoons*.

Thus along coasts there is often a drift of cool, heavy air from land to water at night (corresponding to winter) and a reversed wind direction, sea to land, during the heat of the day. Usually the sea breeze begins between 11 and 12 A.M. and seldom lasts much later than 4 in the afternoon. It is a shallow wind, penetrating only a short distance inland, usually not over 20 miles. Along tropical shores the sea breeze is a remarkably important climatic phenomenon, causing these places to be more livable

and healthful than they otherwise would be. The beginning of the sea breeze may cause a drop in temperature of 15° to 20° within $\frac{1}{4}$ to $\frac{1}{2}$ hour. Coasts with well-developed sea breezes are inclined to have modified marine climates, with the daily temperature extremes much reduced. The coasts of New Jersey and northern Chile are examples of regions having well-developed sea breezes in summer.

Mountain and Valley Breezes. Like land and sea breezes, these local winds have a distinct diurnal periodicity. During the day the air of an enclosed valley, or that adjacent to a slope receiving relatively direct rays of the sun, becomes heated so that active convectional ascent of the warm and expanded air takes place up the valleys and along the mountain slopes. This daytime updraft of warm air, or valley breeze, is indicated by the masses of cumulus clouds that collect about the peaks of mountains during summer days. They are the visible tops of invisible ascending air currents. Daily summer afternoon rains are therefore common in mountains, and visibility, because of the cloud masses, is restricted during the warm hours of the day.

After sundown, as the rapidly cooling slopes begin to chill the air layers next to them, the cooler, heavier air begins to slip down the mountain sides into the valleys (the principle of air drainage discussed in the previous chapter). This is a reversal of the day current and is known as the *mountain breeze.* It is often very perceptible at the mouth of a gulch. Where there are marked constrictions in a valley that drains a large area, strong winds may result. Summer camps are sometimes pitched at the mouth of a valley in order to benefit from the cooling effect and ventilation provided by the mountain breeze. The cool evening breeze attracts thousands of vacationists to mountain resorts in summer.

Winds and Ocean Currents. The slow moving of surface waters of the ocean (average rate about $2\frac{1}{4}$ miles per hour) is largely due to the friction of steady winds blowing over the water surface day after day. Thus the trade winds cause a slow drift of ocean water toward the west, both north and south of the equator, and the westerlies cause an eastward movement. A more detailed discussion of ocean currents is given in a later chapter.

Summary

Air has weight and therefore exerts pressure on all surfaces. Air pressure decreases about 1 inch per 900 feet increase in elevation. Isobaric charts indicate certain pressure belts on the earth. These pressure belts are directly related to the planetary winds of the world. Planetary winds greatly influence climate. They are modified in places by differences in temperature between land and water bodies.

Water evaporates into the air in the form of invisible water vapor. Winds carry water vapor from the oceans to the continents. This water vapor condenses to form clouds which in turn bring rain. Our next chapter, therefore, deals with atmospheric moisture and precipitation.

Questions

1. What is the most important function of the wind?
2. What is barometric pressure at sea level in inches of mercury? In pounds per square inch?
3. Which is heavier, warm air or cold air?
4. Why does a barometer rise and fall?
5. Normally, does high or low barometer result from high temperature? From low temperature?
6. Why do the lower layers of air have greater density than those at high altitudes?
7. How much does air pressure decrease with increase in altitude?
8. One-half the atmosphere by weight is within how many feet of the earth's surface?
9. Define isobar.
10. Why is the ideal arrangement of wind belts more easily recognized in the Southern than in the Northern Hemisphere?
11. What are the four most noticeable features of average atmospheric pressure over the earth's surface?
12. What is wind? What causes wind?
13. Define pressure gradient.
14. State the two fundamental rules dealing with the relationship between pressure and winds.
15. How do isobars help to indicate wind velocity?
16. Define windward, leeward, prevailing wind.
17. What is the prevailing direction of the wind in the Central states in summer? Why? In winter? Why?

18. During droughts in the United States, what are the prevailing wind directions?

19. How are direction and velocity of upper winds ascertained?

20. What are the prevailing directions of upper winds in the Central and Eastern states? How does wind velocity usually change with increase in altitude?

21. Why is a knowledge of upper winds so important to an airplane pilot?

22. Why does an airplane take off and land against the wind?

23. What is an anemometer?

24. Why are winds steadier over water than over land? Give two reasons.

25. What is the average wind velocity in the Central states?

26. In aviation, what is meant by a head wind? Tail wind? Side wind?

27. Why is wind velocity important in aviation?

28. Where is Mt. Washington? What wind velocity has been recorded there?

29. Name the planetary winds.

30. How are they deflected by the earth's rotation?

31. Why are wind belts less continuous in the Northern than in the Southern Hemisphere?

32. Where are the two principal low-pressure "centers of action" in the Northern Hemisphere? Give their names.

33. In the doldrums, what is the nature of winds? Of rainfall?

34. Why did sailing vessels avoid the doldrums when possible?

35. Most of the doldrum belt probably lies between what parallels?

36. What is the approximate latitude of the trade winds? From what direction do they blow south of the equator? North?

37. In general, trade-wind regions have what kind of weather?

38. Where do trades produce copious rainfall?

39. Why were the trade winds favorable to sailing vessels?

40. What are the longitude and latitude of the Hawaiian Islands? They are in which wind belt? Which mountain slopes receive heavy rain?

41. What route is followed by sailing vessels across the Atlantic? By airplanes from California to China? Trace on a map.

42. What is the nature of winds in the horse latitudes? Describe the weather in these regions. Why is it relatively dry?

43. What parts of what continents are in the stormy westerlies?

44. Describe wind behavior in the stormy westerlies. Why such a great variability in direction and velocity?

45. In what latitudes are the westerlies least interrupted?

46. Where are the "roaring forties"? What is the nature of weather there?

47. What is the general nature of polar winds?

48. What is meant by "latitudinal shifting of wind belts"?

49. What causes the winter monsoon of Asia? Effects on temperature?

50. Why is winter the dry season in monsoon regions?

51. What causes the summer monsoon of Asia?

52. Why is summer the wet season in monsoon regions?

53. Why does India have a monsoon wind system of local origin?

54. North America has a monsoon tendency. Is such influence more noticeable on the East or West coast? Why?

55. Explain the cause of land sea breezes. Where do such breezes influence daily weather in the United States?

56. What is the cause of mountain and valley breezes?

57. What is probably the principal cause of ocean currents?

Suggested Activities

1. On a map of the world, draw arrows to indicate wind "belts." Show a few routes of sailing vessels with red lines and steamship routes with blue lines. Explain some of the contrasts shown. Use another color for principal air lines.

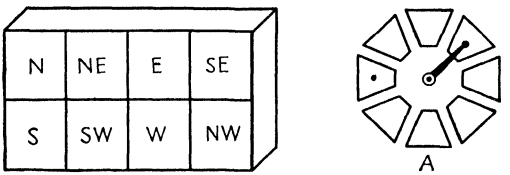


Fig. 48.

2. Construct an electrical indicator for wind direction. In a box about 12 by 20 inches and 3 inches deep build partitions to divide the space into eight equal parts. Place a small electric light in each pocket. Over the top of the box fasten a piece of translucent glass with the wind directions shown as in Fig. 48. On the roof, build an eight-pointed switch as shown at *A*. At the center is the upright rod of a wind vane. A sliding contact is fastened to the upright rod and moves over the eight segments as the wind vane changes direction. Run a cable of nine wires from the eight-pointed switch to the box of lights in the laboratory.

Build an anemometer such that the center rod that supports the cups rotates with the cups. On the center rod arrange an electrical switch in such a way that when the cups rotate sufficiently, elec-

trical contact is made, closing a circuit that causes a light in the laboratory to flash. The number of flashes per minute will provide an idea of wind velocity.

3. If a barograph is not available, record the barometer readings every hour, and plot a curve to show changes in atmospheric pressure during the day.

4. Find out the elevation above sea level of your school building. Reduce the barometer reading to sea level by adding the necessary amount. Do the same for Denver, Salt Lake City, Yellowstone Park, and Pike's Peak. This is the necessary procedure in construction of the daily weather map.

5. If possible, visit an airport. Observe the care with which wind velocity and direction are recorded. At the larger airports you may hear the radio operator advising a pilot in the air to fly at a certain altitude in order to take advantage of favorable winds.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Local Conditions of Atmospheric Pressure and Winds
2. Results of Upper Air Observations in the United States
3. Pilot Charts of the Various Oceans (U.S. Hydrographic Office)
4. The Use of Air Pressure in Ascertaining Altitude
5. Balloon and Airplane Soundings of Upper Air Conditions
6. The Monsoon Winds of India
7. The Routes of Sailing Vessels
8. The Contrasting Weather Conditions in the Trades and Westerlies
9. Contrasting Pressure Gradients in Summer and Winter (See U.S. Weather maps)
10. Windward and Leeward Coasts of South America

REFERENCES

BLAIR, THOMAS A.: *Weather Elements*, Chap. 2, Prentice-Hall, Inc., New York, 1937.

BROOKS, CHARLES F.: *Why the Weather?* Harcourt, Brace & Company, Inc., New York, 1935.

FLETCHER, G. L.: *Earth Science*, Chaps. 25 and 26, D. C. Heath & Company, Boston, 1938.

MILHAM, W. I.: *Meteorology*, The Macmillan Company, New York, 1912.

TREWARTHA, GLENN T.: *An Introduction to Weather and Climate*, Chap. 2, McGraw-Hill Book Company, Inc., New York, 1937.

"Weather Forecasting," *Bulletin* 42 of the U.S. Weather Bureau, Government Printing Office, Washington, D.C.

Chapter IV. Atmospheric Moisture and Precipitation

The composition of the atmosphere is fairly constant from time to time and place to place. The amount of water vapor in the air, however, is by no means uniform, since it varies from nearly zero to almost 5 per cent. This variability is of outstanding importance for the following reasons: (1) The amount of moisture in the air is directly related to rainfall possibilities. (2) Water vapor absorbs energy radiated from the earth and thus tends to regulate temperature. (3) The greater the amount of water vapor in the air the greater the quantity of stored-up energy for the production of storms. (4) The amount of water vapor is likewise an important factor affecting the human body's rate of cooling, *i.e.*, the sensible temperature.

Sources of Water Vapor. Like all the other gases in the atmosphere, water vapor is invisible. The primary source of this important gas is the great oceans which cover approximately three-quarters of the earth's surface. By winds and diffusion methods, the water vapor evaporated from these bodies of water through the expenditure of solar energy is carried in over the continents. Less important, but nevertheless significant, sources of atmospheric moisture are the moist land surfaces, the vegetation cover, and the minor bodies of water. Plants give off more moisture to the air than does bare ground but not so much as a freely exposed water surface. A constant turnover is forever in progress as regards the atmosphere's water vapor, additions being made through evaporation of water in its solid and liquid states, while some is being lost to the atmosphere by condensation. As winds carry the moisture in gas form from the oceans to the land, so rivers and glaciers deliver it again in

liquid or solid form to the seas. Half the water vapor in the air lies below an altitude of 6,500 feet.

Evaporation and Condensation. *Evaporation* is the changing of a liquid to a gas. Some solids, such as ice, evaporate. The rate of evaporation of water depends upon (1) the temperature of the water, (2) the temperature of the air that is in contact with the water, (3) the amount of water vapor already in the air, and (4) the velocity of the wind. *Condensation* is the changing of a gas to a liquid or solid. Water vapor, which is invisible, condenses into a visible liquid form (cloud) when air is sufficiently cooled (Fig. 49). These processes are well illustrated by an airplane in flight. In one stratum of air having a temperature a few degrees below freezing and containing some water in liquid form, moisture may condense in the form of ice on the leading edge of the wing; in another stratum the ice may evaporate rapidly. It is evident that the two strata differ in the quantity of water vapor present.

Latent Energy in Water Vapor. Heat and motion are forms of energy. Heat energy is required to change water in the liquid form into steam or water vapor. The unit of heat energy, the calorie, is the amount of heat required to raise the temperature of 1 gram of water 1°C. It takes 80 calories to convert a gram of ice into a gram of water at freezing temperature. A much greater quantity of heat, 607 calories, is required to evaporate a gram of water at 32° into water vapor at the same temperature. Thus it is evident that water vapor contains more potential energy than the liquid form. This stored-up energy is called *latent heat.* For the most part it is transformed sun energy which was employed in evaporation. One reason why bodies of water heat slowly is that so much energy is consumed by evaporation at the surface. That evaporation requires heat is evident from the cool sensation experienced when the skin is moistened with water or, better, gasoline or ether. In this case heat is subtracted from the skin to convert the liquid into a gas. If energy is consumed in the process of evaporation, then, conversely, energy should again be released during condensation. *Latent heat of condensation* is the heat released by the condensation of water vapor, especially in the formation of clouds. This heat increases the strength of convection currents in the center of a storm,

thus increasing the intensity or severity of the storm itself. On a cloudy night when condensation is taking place, latent heat of condensation aids in preventing the normal cooling of the lower layers of air.

Humidity

The amount of water vapor that air can hold depends largely upon its temperature. *Capacity* is the maximum amount of water vapor that a cubic foot of air can hold at a given temperature.

MAXIMUM WATER-VAPOR CAPACITY OF 1 CU. FT. OF AIR AT VARYING TEMPERATURES

Temperature, Degrees Fahrenheit	*Water Vapor, Grains*	*Difference between Successive 10° Intervals*
30	1.9	
40	2.9	1.0
50	4.1	1.2
60	5.7	1.6
70	8.0	2.3
80	10.9	2.9
90	14.7	3.8
100	19.7	5.0

It is evident from the foregoing table that warm air is capable of holding much more water vapor than cold air. Warm air, therefore, has greater potentialities for producing abundant rain than does cold air. Air is said to be *saturated* when it contains all the water vapor possible. Water vapor, at the same temperature and pressure, is lighter than air in the ratio of 5 to 8. Very humid air is, therefore, lighter than dry air. Moist air consequently is less able to support the weight of smoke particles than is dry air at the same temperature.

Absolute humidity is the actual amount of water vapor in the air measured in grains per cubic foot (or grams per cubic meter). This amount is usually greatest in the vicinity of the equator and decreases toward the poles, varying considerably, however, with distance from the ocean and smaller bodies of water. Masses of air differ greatly in absolute humidity. This is especially noticeable in winter. A tropical air mass, originating

over the Caribbean Sea or the Gulf of Mexico and moving north, usually has a high absolute humidity, whereas a polar air mass, moving from northern Canada toward the south, contains much less water vapor per cubic unit. Absolute humidity is usually very low when an air mass from northern Mexico, New Mexico, and western Texas moves from the southwest toward the Central states. This air from the southwest may carry much dust. At such times both absolute and relative humidity are very low, owing partly to the absorption of moisture by the dust. During one dust storm in March, 1936, the relative humidity at Kansas City, Mo., was 8 per cent at 11 P.M., a time of day when relative humidity often is in the neighborhood of 80 per cent.

Relative humidity is the percentage of water vapor in the air and is determined by the ratio of absolute humidity to capacity. Stated in another way, relative humidity may be said to be an expression of the relationship between the actual amount of water vapor in the air (absolute humidity) and the total amount of water vapor that the air could hold at the same temperature (capacity). For example, air at 70°F. can contain approximately 8 grains of water vapor per cubic foot (its capacity). If, however, it contains only 6 grains (its absolute humidity), then it is only three-fourths saturated, and its relative humidity is 75 per cent. Whenever temperature of the air changes, capacity also changes, and therefore relative humidity. This is illustrated by the following figures:

Temperature, Degrees F.	*Absolute Humidity, Grains*	*Relative Humidity, Per Cent*
40	2.9	100 saturated
50	2.9	71 saturated
60	2.9	51 saturated
70	2.9	36 saturated
80	2.9	27 saturated
90	2.9	19 saturated

The relationship existing between absolute humidity (*AH*), capacity (*C*), and relative humidity (*RH*) may be expressed by

the following formula:

$$RH = \frac{AH}{C} \text{ (expressed in percentage)}$$

If air that is not saturated is sufficiently cooled, thereby reducing its capacity for moisture, a temperature is eventually reached at which the mass of air is saturated. The *dew point* is the temperature at which the air is saturated and below which condensation takes place. Thus air at 90° that contains 5.7 grains of water vapor per cubic foot (its absolute humidity) has a dew point of 60° because 5.7 is capacity at 60°. Further cooling below the dew point causes condensation, forming minute water particles (cloud or fog) if above 32° and ice crystals if below 32°. Suppose that this air is cooled to 40°. The amount of water vapor condensed per cubic foot is 5.7 − 2.9 = 2.8 grains (see table, page 80).

Much moisture is condensed when warm, saturated air is cooled. Comparing warm and cool air, the following may be noted: saturated air at 90° cooled 20° yields 6.7 grains per cubic foot; saturated air at 50° cooled 20° yields 2.2 grains per cubic foot.

Problem 1. Air at 70° has a relative humidity of 72 per cent. What is the absolute humidity? The dew point?

$$AH = RH \times C \qquad \text{Capacity at } 70° = 8.0$$
$$= 0.72 \times 8.0$$
$$= 5.76 \text{ grains per cubic foot}$$

According to the table of capacities, this air would be saturated if its temperature were reduced to 60°. The dew point is therefore 60°.

Problem 2. Outdoor air at 30° with a relative humidity of 80 per cent is brought indoors and heated to 70° without the addition of any water vapor. What is the relative humidity indoors?

$$AH = RH \times C \qquad AH = 0.80 \times 1.9 = 1.52$$

Temperature indoors is 70°; therefore $C = 8.0$

$$RH = \frac{1.52}{8.00} = 19 \text{ per cent indoors}$$

Problem 2 illustrates a condition that too often exists in our homes and public buildings in winter. Relative humidity of

19 per cent indicates very dry air which, together with dust, causes inflammation of the tender membranes of the nose and throat, possibly making us more susceptible to contagious diseases of many kinds. Since dry air causes more rapid evaporation of moisture from the body, with the resulting cooling effects, it follows that increased humidity would improve the quality of the air from the standpoint of human comfort. For these reasons and others, effort should be made to add moisture to the air indoors in winter. Some furnaces are equipped with humidifiers. Evaporating pans can be placed at suitable places.

In the summer, especially in our Central and Eastern states, relative humidity is often abnormally high, causing us to be extremely uncomfortable. We speak of such weather as "muggy," or "sticky." On such days, indoors, we should seek not only to cool the air but to reduce its water vapor content.

Air conditioning involves those methods by which air is brought to and kept at the most desirable temperature and humidity for the comfort of the human body. Such conditioning includes the following: (1) filtration of the air, (2) disinfecting, (3) regulation of temperature, (4) regulation of humidity, (5) circulation, and (6) proper insulation of the building. Many modern homes are equipped with air-conditioning units. Certain railroads are featuring fast, streamlined, air-conditioned trains. Steamship companies whose vessels travel in tropical waters are offering as an added attraction air-conditioned sleeping quarters aboard ship. It is a rather remarkable fact that the people of a large city will spend considerable sums of money for the heating of homes in winter but that relatively small expenditures are made for cooling in summer. And yet in that same city deaths from heat prostration may actually exceed those caused by severe cold.

Condensation

What Causes Condensation. The only known method whereby water vapor in the atmosphere can be converted into the liquid or solid state (condensation) is to reduce the temperature of the air below the dew point. When air is cooled, its capacity for water vapor is lowered; and if the cooling is sufficient, condensation of water vapor must result. The dew point

of any mass of air is closely related to its relative humidity. When the relative humidity is high and the air is close to the saturation point, only a slight cooling is necessary for the dew point to be reached and for condensation to begin. On the other hand, when relative humidity is low, as it usually is over the hot deserts, a large amount of cooling is required before the dew point is reached. Condensation, therefore, depends upon two variables: (1) the amount of cooling and (2) the relative humidity of the air. If the dew point is not reached until the temperature falls below 32°, the condensed water vapor may be in the form of tiny ice crystals (white frost, snow, and some clouds); if condensation occurs above the freezing point, it will be in the liquid state (dew, fog, and most clouds).

Methods of Cooling the Atmosphere and Resulting Forms of Condensation

Quiet Air in Contact with Cold Earth's Surface. Day and night the earth radiates its heat into space. If the surface cools, the air in contact with it also cools, owing largely to conduction of heat from the lower layers of air to the earth. Clear skies and dry air are relatively essential to this process, since they permit rapid loss of heat from the earth. Windy nights are not conducive to surface cooling, for under these conditions there is a constant "churning" of the lower air so that it does not remain long enough in contact with the earth's surface to be markedly cooled. Moreover, the cooling is distributed throughout a larger mass of air. It is a well-known fact that both dew and frost are much more likely to occur on nights that are clear and calm than on those when the sky is overcast and a wind is blowing. Condensation may take place throughout a shallow layer of surface air, producing a fog. Such fogs are particularly noticeable in lowlands, where, as a result of air drainage, the colder, heavier air has collected. Fogs of this nature are called *radiation*, or *lowland*, fogs. From a hilltop one may observe "lakes" of fog, or patches of frost, occupying the surrounding depressions. As the sun rises, these lowland fogs usually are quickly evaporated. The famous London fogs are of this type, the chilled air collecting in the Thames lowland. Their darkness and persistence are a result of a "lid" of smoke and soot which

prevents the penetration of sunlight which would cause evaporation of the moisture particles.

Dew is formed when water vapor condenses on the earth's surface and the temperature is above 32°. Dew forms quickly on grass mainly for two reasons: (1) Transpiration of water from the grass increases the relative humidity of the air near the ground, assuming a calm night. (2) The millions of blades of grass offer a tremendous surface from which heat is radiated, thus lowering

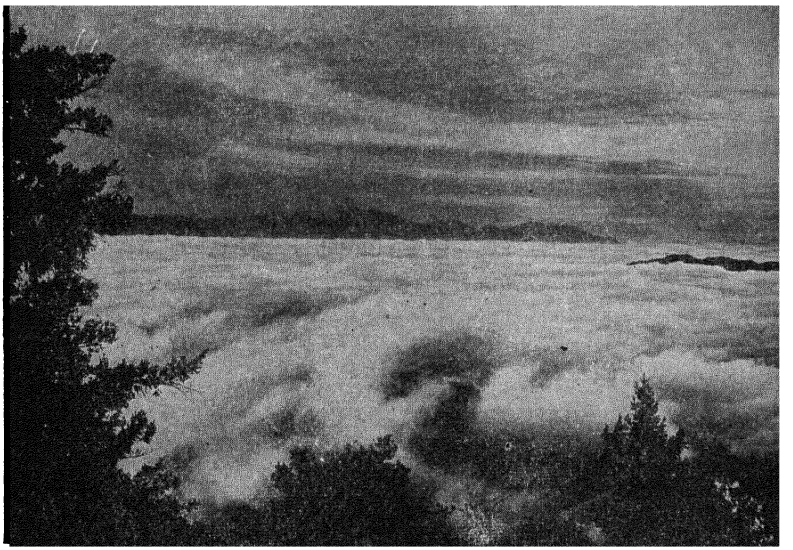


FIG. 49.—Stratus clouds and advection fog, seen from Mt. Wilson, California. (*Photograph by F. Ellerman.*)

the temperature below the dew point. Drops of water condensed on the outside of a pitcher of ice water illustrate the formation of dew. The approximate dew point of the air can be found by noting the temperature of the water inside the pitcher at the moment when condensation first begins on the outside surface. White frost is formed when condensation occurs below 32°. For the most part, frost consists of delicate ice crystals resulting from the direct change of water vapor to ice. A similar change at high altitudes causes the formation of snow. There are times, on the earth's surface, when the temperature drops below 32° but does not reach the dew point, and no white frost appears.

Nevertheless, a frost has occurred. This type is called a *dry freeze.*

Moist Air Moving over Cold Surfaces. This process of cooling the air produces relatively widespread, dense, and persistent fogs, the type that seriously hinders aviation. Such are known as *advection* fogs (Fig. 49). Especially in winter, moist air from the south may blow over the cold, often snow-covered land, resulting in fog formation. The dense fogs along the California coast are largely due to the chilling of moist ocean winds as they pass over a belt of upwelling, cold water near shore. Fogs over the Great Lakes often result, especially in spring, when warm winds from the land blow over the colder water. In the region of the Grand Banks off Newfoundland, the Gulf Stream, a warm ocean current, comes near the cold Labrador Current. Extremely dense fogs result, as the relatively warm air from over the Gulf Stream drifts over the colder water of the Labrador Current (Fig. 50). Cool ocean currents along the coasts of Chile and southwest Africa are largely responsible for fogs in those regions.

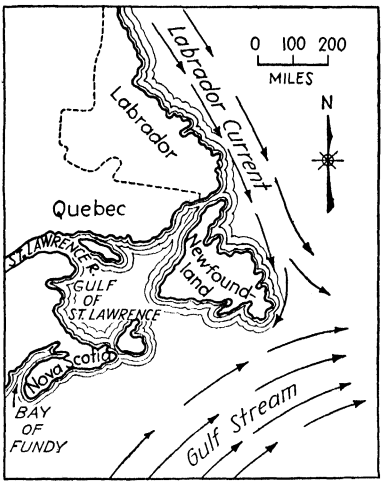


FIG. 50.—The cold Labrador Current and relatively warm Gulf Stream are largely responsible for the dense fogs in the vicinity of Newfoundland. It is the Labrador Current that carries icebergs south into the paths of ocean liners. Observe the location of the Bay of Fundy, noted for its extremely high tides.

Cooling Resulting from Expansion of the Air in Rising Currents. When air rises, no matter for what reason, it expands, because there is less pressure upon it at the higher altitudes. At 17,500 feet, pressure is about one-half that at sea level. As the air rises and expands, it cools at the rate of about 5° per 1,000 feet. This rate of cooling is much more rapid than that shown when a thermometer is carried upward through the atmosphere (about 3.2° per 1,000 feet). When air descends, it is compressed by the denser, lower layers, and as a result its temperature increases.

Ascending air currents → expansion → cooling
Descending air currents → compression → warming
Cooling air → capacity for water vapor decreases → condensation
Warming air → capacity for water vapor increases → evaporation

Heated air continues to rise until it reaches air layers of its own temperature and density. This process of cooling, by expansion of rising air currents, is the only one capable of reducing the temperature of great masses of air below the dew point, thereby causing condensation of water vapor on such a large scale that abundant precipitation results. As air rises, it finally reaches an altitude where condensation of the water vapor present takes place, forming clouds. A *cloud* consists of billions of tiny water particles, so light in weight that they are easily carried from place to place or from low to high altitudes by winds and air currents. Clouds often are composed of tiny ice crystals (snow) in winter and at high elevations in summer. Fog and cloud are identical except for differences in height above the ground. Not all clouds give rise to precipitation, but all precipitation has its origin in clouds and is the result of exaggerated condensation processes taking place within them.

Cloud Particles and Light Rays. When light rays pass from air into water they are reflected at the surface and refracted (bent) as they pass through. Thus the colors of the solar spectrum (violet, indigo, blue, green, yellow, orange, and red) are brought out by the *rainbow*, caused by refraction and reflection of sunlight acting on multitudes of water particles in the air. The action of moonlight on water and ice particles in the upper air is responsible for the *halo* of the moon. Beautiful colors of sunrise and sunset are due to the breaking up of sunlight not only by moisture but also by dust particles in the atmosphere. These colors are more brilliant in the morning and evening because there are far more dust and water particles between the eye and the sun at those times of day than, let us say, at noon.

Cloud Types. Four principal, or pure, cloud types are usually recognized. The other numerous types that can be observed are modifications or combinations of these four.

Cumulus. These relatively fair-weather clouds are distinguished by their flat bases and their beautiful, towering, cauliflower tops (Figs. 51, 52). The flat bases mark condensation

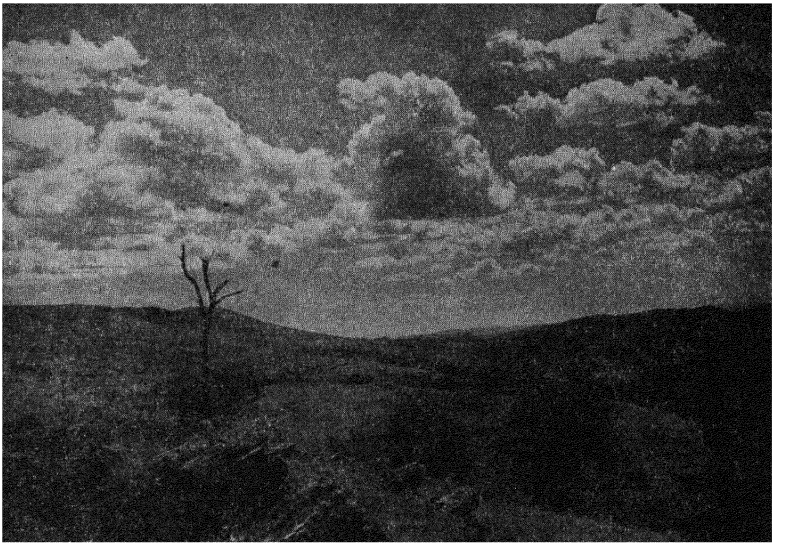


FIG. 51.—Cumulus clouds. (*Photograph by L. W. Humphreys.*)

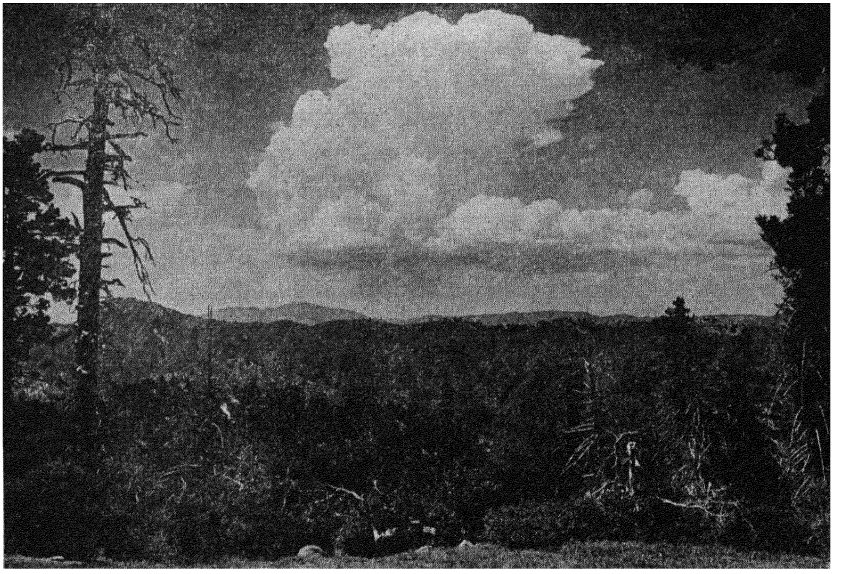


FIG. 52.—Cumulo-nimbus clouds. (*Courtesy of U.S. Weather Bureau.*)

level. Cumulus clouds are the result of vertically ascending air currents and are usually associated with local surface heating on warm summer days. Of course, convectional ascent does not take place over the entire heated surface. In some places warm air masses are rising; in others cooler air masses are settling to the earth. Thus separate and isolated cumuli occur with patches of blue sky between. Sometimes on hot, humid days



FIG. 53.—Cirrus clouds. (*Courtesy of U.S. Weather Bureau.*)



FIG. 54.—Stratus clouds. (*Courtesy of U.S. Weather Bureau.*)

when convection is exceedingly well developed, the cumulus clouds may extend to great heights and develop into thunderheads. These overgrown cumulus, or *cumulo-nimbus*, clouds are the sources of many local thunderstorms and a considerable part of the earth's rainfall (Fig. 52).

Cirrus. These also are fair-weather clouds, although not infrequently they may be forerunners of an approaching storm. They occur at great altitudes (5 to 9 miles) where temperatures are usually well below freezing so that they are composed of

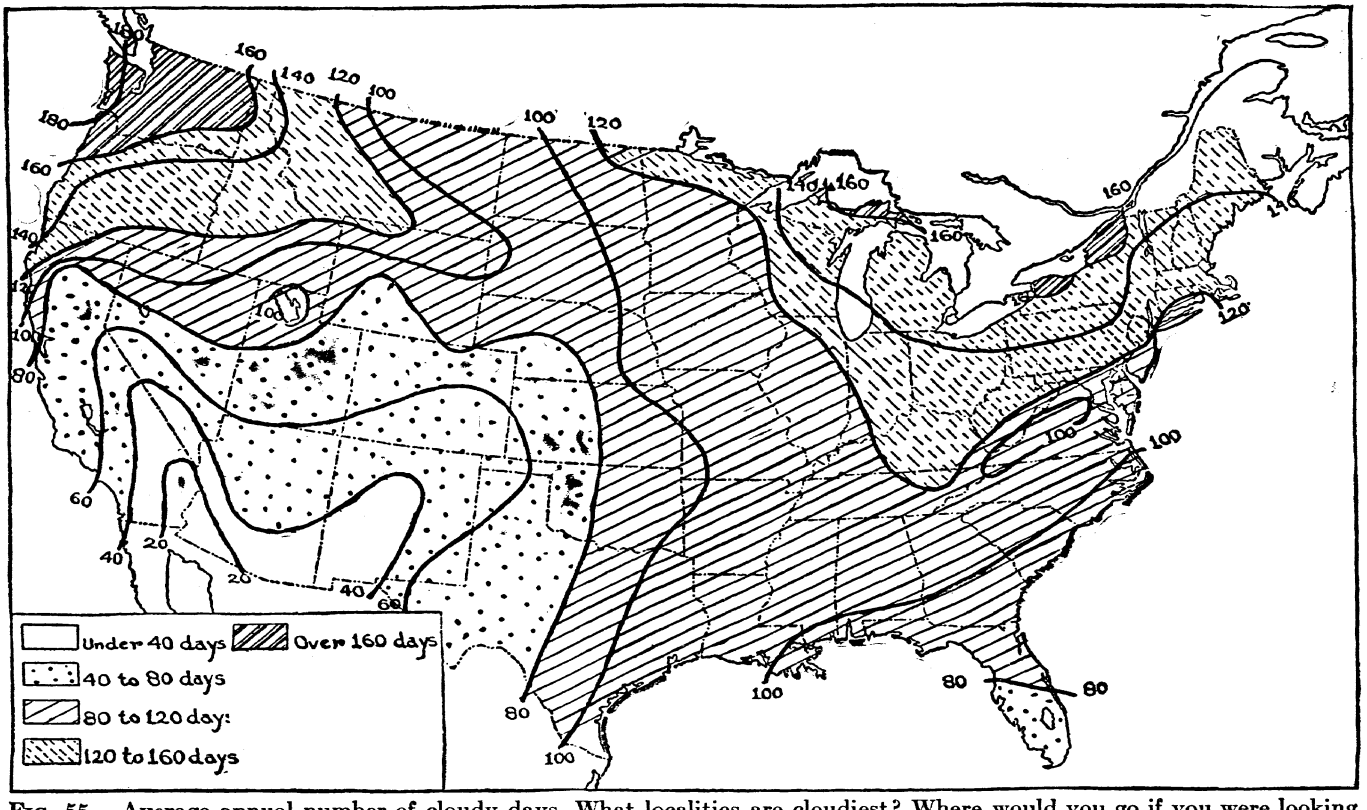


FIG. 55.—Average annual number of cloudy days. What localities are cloudiest? Where would you go if you were looking for a maximum amount of sunshine?

minute ice crystals. Cirrus clouds assume various forms, sometimes appearing like white ringlets, curls, or wisps of hair (Fig. 53). At other times they seem to form an unbroken thin veil of fibrous texture over the whole sky. In the latter case they produce halos around the moon or sun. Never are they thick enough to produce shadows, so they always appear white.

Stratus. These low-lying layers, or sheets, of cloud form a dull, gray sky of uniform color (Fig. 54). Often the gray ceiling stretches unbroken from horizon to horizon. They are relatively common in winter, producing gray, depressing days. A common method of their origin is mixture along the contact plane between two masses of air of different temperatures. These clouds sometimes bring the ceiling (altitude of bottom side of cloud layer) for airplanes to within 100 or 200 feet of the earth's surface; and since they often cover such great areas, they are a serious hindrance to commercial aviation (Fig. 55).

Nimbus. Thick, dark masses of cloud from which rain is falling are called *nimbus.* The word "nimbus" is usually used in combination with another, such as cumulo-nimbus.

The prefix *alto-* before any of the foregoing names of clouds means *higher than usual. Fracto-* means *broken up.* Thus a rather common cloud type is the fracto-cumulus.

Forms of Precipitation

Rain, Snow, and Sleet. The commonest form of precipitation is *rain.* As stated previously, it is the result of exaggerated condensation in rising air currents, at temperatures above 32°, whereas *snow* forms at temperatures below freezing. *Sleet* is frozen rain and results when raindrops from a warmer air mass above fall through a cold surface layer of air. It is characteristic of the cooler seasons.

Glaze. The accumulation of a coating of ice on objects near the earth, often called *glaze,* is really not a form of precipitation. Fortunately it is not of common occurrence, for the so-called *ice storm* that produces glaze is one of the most destructive of the cool-season types of weather. It occurs when rain, near the freezing point, strikes surface objects whose temperatures are below 32° and is immediately converted into ice. So great may become the weight of the ice accumulation

that trees are often wrecked and telephone, telegraph, and electric wires broken and their posts snapped off (Fig. 56). Such a coating of ice on an airplane may make a forced landing necessary. Most commercial airplanes used for winter flying are equipped with "de-icers," especially on the leading edge of the wing. To prevent a coating of ice from forming on the propeller, a thin spray of oil is thrown on the blades while in flight.

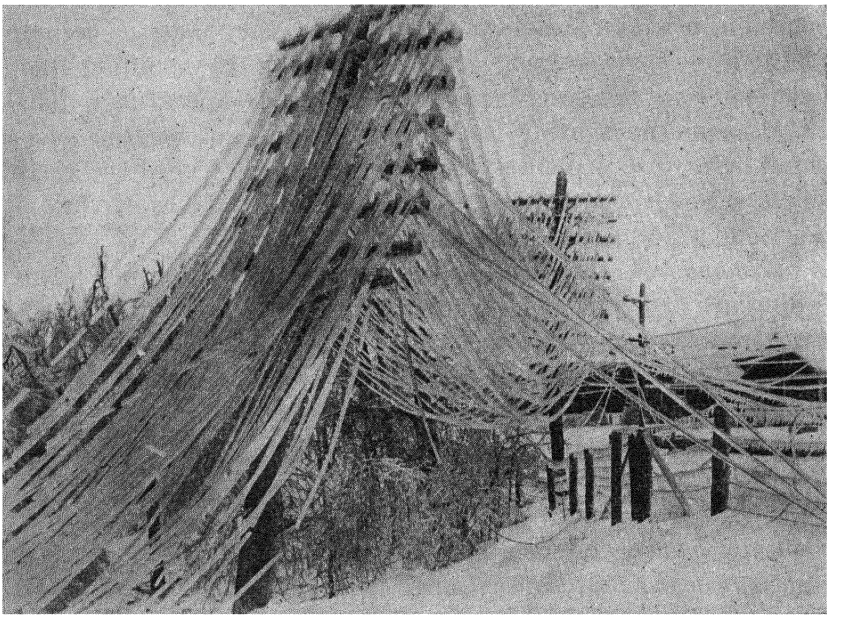


FIG. 56.—After an ice storm. The ice on these telephone wires weighed 800 pounds per wire between poles and was 3 inches in diameter. (*Courtesy of U.S. Weather Bureau.*)

Hail. The heaviest and largest unit of precipitation existing in solid form is *hail.* It is exclusively the product of vigorous convection, occurring in thunderstorms, which in turn usually belong to the warm season. Hailstones are composed of concentric layers or shells of clear ice and of partially melted and refrozen snow, representing the successive vertical descents and ascents in the tumultuous convectional currents of a thunderstorm.

Convectional Precipitation. As a result of the heating of surface air, it expands and is forced to rise by the cooler, heavier

air above and around it. Ordinarily such rising air, since it cools at nearly double the rate of the normal vertical temperature decrease, will rise only a few thousand feet before its temperature has been reduced to the point where it is the same as that of the surrounding air. At that point where the rising air reaches air strata of its own temperature and density, further ascent ceases. But if abundant condensation begins before this stage is reached, then heat of condensation is released, so that with this added source of energy the rising air will be forced to ascend much higher before reaching atmospheric strata of its own temperature. Thus on a hot, humid summer afternoon, when surface heating is intense and condensation abundant, the towering cumulo-nimbus clouds resulting from convectional ascent may be several miles in vertical depth, and precipitation from them may be copious.

Convectional ascent is usually associated with the warm season of the year and the warm hours of the day. Since it is essentially a vertical movement of warm, humid air, cooling is rapid, and the rainfall resulting is likely to be in the form of heavy showers. Because a cumulo-nimbus cloud usually covers only a relatively small area, it quickly drifts by, so that the associated shower is not of long duration. Such "dash" rains are "spotty" and are entirely unlike the general rains over large areas produced by cool-weather lows, or cyclones. Convectional rain, because it comes in the form of heavy showers, is less effective for crop growth, since much of it instead of entering the soil runs off in the form of surface drainage. This is a genuine menace to plowed fields. Soil removal through slope wash and gullying is likely to be serious. On the other hand, for the middle and higher latitudes, convectional rain, since it occurs in the warm season of the year when vegetation is active and crops are growing, comes at the most strategic time. Moreover, it provides the maximum rainfall with the minimum amount of cloudiness.

Orographic Precipitation. Air also may be forced to rise when landform barriers, such as mountain ranges, plateau escarpments, or even high hills, lie athwart the paths of winds. Since water vapor is largely confined to the lower layers of atmosphere and rapidly decreases in amount upward, heavy

orographic rainfall is the result of such forced ascent of air, associated with the blocking effect of landform obstacles. Witness, for example, the abundant precipitation along the western, or windward, flanks of the Cascade Mountains in Washington and Oregon, along parts of the precipitous east coast of Brazil which lies in the southeast trades, or along the abrupt west coast of India which the summer monsoon meets at practically right angles. The leeward sides of such mountain barriers, where the air is descending and warming, are characteristically drier. This arid to semiarid side of a mountain range is called the *rain shadow.*

The most ideal condition for producing heavy orographic rainfall is a high and relatively continuous mountain barrier lying close to a coast, and the winds from off a warm ocean

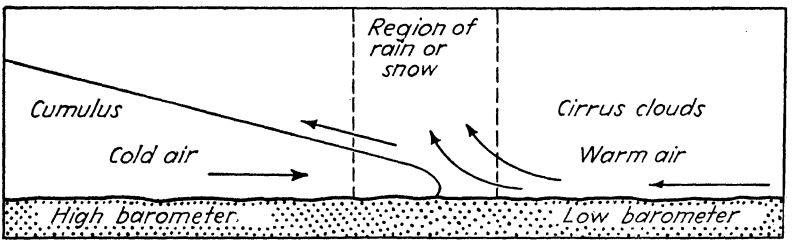
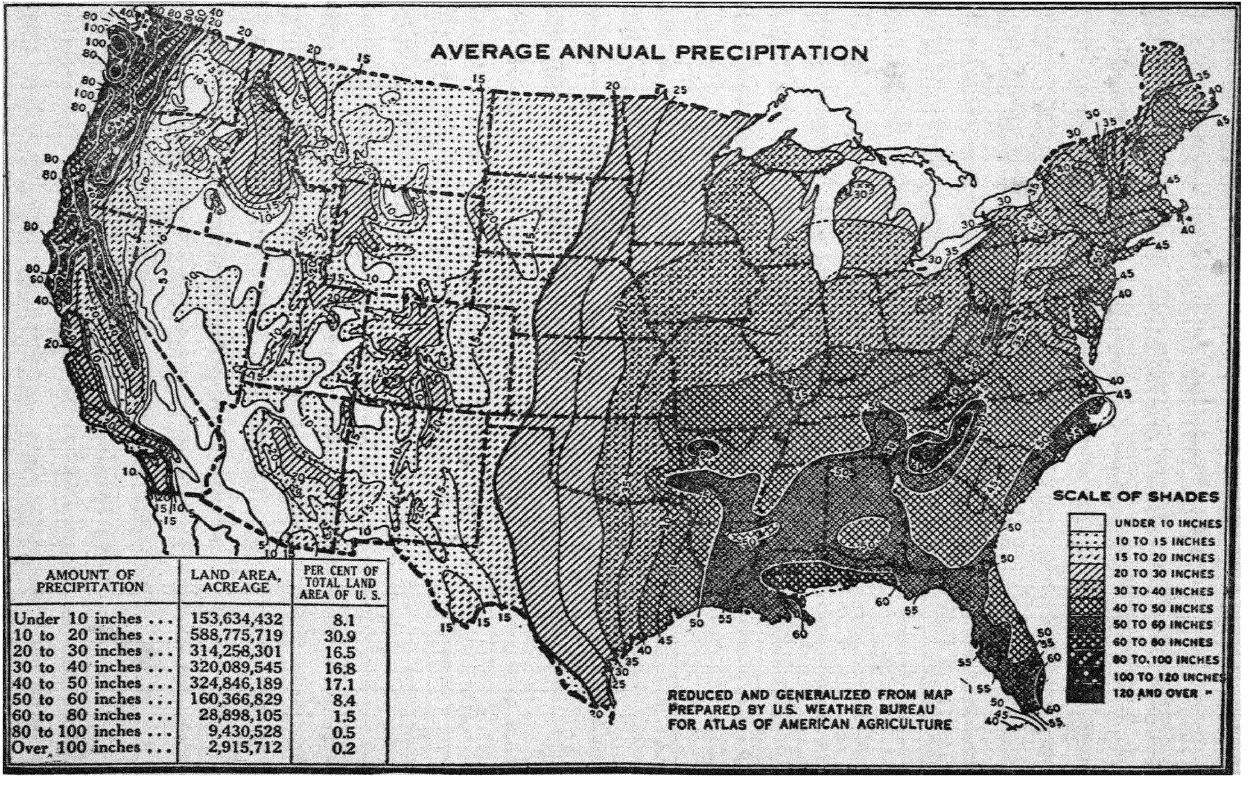


FIG. 57.—A wedge of cold air undermining and uplifting a mass of warm air. Sometimes the lifting is very rapid, causing thunderstorms. At other times it is slow, causing layers of stratus clouds to develop.

meet the barrier at right angles. Orographic rains have less seasonal and daily periodicity than do those of convectional origin. In monsoon regions, very naturally, the maximum is at the time when air is moving from sea to land, usually high sun, or summer. In other regions the strength of the winds, the angle at which they meet the mountain barrier, or the contrast between land and water temperatures may determine the season of maximum orographic rainfall.

Cyclonic Precipitation. In low-pressure storms (cyclones), winds from various directions, and consequently of different temperatures and densities, tend to come together about a center of low barometric pressure (see following chapter). As a result of such movement, great volumes of air are lifted and cooled. When a warm tropical air mass moves toward a colder polar air mass, the warmer, lighter air will be lifted by the



AMOUNT OF PRECIPITATION	LAND AREA, ACREAGE	PER CENT OF TOTAL LAND AREA OF U. S.
Under 10 inches ...	153,634,432	8.1
10 to 20 inches ...	588,775,719	30.9
20 to 30 inches ...	314,258,301	16.5
30 to 40 inches ...	320,089,545	16.8
40 to 50 inches ...	324,846,189	17.1
50 to 60 inches ...	160,366,829	8.4
60 to 80 inches ...	28,898,105	1.5
80 to 100 inches ...	9,430,528	0.5
Over 100 inches ...	2,915,712	0.2

FIG. 58.—Average annual rainfall. (*Reduced and generalized from map prepared by U.S. Weather Bureau for Atlas of American Agriculture.*)

cooler, heavier air. Unlike convectional ascent, which involves direct vertical lifting, the warmer air in cyclones more often rises obliquely and therefore slowly, along mildly inclined surfaces of cold, dense air, and cooling as a consequence is less rapid (Fig. 57). As a result of the slower ascent and cooling, precipitation in cyclones is characteristically less violent than in thunderstorms and is inclined to be steadier and longer continued.

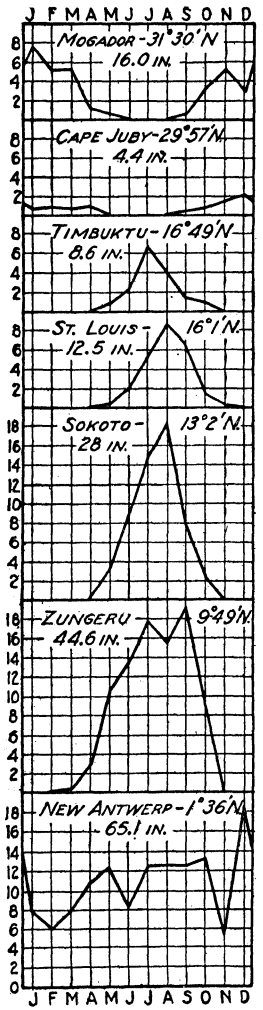


FIG. 59.—These rainfall charts for seven stations in Africa north of the equator illustrate rainfall regimes in low latitudes. Stations are arranged according to latitude with Nouvelle Anvers (New Antwerp) closest to the equator.

The dull, gray, overcast skies and drizzly precipitation of the cooler months in middle latitudes, producing some of the most unpleasant weather of those seasons, are usually associated with cyclones. These storms are most numerous and best developed during the cool season. Where they dominate weather conditions, therefore, they tend to produce more rain in autumn or winter than in summer. Most of the winter precipitation of lowlands in the middle latitudes is cyclonic in origin. In the tropics, as well as in the middle latitudes, cyclones are important generators of precipitation, although the storms of low latitudes are of a different origin and their rainfall may be likewise.

Important Precipitation Data. At least three items concerning precipitation of a region are of outstanding importance: (1) its total average amount or depth for the year (Fig. 58); (2) its seasonal distribution (Fig. 59); and (3) its dependability, both annual and seasonal.

The total annual amount of rain is important, and seasonal distribution is equally so. Omaha, Neb., receives 30 inches of rainfall annually. During the months from May to August inclusive the rainfall is 17.4 inches (57 per cent),

and only 3.3 inches (11 per cent) during the period November to February inclusive. The fact that the majority of the precipitation occurs during the growing (warm) months is extremely important from the standpoint of the production of economic crops. Variability in the total amount of precipitation from year to year (its dependability) is hardly of less importance, especially for regions that are normally subhumid. It is a general rule that variability increases as the amount of rainfall decreases.

The average annual amount of rainfall and its characteristic seasonal distribution at any place (rainfall regime) depend upon (1) accessibility to moisture-bearing winds, usually from the ocean, and (2) the existence of conditions, principally storms, favorable for the condensation of water vapor. Both conditions are essential. The accessibility of a region to moisture-bearing winds is related to (1) the general distribution of pressure and winds, (2) the character of relief features on the land surface, and (3) the distance from oceans, the principal source of water vapor for the lands. The distribution of rainfall over the continents is discussed more fully in the chapters dealing with climate.

Summary

The ratio of absolute humidity to capacity, expressed in percentage, is called relative humidity. When air is warmed, its capacity to hold water vapor increases. On the other hand, if air is cooled below the dew point, water vapor condenses into such forms as clouds, fog, dew, and frost. The lifting of great masses of air causes condensation of water vapor on a large scale. This in turn brings about the precipitation so necessary to the growth of vegetation. Based on origin, there are three types of precipitation: convectional, orographic, and cyclonic. Annual rainfall and seasonal distribution are extremely important factors in the production of economic crops.

In the last three chapters we have studied the temperature, pressure, and moisture of the atmosphere. All these are involved in great disturbances of the air, which go by the general name of storms. Our next chapter deals with the subject of storms, the paths that they follow, and the changes in weather that they bring.

Questions

1. State four ways in which water vapor in the air is of considerable importance.

2. What is the primary source of water vapor in the air?

3. What is evaporation? What factors determine the rate of evaporation?

4. What is condensation? Is it caused by heating or cooling of the air?

5. At what temperature does air condense into liquid air?

6. What is the nature of air that causes ice to form on airplanes in flight?

7. What is a calorie? How many calories are required to change 1 gram of ice into water at 32°? To change water into water vapor at the same temperature?

8. What is one reason why water bodies heat slowly?

9. What is meant by latent heat of condensation? How does it affect the intensity of a storm? Why?

10. What is capacity? Saturated air? Which is heavier, air or water vapor?

11. What is absolute humidity? Which ordinarily has greater A.H., a tropical or a polar air mass? Why?

12. Why are absolute and relative humidity often very low during dust storms?

13. On the average, when would you expect R.H. to be lower, at noon or at midnight? Why?

14. What is meant by relative humidity? If A.H. remains the same, what happens to R. H. when temperature increases? Decreases?

15. What is dew point? What is the dew point of air at 70° that has an A.H. of 4.1 grains per cubic foot?

16. How much water vapor is condensed when 100 cubic feet of saturated air is cooled from 80° to 40°?

17. Air at 100° has a R.H. of 10 per cent. What is A.H.? The dew point?

18. Air at 80° has a R.H. of 50 per cent. What is the dew point?

19. Certain air at 90° has A.H. of 3.35. What is R.H.?

20. If AH = 2 and RH = 25 per cent, what is C? What is the temperature?

21. Outdoor air at 40° with R.H. of 70 per cent is brought indoors and heated to 70° with no water vapor added. What is R.H. indoors?

22. A theater brings indoors 100,000 cubic feet of air at 90° with R.H. of 80 per cent. This air is cooled to 70° with R.H. of 50 per cent. How much water is condensed? (7,000 grains = 1 pound)

23. Why is dry air indoors in winter possibly detrimental to health?

24. How can moisture be added to air indoors in winter?

25. Why do we feel uncomfortable on hot, humid days?

26. What is air conditioning? What processes are involved?

27. Which has a lower dew point, moist or dry air? Why?

28. Why is dew (or frost) more likely to form on clear, calm nights than on cloudy, windy nights?

29. Why do we often see "lakes" of fog in low places?

30. What causes the darkness and persistence of London fogs?

31. What is dew? Why does it form quickly on grass?

32. What is frost? Is most frost frozen dew?

33. Differentiate between radiation and advection fogs.

34. What causes the dense fogs in our Central states in winter? On the coast of California? Around Newfoundland?

35. What is the rate of cooling of rising air currents?

36. When air descends, what happens to its temperature? Why?

37. What is the principal cause of abundant precipitation?

38. What is a cloud?

39. Clouds and fog differ in what respect?

40. Precipitation has its origin in clouds as a result of what process?

41. What are the colors of the solar spectrum as shown by a rainbow?

42. What causes a rainbow? A halo of the moon? The colors of sunrise and sunset?

43. What are the four principal types of clouds? Describe each.

44. Which cloud type is the source of a thunderstorm?

45. Which is the highest cloud type? The lowest?

46. Why are stratus clouds a hindrance to aviation, probably more than any other type?

47. What is meant by the cloud prefix alto-? Fracto-?

48. What is sleet? Glaze? Hail?

49. Explain the cause of convectional rain. What are some objections to this type of rain?

50. Explain the cause of orographic rain. Mention a few exact locations where such rain occurs.

51. What is a rain shadow? Give an example.

52. What are the ideal conditions that produce heavy orographic rain?

53. Explain the cause of cyclonic precipitation. Why is it usually less violent than convectional?

54. What precipitation data are important?
55. What two factors determine the rainfall regime of a region?

Suggested Activities

1. Using the wet-and-dry bulb method, test relative humidity of the air every hour of the day, outdoors and indoors. Plot curves to show results. Repeat during the various seasons of the year.

2. Observe a hygrograph, if one is available. It records relative humidity on graph paper. Most of them operate for a week at a time. The hygrograph curve shows clearly the change in relative humidity during day and night and the difference in moisture content of the air during rainy spells and dry weather.

3. Determine the dew point of air, indoors and outdoors. Explain the difference, if any.

4. If possible, visit a weather bureau, and observe the instruments for measuring and recording rain and snow. Note also the care with which all data are recorded.

5. If possible, visit an airport. Make inquiry concerning ice formation on airplanes and methods of prevention.

6. Using a triangular glass prism, observe the colors of the solar spectrum. Note these colors also in a rainbow, when visible.

7. Study the operation of a hair hygrometer, if one is available.

8. Construct or purchase a rain gauge. Send to U.S. Weather Bureau, Washington, D.C., for bulletin on meteorological instruments. Secure catalogues from manufacturers, giving descriptions and prices of instruments.

9. Keep a daily record of cloud types and rainfall.

10. Using climatic data available, plot relative humidity and rainfall curves for selected places.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Air Conditioning
2. Methods of Testing Air for Relative Humidity
3. Variation in Relative Humidity over the United States
4. Clouds and Their Meaning
5. Measuring Rain and Snow
6. Methods of Determining the Dew Point
7. Variations in Annual Rainfall in Your Home Community during the Past 20 Years
8. The Quantity of Rain Needed for Certain Economic Crops
9. Examples of Orographic Rain and Rain Shadow

10. Contrasting Rainfall Distribution over North and South America

References

BLAIR, THOMAS A.: *Weather Elements*, Chaps. 3 and 5, Prentice-Hall, Inc., New York, 1937.

FLETCHER, G. L.: *Earth Science*, Chap. 27, D. C. Heath & Company, Boston, 1938

HUNTINGTON, ELLSWORTH, and F. E. WILLIAMS: *Business Geography*, Chaps. 3 and 9, John Wiley & Sons, Inc., New York, 1926.

TREWARTHA, GLENN T.: *An Introduction to Weather and Climate*, Chap. 3, McGraw-Hill Book Company, Inc., New York, 1937.

"Weather Forecasting," *Bulletin* 42 of the U.S. Weather Bureau, Government Printing Office, Washington, D.C.

World Weather Records (Collected from official sources), Smithsonian Institution, Washington, D.C., 1934.

Chapter V. Storms and Their Weather Types

The coming and going of a big thunderstorm is often a fascinating sight. If we were to take note of the storm's behavior, we should find that the sequence of events is about as follows:

On a quiet, hot, humid morning fleecy cirrus clouds are visible in the sky. The barometer shows a slight, steady drop. There is a high degree of humidity, and gradually the heat becomes more intense. The rapid rising of the warm, moist air causes great cumulus clouds to appear in the west. As these clouds approach, they darken to cumulo-nimbus and are churned and tossed about by high winds. A flash of lightning produces a loud clap of thunder. Suddenly, a brisk, cool breeze starts blowing. This cool air causes the barometer to rise quickly.

Now huge clouds obscure the sun. There are vivid flashes of lightning, followed by peals of thunder. An enormous amount of energy is being released in the atmosphere. Rain is falling in great sheets, and for a few minutes small hailstones patter against the window. The downpour continues for perhaps an hour. During this time the lightning and thunder become less and less frequent. Finally the sky clears in the west, as the storm retreats toward the east. A cool breeze begins blowing from the northwest, and the drop in temperature is noticeable. We look at the barograph and notice that the passing of the storm has produced a jagged appearance in the pressure curve traced by this instrument.

Such storms as the one just described occur during the warm months over much of the United States. In connection with the preceding description, certain things that we have learned should be recalled.

1. Convection currents produce cumulus clouds.

2. Condensation within the storm liberates latent, or stored-up, heat, increasing the strength of rising air currents and the intensity of the storm.

3. The coming and going of the storm cause changes in wind direction and air pressure.

The torrential rain may cause considerable soil wash, but the moisture is welcomed by growing crops. It is well to remember that storms are the earth's principal generators of precipitation. Without them, the great lowlands of the earth would be far less habitable than under existing conditions.

The present chapter deals with storms. It is concerned mainly with (1) the nonviolent cyclones and anticyclones of the middle latitudes, or intermediate zones; and to a lesser extent with (2) thunderstorms; (3) tornadoes; and (4) tropical storms.

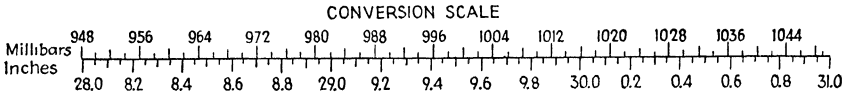
Middle-latitude Cyclones and Anticyclones

Nature and Location. As we have already said, cyclones are characterized by low barometric pressure and commonly go by the name of *lows*. Anticyclones are characterized by high pressure and are called *highs*. The cyclone, therefore, must consist largely of a mass of relatively light air, and the anticyclone of heavier air. This difference in weight, or pressure, is not noticeable except by watching the changes in a barometer or barograph. A low barometer indicates cyclonic; a high barometer, anticyclonic weather. Since these disturbances occur within the belt of westerly winds, they are best known in those latitudes between parallels 35 and 65 in both Northern and Southern hemispheres. Cyclones and anticyclones are *not violent* atmospheric disturbances as are tornadoes and hurricanes.

Appearance and Pressure. On the daily weather map, these storms are shown by a number of V-shaped or circular isobars drawn around a point of low pressure. In the center of the cyclone the word *low* indicates the region of lowest pressure. From the center toward the margins the pressure *increases*. In the center of an anticyclone the word *high* indicates the region of highest pressure. From the center toward the margins, the pressure *decreases*.

Average barometric pressure at sea level is about 30 inches, or 1,015 millibars. The millibar is a term used in the metric

system and is applied to a very tiny amount of force. In round numbers, $\frac{1}{10}$ inch on a barometer or barograph is equivalent to about 3 millibars. Either inches or millibars may be used in numbering the isobars on a weather map. The relation of millibars to inches is shown by the following scale:



On the weather map all pressure readings are reduced to sea level by adding approximately 1 inch for each 900 feet above sea level. At a place 4,500 feet above sea level, about 5 inches would be added to the local barometer reading in transferring the pressure to the weather map. The isobars are drawn for each tenth of an inch of pressure. In the autumn, winter, and spring,

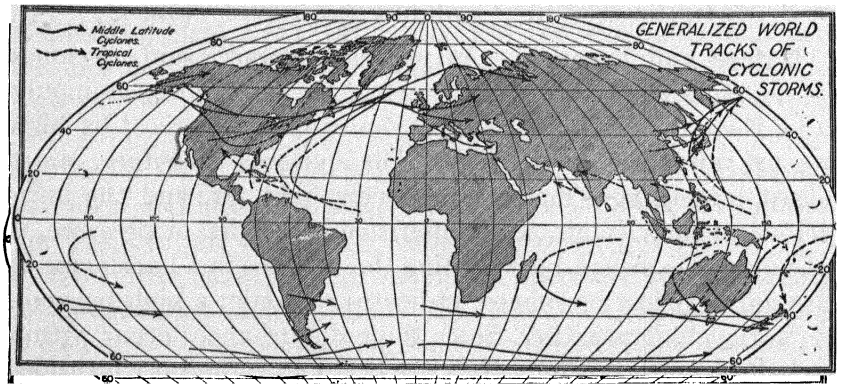


FIG. 60.—The tracks here shown are much generalized. (*Modified from Knight.*)

the pressure in the center of a cyclone may be $\frac{1}{2}$ inch or more below normal (30 inches); and in the center of an anticyclone, $\frac{1}{2}$ inch or more above normal. In well-developed storms the difference in pressure between the high and low may be more than 1 inch. A general rule is that both cyclones and anticyclones are less well developed, have smaller differences in pressure and weaker pressure gradients, and travel at slower speeds in summer than in winter. Cyclones are extensive rather than intensive storms. In some cases they are 1,000 miles or more in diameter. In cyclones with V-shaped isobars, the north-south distance across the storm frequently is greater than the east-west.

Direction and Rate of Movement. Lows and highs travel in general toward the east, carried along by the upper air system of westerly winds in which they exist. This is not to say, however, that they always travel due east. Certain paths are followed more frequently than others (Fig. 60). It is evident that in forecasting weather one should observe storm developments to the west and not to the east of a given place. Those storms to the east have already gone by; those to the west are approaching.

Lows and highs sometimes vary considerably in the speed at which they move across the country. Changes in speed and direction may account for failure in forecasting. In the United States, lows move across the country at an average speed of 20 miles per hour in summer and 30 miles per hour in winter. Highs usually move more slowly than lows. In summer, the intensity of highs and lows is greatly reduced. As a consequence, warm-season weather is less changeable, and atmospheric disturbances are less violent. In winter, a well-developed low usually crosses the United States in 3 to 5 days.

Wind Systems in Cyclones and Anticyclones

Wind System in Cyclones. Air flows from high to low pressure. Since the lowest pressure is in the center of a cyclone, it is evident that winds will blow toward that center. As air masses of contrasting origins, temperature, and humidity move toward the center of a low, the warmer and more humid air is lifted, sliding upward over cooler or drier air. This lifting of humid air usually results in the formation of clouds from which rain or snow may fall.

Surface winds blow in a general way toward the center of a low. On the east side, or front, of the storm, the winds blow mainly from easterly points. On the west side, or rear, of the storm the wind directions are westerly. Southeast and south winds prevail in the southeast quadrant (Fig. 61). These winds in central or eastern United States are likely to be mild and humid, since they may come from the Gulf of Mexico or the Atlantic Ocean. They are thus valuable importers of much needed moisture. Northwest wind prevails in the northwest quadrant of the storm. This wind often comes from western or central Canada and is cooler and drier than the southeast and

south winds. In winter, the northerly winds often are bitterly cold. The cyclone, then, is a meeting place of contrasting air masses. Thus a mild, humid air mass arrives from warmer latitudes on the front and equatorward sides of the storm. A colder, drier, and heavier air mass arrives from higher latitudes on the rear and poleward sides.

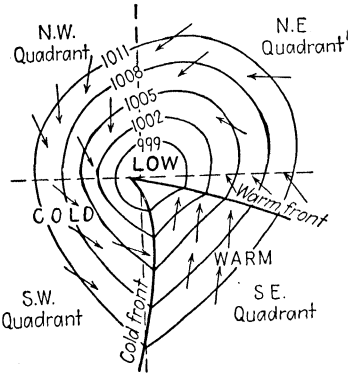


FIG. 61.—A cyclone, or low, as it often appears on the weather map. Arrows fly with the wind. Note that south and southeast winds prevail in the southeast quadrant, north-northwest winds in the northwest quadrant, and east-northeast winds in the northeast quadrant. The advancing cold front, which causes a wind shift from south to northwest is shown in the southeast quadrant. It is along the cold front that squalls, rain, snow, and sometimes severe thunderstorms are likely to occur.

Wind Shift with the Passing of a Cyclone. Although the center of a cyclone is west of an observer, he will experience general easterly winds. As the center passes and the observer finds himself in the west side, or rear, of the cyclone, he will note mainly northwest or west winds. Easterly surface winds, therefore, often indicate the approach of a cyclone with its accompanying clouds and rain. Westerly surface winds more often foretell the retreat of the storm center toward the east and the coming of clearing weather as an anticyclone moves in from a westerly direction.

In most storms the shift from easterly to westerly winds is rather gradual. In some, however, the wind shift is very abrupt. Especially is this true where isobars south of the storm center tend to take the form of a letter V pointing toward the south or southwest (Fig. 62). In such a low an irregular line extending

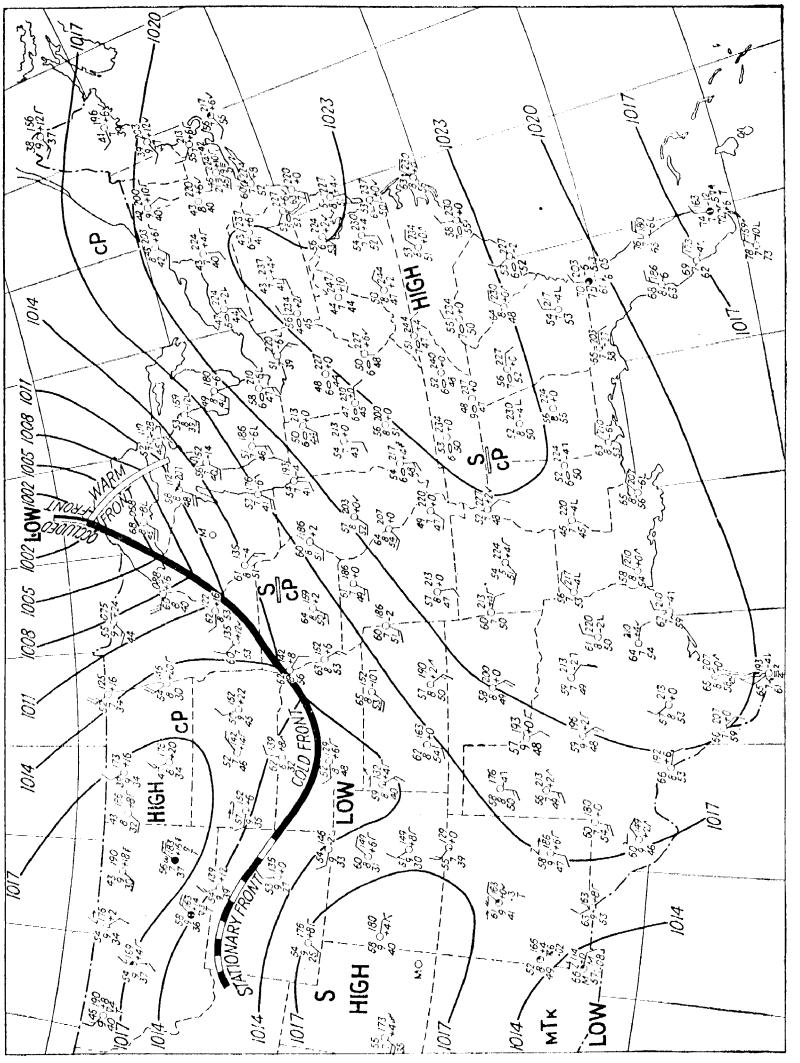


FIG. 62.—Daily weather map.

usually from the center toward the southwest is called the *wind-shift line.* Along this line, the wind is in the process of shifting from southerly to northerly points. The wind-shift line is also known as the *surface cold front,* since it marks the front edge of the cool or cold polar-air mass which is advancing toward the south and east. This cold-air mass, being relatively denser, undermines and forces upward the warmer and more humid air masses that it encounters. Along the wind-shift line of such a cyclone, therefore, violent atmospheric disturbances may occur. These often include a sharp drop in temperature as the wind suddenly changes from southeast to northwest, accompanied by rain or snow and, in warm seasons, thunderstorms.

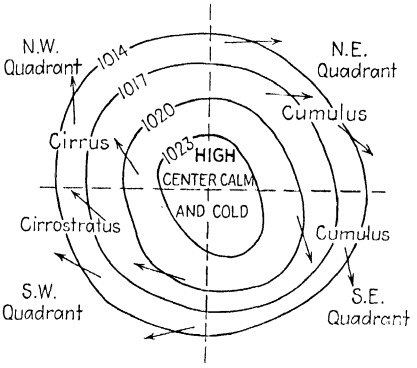


FIG. 63.—An anticyclone, or high, as it often appears on the weather map. Note the prevailing wind direction and cloud type in each of the four quadrants. Arrows fly with the wind.

The cold front is the boundary between two masses of air having different characteristics with respect to temperature and humidity. Ahead, or to the east, of the front is found relatively warm air of high water vapor content; behind, or to the west of, the cold front the air is usually noticed to be of lower temperature and less moisture. Along the front iself there is a reaction between the two masses of air of different density values. This reaction often results in weather types which pilots are particularly interested in knowing about. Such phenomena as extremely bumpy air, showers, thunderstorms, poor visibility and low ceiling are common, and pilots need all the information which is available concerning cold fronts in areas where flights are contemplated. Fortunately cold fronts are easy to identify on

weather maps, and their rates and direction of movement can be forecast more certainly than some other weather types.

Wind System of an Anticyclone. Surface winds blow out from the center of an anticyclone, or high (Fig. 63). Cooler, heavier air evidently settles to the earth at the center. To the east of the center, therefore, winds blow in general from westerly directions. To the west of the center they blow from easterly directions. The center of an anticyclone often brings relatively calm and fair weather.

Cyclones and anticyclones follow one another in a sort of parade across the United States, resulting in many and varied changes in weather. The northwest wind to the south and east of a high that is centered in western Canada may bring a severe cold wave or blizzard to central and eastern United States. At such times the cold polar-air mass may move as far south as the Gulf states, causing considerable suffering among people and livestock.

Precipitation in Cyclones and Anticyclones. In general, cyclones bring unsettled weather with rain or snow, and anticyclones bring fair or partly cloudy weather. Precipitation is more likely to occur in the cyclone, because it is a region where unlike air masses comes together. The warmer and more humid air masses are lifted by the colder and denser ones so that cooling and condensation of water vapor are likely to result. Not every cyclone is accompanied by precipitation, because (1) absolute humidity of the air may be too low and (2) there may not be sufficient lifting of the air to cause it to reach the condensation level. In the anticyclone, air at the center is slowly settling from higher altitudes. As it settles, it becomes warmer, its capacity for moisture increases, and little precipitation results.

Precipitation over the lowlands of the United States in the cool months is largely cyclonic in origin. In the summer months the heat increases the strength of rising air currents, and convectional rainfall results. Thunderstorms bring heavy "dash" rains of short duration. Cyclonic rainfall, on the other hand, tends to be light and steady, lasting for hours, sometimes days, and often covering considerable areas. This is due to the *slow* lifting of warm, humid air masses by underrunning cooler air (Fig. 57). Such lifting is much less rapid than that caused by

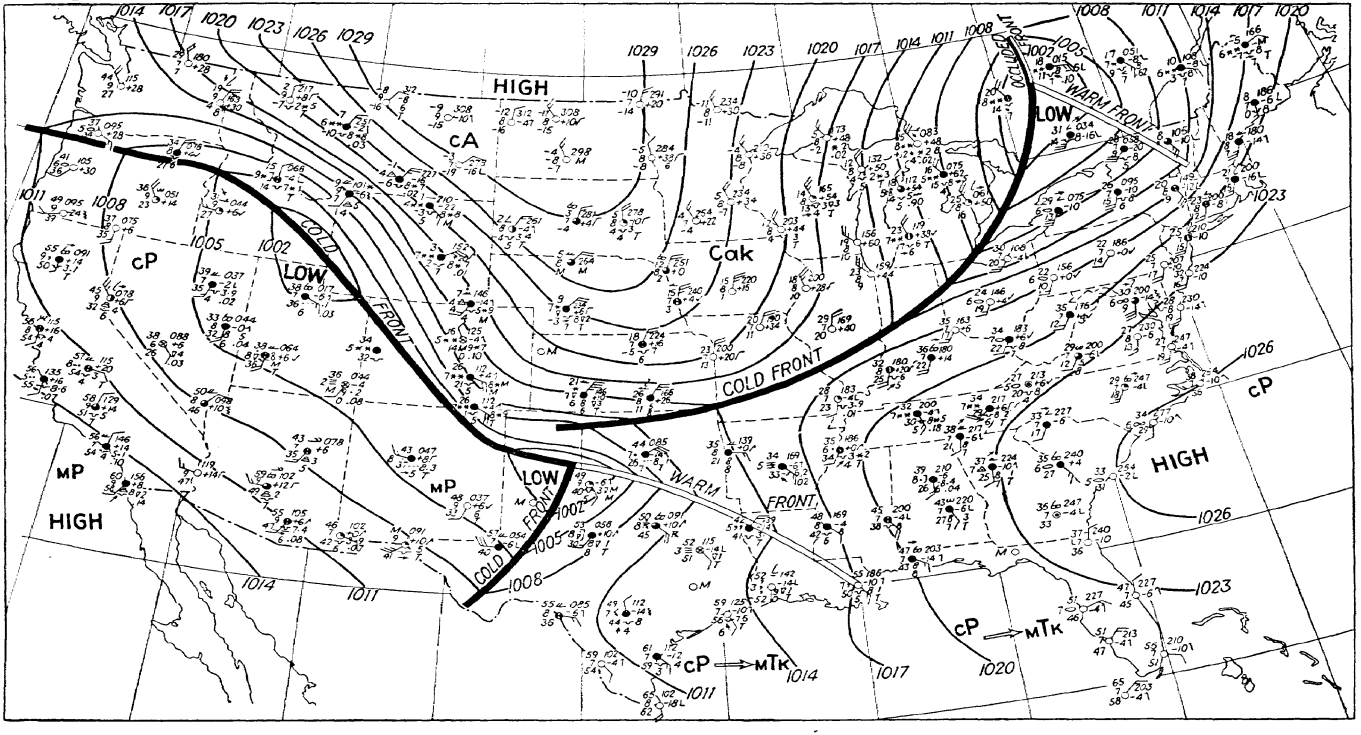


FIG. 64.—Daily weather map. The large anticyclone, or high, was caused by a Continental Arctic (*cA*) air mass which moved southeastward from the arctic region to the Gulf of Mexico. Notice the cold temperatures in the northern plains states where the air mass is moving into the United States. This map is typical of those of the early part of winter; later in the winter season even colder temperatures occur. Note that isobars are numbered in millibars. Three millibars is equivalent to about $\frac{1}{10}$ inch on the mercurial barometer.

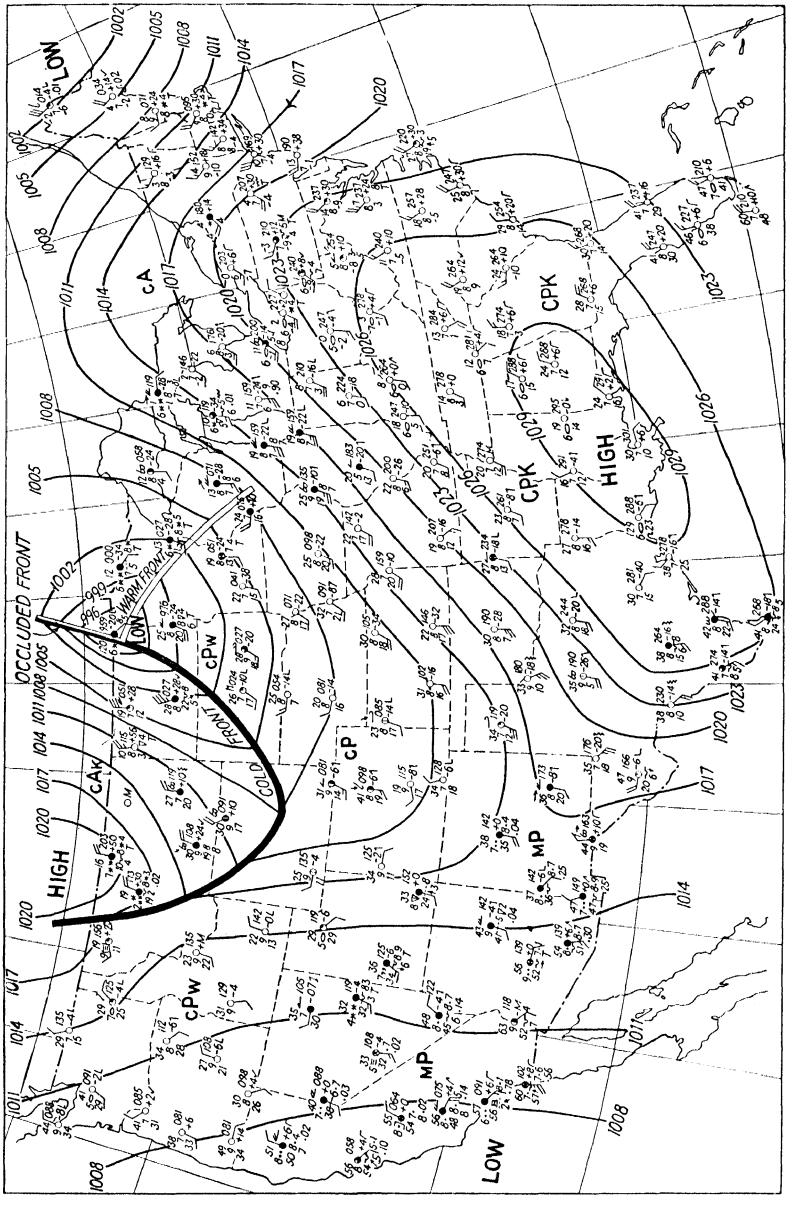


FIG. 64*a*.—Surface map.

Weather Symbols

- Haze
- Fog
- Signs of tropical storm
- Dust or sand storm
- Continuous moderate drizzle
- Intermittent moderate rain
- Continuous heavy snow in flakes
- Showers of heavy rain
- Thunderstorm

Cloud Symbols

- Cumulus of fine weather
- Layer of stratus or stratocumulus
- Low broken-up clouds of bad weather
- Cumulonimbus
- Typical altostratus, thin
- Veil of cirrostratus covering the whole sky.

COMPLETE U.S. MODEL

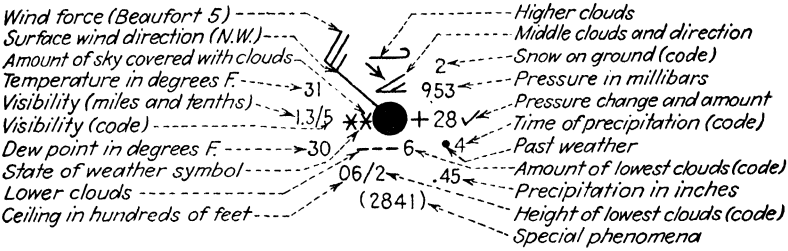
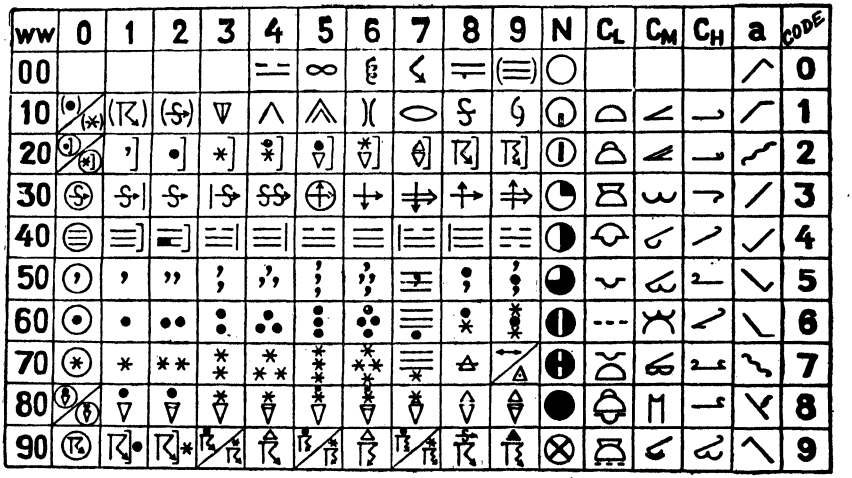


FIG. 64*b*.—Station model adopted by the U.S. Weather Bureau on August 1, 1942.



(Courtesy of U.S. Weather Bureau.)

FIG. 64*c*.—Table of symbols. Columns *ww* to 9 show map weather symbols. The filled-in portion of the circles in column *N* represent the approximate portion of the sky which is covered with clouds. Columns C_L, C_M, and C_H contain symbols representing low, medium, and high altitude clouds. The symbols in column *a* represent the trend of the barograph trace during the three hours prior to a report.

strong convection currents in thunderstorms. The steady cyclonic rain is beneficial in that much of it seeps into the ground. On the other hand, a considerable part of thunderstorm down-

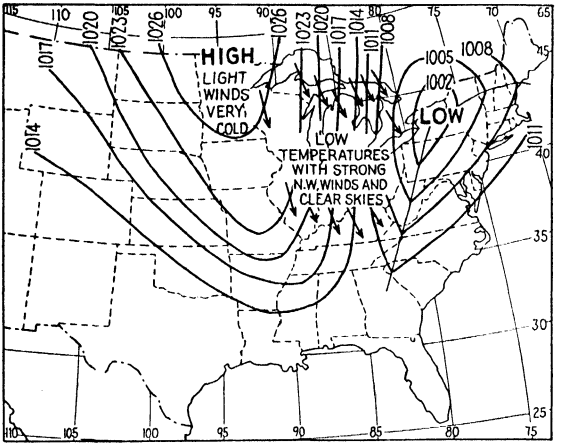


FIG. 65.—A winter anticyclone advancing southeastward as a mass of Cold Polar Continental air.

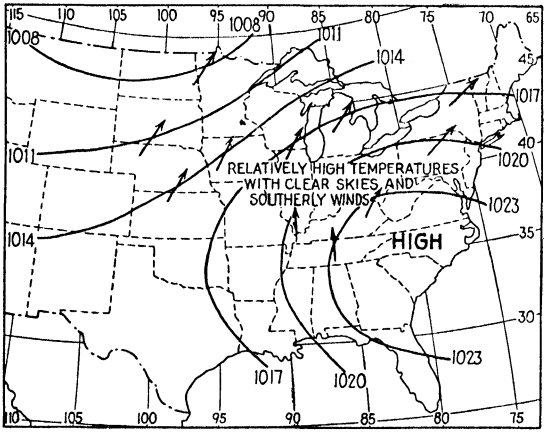


FIG. 66.—A relatively stagnant anticyclone over southeastern United States producing unseasonably warm weather over the central and eastern parts of the country.

pour disappears by rapid surface runoff. Especially in freshly plowed fields, this causes disastrous soil erosion.

Temperatures in Anticyclones. In winter a well-developed high advances toward the east and southeast. It is a mass of Polar Continental air from northern and western Canada. Its temperature is so low that it brings a cold wave to central and eastern United States (Figs. 64 and 65). In such highs the

temperature ranges from zero to 20° or 30° below. If accompanied by high winds and snow, a blizzard is the result. For example, the weather map in Fig. 64 shows a high over the Northern Plains states. The cold weather produced at this time resulted in temperature readings well below the normal. In summer a similar high brings a few days of relatively cool delightful weather. It is relatively easy to forecast.

Occasionally in summer a high develops over the Southern states, and a slow-moving low travels along the Canadian border (Fig. 66). A hot wave results from the hot, dry south and southeast winds that blow for several days from the high to the low. Prolonged periods of such dry weather are called *droughts*. At such times evaporation of moisture from soil and growing crops is tremendous. Pastures dry up, and corn "fires," meaning that the lower portions of the corn plant turn to a yellowish-brown color.

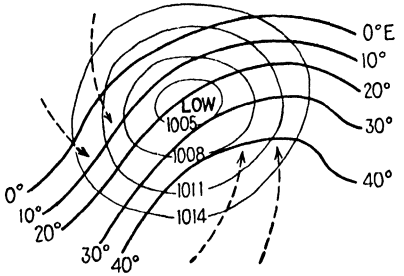


FIG. 67.—Characteristic arrangement of isotherms in a winter cyclone over central and eastern United States. The front half is usually warmer than the rear half.

Temperatures in Cyclones. Severe contrasts in temperature often occur within a cyclone area. In the southeast quadrant of a low the temperature is usually relatively high as the result of southeast and south winds. In the northwest quadrant, lower temperatures are due to northwest winds. The front, or east half, of the cyclone is generally a region of higher temperatures than the rear, or west half (Figs. 62, 67). This is because the southerly winds import warmth from lower latitudes. In winter, in central and eastern United States, the temperature in the southeast quadrant of a low may be 50°; in the northwest quadrant it may be down to zero or below.

As the storm center passes, a sudden drop in temperature of some 40° or 50° may occur. The warm air of the southeast quadrant is usually humid. In summer it produces "sticky, muggy weather." In the northeast quadrant, where northeast winds often prevail, temperatures are usually lower than in the southeast quadrant. In winter the drop in temperature caused by the advancing cold front may cause rain to change to snow.

Sometimes in the colder months the cloud cover that accompanies a low often results in temperatures above normal. This is because the clouds prevent rapid radiation of heat from the earth at night. A similar cloud cover in summer may produce temperatures below normal, because the clouds tend to weaken incoming solar radiation.

As a low approaches from the west, the warmer, lighter air mass in the southeast quadrant causes the barometer to fall steadily. When the storm center has passed, the cooler or colder denser air mass (northwest or west winds) in the west quadrants causes the barometer to rise (Fig. 68).

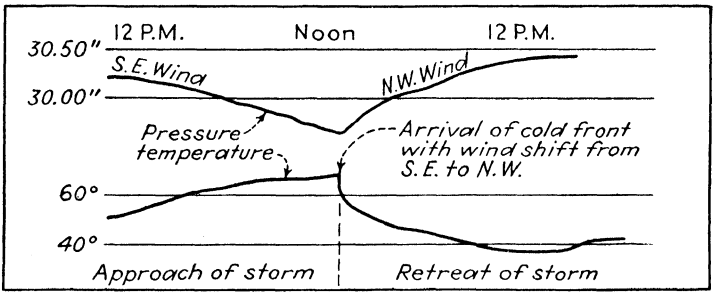


FIG. 68.—Behavior of temperature and pressure during the approach and retreat of a low. As the storm approaches from the west, temperature rises and pressure falls. The arrival of the cold front causes a sharp drop in temperature and a rise in pressure. The temperature curve is made by a thermograph, or self-recording thermometer. The pressure curve is made by a barograph, or self-recording barometer (see Appendix C).

Paths of Cyclonic Storms. Although cyclones do not follow definite tracks around the world, certain paths are frequented more than others. In North America more lows move eastward along the Alberta and North Pacific tracks than along any other two paths (Fig. 69). In the cool seasons lows follow paths farther south, *e.g.*, the South Pacific. Storms that follow this path sometimes bring prolonged rains or heavy snows. Other paths, frequented especially in winter, extend from Texas and Florida northward along the Atlantic Coast.

In Europe, lows follow mainly a path across the British Isles and northern Germany. In winter they sometimes travel farther south, crossing Mediterranean countries.

In the Southern Hemisphere, lows are energetic throughout the year. They travel eastward, following paths located for the most part between the parallels 40°S. and 60°S. The Cape Horn region

of South America, extending as it does to nearly latitude 55°S., is a stormy area at all times of the year.

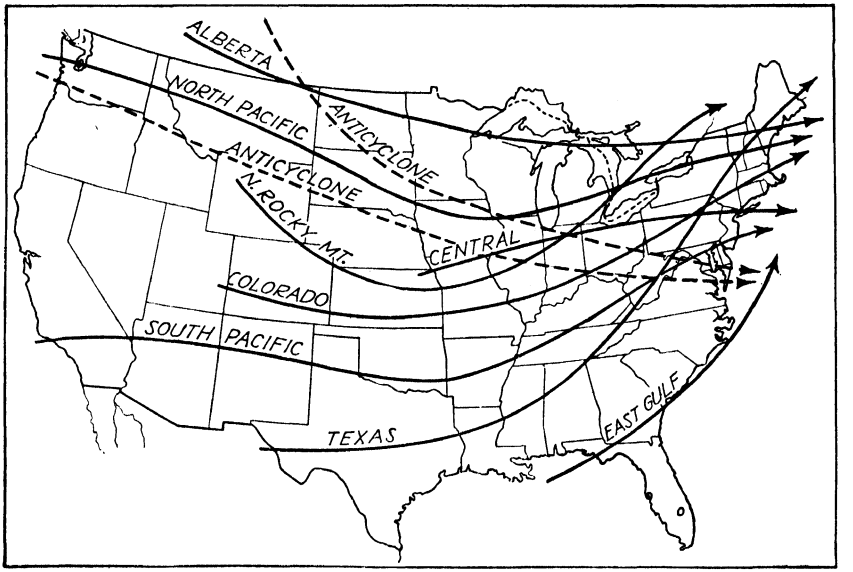


FIG. 69.—Solid lines show principal tracks of cyclones as they cross the United States; broken lines are principal tracks of anticyclones. Anticyclones that move southeast from western Canada sometimes bring extremely cold weather in winter; those from the western states bring moderately cold or cool weather. (*After map by U.S. Weather Bureau.*)

Weather Forecasting

Daily Weather Map. At 1:30 and 7:30 A.M. and P.M., Eastern Standard time, the condition of the weather is recorded at some 300 stations scattered over North America. This information is transmitted by telegraph and teletype to all parts of the United States and much of Canada. Trained men assemble the data on a large map, locate the highs and lows and the warm and cold fronts, draw the isobars, and label the air masses. The result is the completed daily weather map (see Appendix C).

The official forecaster studies this map and tries to picture the changes in positions of storm centers and fronts during the next 24 to 36 hours and the effects that these changes will have on the weather in his own local district. Since weather conditions differ in different localities, it stands to reason that a forecaster's accuracy should increase the longer he is stationed at one city. Regional experience is the best teacher.

Certain rules and types of weather maps should be mentioned with reference to weather forecasting.

1. In general, weather travels eastward.

2. Lows tend to follow certain paths at certain seasons of the year.

3. A low usually crosses the United States in 3 to 5 days.

4. The approach of a low from the west usually foretells unsettled weather; a high, fair or partly cloudy and cooler or colder weather.

5. Lows that follow paths across southern United States in winter are usually more intense and energetic than those which travel east along the Canadian border.

6. As a storm center passes, the temperature will drop, the amount of drop being determined largely by the *contrast* in temperature between the low and the high that lies to the west or northwest.

7. Highs tend to travel from western Canada and the Pacific Coast toward the Central Atlantic states; lows move toward New England.

8. In general, lows travel faster than highs.

9. A high over Montana, the Dakotas, and western Canada with temperatures 20° to 40° below zero may advance toward the southeast, causing a severe "cold wave" to reach sometimes as far south as the Gulf states. Along the advancing cold front of such a high, blizzards may be experienced.

10. A high-pressure area over Nevada, Utah, and Idaho, called a *Great Basin high*, may remain stationary for several days, causing fair weather and westerly winds to prevail over most of the states between the Rocky Mountains and the Mississippi River. Such highs bring moderately cold weather.

11. In summer, a stationary low in central North America, with a high over the Southeastern states may cause a hot wave and drought over much of central and eastern United States.

12. A northeast or east wind, a falling barometer, and a temperature near freezing are good indications of an approaching snowstorm.

13. The *change* in temperature is usually greater when the storm center passes *north* of the observer.

14. In the United States, storms tend to increase in intensity east of the Mississippi River.

15. During the cool months, a high over Minnesota and the Lake Superior region, together with a low in the Southwestern states, often causes cloudy weather with rain or snow over the Central states west of the Mississippi River.

16. The southwest quadrant of a high often tends to be a region of stratus clouds and light, drizzle rains.

17. Violent atmospheric disturbances often develop along the cold front, or wind-shift line.

18. In general, winds from points east, with a falling barometer, indicate foul weather; winds shifting to points west indicate clearing and fair weather.

Suppose that a cyclone is moving eastward across the United States. If the center of the low passes to the north of an observer, so that he is in the southern quadrants of the storm, the succession of winds experienced will be southeast, south, southwest, and finally west and northwest (Fig. 61). This is called a *veering wind shift*. On the other hand, if the storm center passes south of the observer, so that he is on the north side of the cyclone, he will experience in succession northeast, north, and finally northwest winds. This is known as a *backing wind shift*.

The following note regarding wind-barometer indications associated with a passing cyclone appears on the United States daily weather map:

> When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

Air-mass Analysis

Forecasting Aided by Knowledge of Air Masses. Weather men devote a great deal of time to the study of air masses. They

are interested especially in (1) the origin of a given air mass, (2) its characteristics, (3) its rate and direction of movement, and (4) the type of weather that is likely to result where two contrasting air masses come together. The movements of air masses and their effects upon weather have been observed for many years.

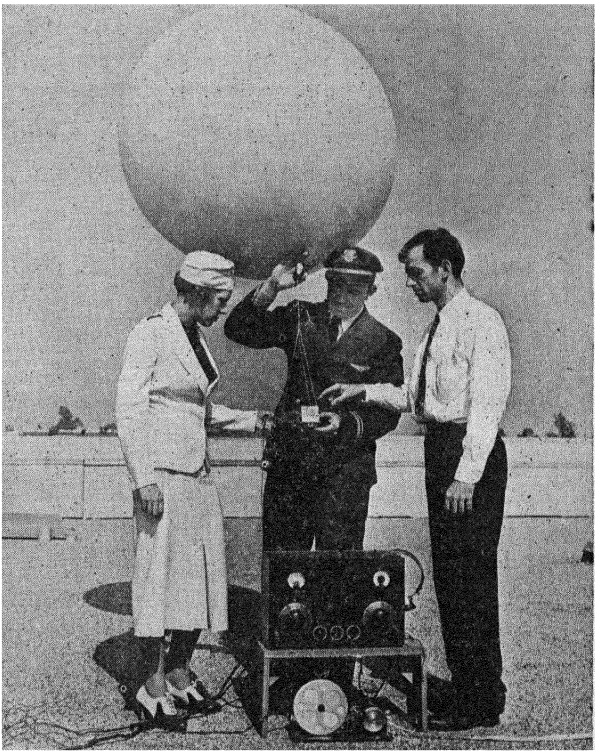


FIG. 70.—A large balloon that carries a radio-meteorograph into the upper atmosphere. This instrument broadcasts temperature, pressure, and humidity. The signals are received by the special radio set shown on the little bench. (*Courtesy of Transcontinental and Western Air, Inc.*)

Today, however, additional data are secured from self-recording instruments carried aloft by airplanes and balloons. These data make possible a more accurate analysis of the air mass. Considerable attention is being given to the development of the *radio-meteorograph* (Fig. 70). This is an instrument which automatically broadcasts by radio upper air data (temperature, pressure, humidity) when it is carried upward by a balloon. The term *radiosonde* is applied to such data.

Wind velocity and direction aloft are ascertained by releasing pilot balloons. These are rubber and about 2 feet in diameter, filled with hydrogen. They are released several times a day, and their movements are observed through a telescopic instrument called a *theodolite* (Fig. 71). The balloon rises a certain number of

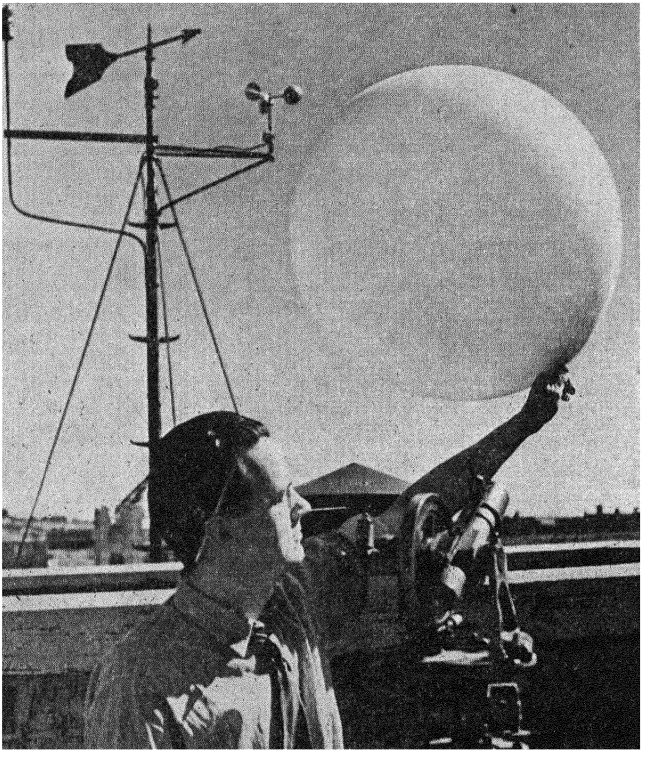


FIG. 71.—A weather observer about to release a balloon that he will watch through the theodolite directly in front of him. Such observations make possible the determination of wind direction and velocity at high elevations. (*Courtesy of Transcontinental and Western Air, Inc.*)

feet per minute. If it goes out of sight in the clouds, the time elapsed is noted. The time interval is changed to feet. This gives the altitude of the bottom side of the clouds, which is called the cloud *ceiling*.

All this means that a more intensive study is being made of the vertical structure of the atmosphere. By using radiosonde and pilot-balloon data, meteorologists make upper-air charts that show temperature gradients, moisture content of the air,

and the direction of winds aloft. These are called *isentropic charts.* The upper-air data also are plotted on special graph paper. This helps the meteorologist in his analysis of air masses and in determining weather changes that may take place within the next day or so. These studies are a step forward in the development of weather science and are contributing to greater accuracy in forecasting.

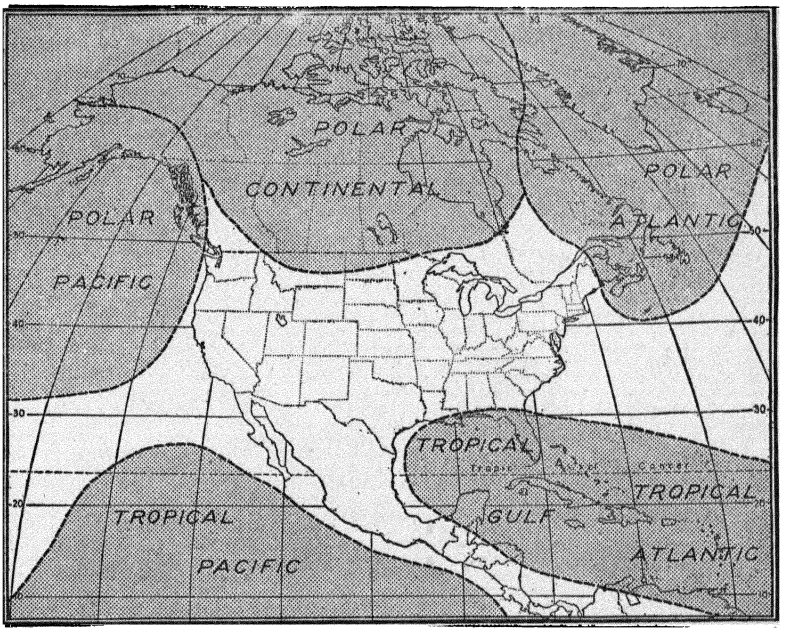


FIG. 72.—Source regions of air masses common to North America. (*After Transcontinental and Western Air, Inc.*)

Figure 72 shows the source regions of air masses common to North America. The *Polar Pacific* (*Pp*) air mass originates in the arctic or subarctic. As it moves over the North Pacific Ocean its moisture content and temperature, at least in the lower layers, are increased somewhat. This air mass along the Pacific Coast often is associated with cloudy weather, with numerous showers, especially in the cool months. After crossing the western mountains its moisture content is much lower. East of the Rockies it tends to produce fair weather with moderate temperatures.

Polar Atlantic (*Pa*) air masses are less important over North America than the Polar Pacific. This is because the prevailing air movement over the continent is from west to east. Along the

Atlantic Coast, from the Carolinas north, Polar Atlantic air may bring unusually cool weather, especially in late spring and early summer.

The *Polar Continental* (*Pc*) air mass moves south over western Canada. It enters the United States mainly through Montana and the Dakotas. This is a typically cool or cold body of air with low absolute humidity. As it moves southward it brings cool

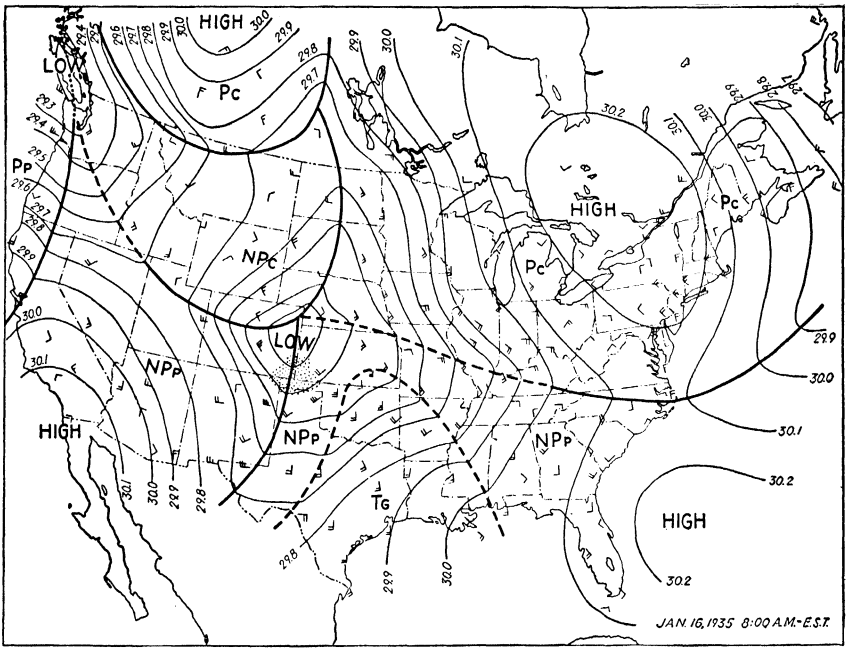


FIG. 73.—Daily weather map. Solid lines indicate cold fronts; dashed lines, warm fronts; stippling, dust-storm area. (*Courtesy of G. R. Parkinson and American Meteorological Society.*)

weather in summer and cold weather in winter. It appears on the weather map as a huge anticyclone, or high. Being of low moisture content, it permits rapid radiation of heat from the earth at night and therefore rapid cooling. As this air mass advances across the continent, its south and east edges are known as the "cold front." It is this cold front that often undermines a Tropical Gulf air mass along the wind-shift line of a cyclone, sometimes producing severe weather changes.

The *Tropical Gulf* (*Tg*) air mass probably originates over the Caribbean Sea or the Gulf of Mexico. It is typically warm and

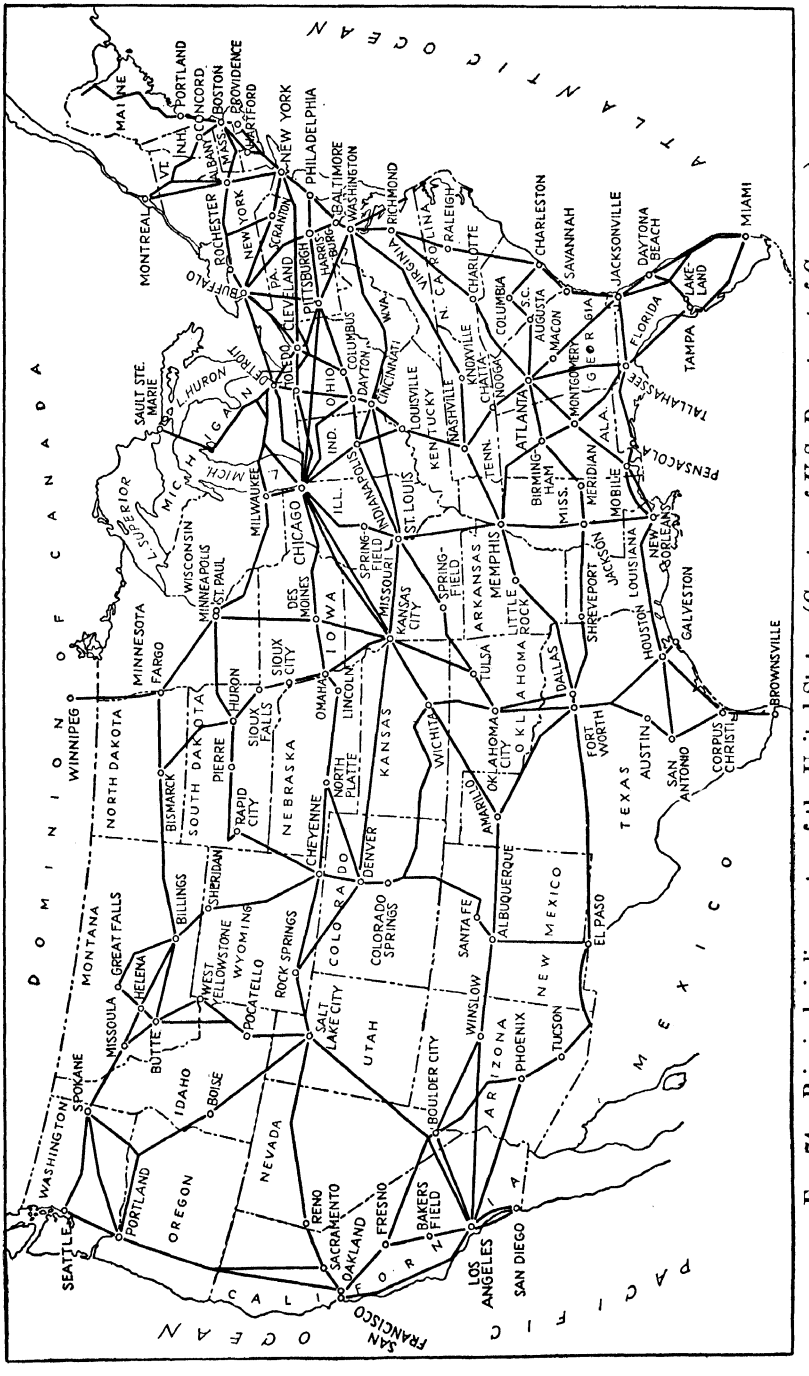


FIG. 74.—Principal air-line routes of the United States. (*Courtesy of U.S. Department of Commerce.*)

humid. As it moves northward, it is the source of much moisture that falls over central and eastern United States. In the warm months, Tropical Gulf air often causes periods of hot, sultry, oppressive weather. When this air mass advances, its northern and eastern edges may form a warm front. It is the warm front that in winter often causes a sharp increase in temperature from zero to 30° or 40° above.

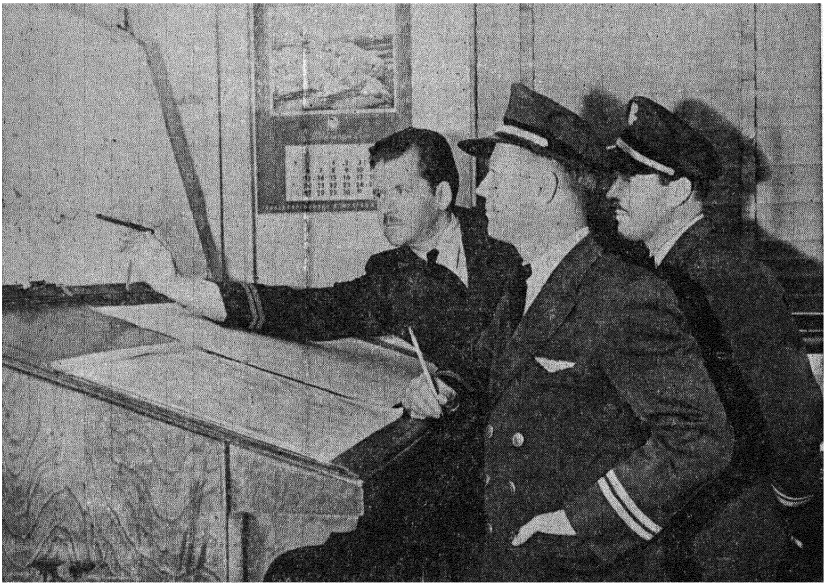


FIG. 75.—Captain, first officer, and dispatcher study the weather map, prior to a flight. (*Courtesy of Transcontinental and Western Air, Inc.*)

The *Tropical Atlantic* (*Ta*) air mass is somewhat similar to the Tropical Gulf.

The *Tropical Pacific* (*Tp*) or *Tropical Superior* (*Ts*) air mass usually is very warm and dry. Its origin is uncertain. Possibly it comes from the higher levels of the subtropical belt of high pressure over the North Pacific. This hot, dry air, especially in summer, causes rapid evaporation and therefore much damage to crops. *Polar Pacific* air, after crossing western mountains, is also relatively dry and may cause excessive evaporation.

On the daily weather map the letter *N* preceding the symbol of an air mass (such as *NPc*) signifies that the air mass is in a transitional stage. This means that its original characteristics

are being modified or neutralized as it passes over the continent (Fig. 73).

Importance of Weather Information to Aviation. The value of accurate and detailed weather information in the field of aviation cannot be overestimated. Today there are many weather observers along the more heavily traveled air routes (Fig. 74). Thus when local weather conditions suddenly become unfavorable for safe flying, the information is teletyped quickly to the larger airports. There, by means of radio, the information

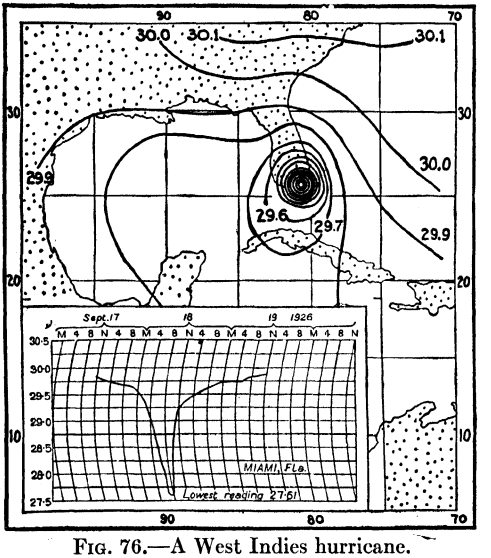


FIG. 76.—A West Indies hurricane.

is broadcast to pilots in the air. All airplanes that carry passengers for hire are required by law to be equipped with two-way radio. Pilots can receive and broadcast weather information while in the air. All these precautions, aided by improved weather service, make for greater safety in aviation (Fig. 75).

Tropical Cyclones of the Hurricane and Typhoon Variety

What They Are and Where They Occur. Hurricanes and typhoons are violent tropical storms and are similar except for location. They occur in late summer and early autumn. The *hurricane* originates in the vicinity of the West Indies, travels toward Florida or other Gulf states, and then curves toward the north and northeast (Fig. 76). The *typhoon* occurs in similar

latitudes off the east coast of Asia, traveling across the Philippines toward the coast of China and then turning northward to southern Japan. These tropical storms are much larger than the tornado. Wind velocities usually reach 75 miles per hour or more. The high winds drive great waves of water into coastal settlements. In the center of the storm the barometer has been known to drop more than 3 inches below normal. Excessive rainfall may cause floods. In the hurricane of September 18, 1926, which devastated Miami, Fla., at least 114 lives were lost in the Miami district, and damage to buildings was estimated at nearly 75 million dollars.

These destructive tropical storms appear to occur over the warmer parts of most of the oceans. In addition to the localities mentioned above, the following regions may be noted: (1) the Arabian Sea and the Bay of Bengal, on either side of peninsular India; (2) the South Indian Ocean east of Madagascar; and (3) the tropical waters to both the northeast and the northwest of Australia.

Thunderstorms

What They Are and Where They Occur. A description of the approach and retreat of a thunderstorm is given at the beginning of this chapter. Thunderstorms are characterized by strong upward currents of moist air and the formation of huge cumulo-nimbus clouds. Gusty winds, lightning, thunder, "dash" rain, and sometimes hail accompany these storms. Such an atmospheric disturbance usually is associated with high temperatures at the earth's surface and moist air. Consequently, thunderstorms are most prevalent (1) in certain tropical regions, (2) in the warm season of the intermediate zones, and (3) at the warmer hours of the day. The heavy rain of short duration is a direct result of rapid condensation of water vapor caused by the strong vertical convection currents within the storm.

Types of Thunderstorms. Two types of thunderstorms are usually recognized:

1. *Local heat thunderstorms* may occur without warning, owing to local convection (Fig. 77). Rising air currents cause the formation of towering cumulus clouds. These grow to cumulo-nimbus which may give rise to a thundershower. In central and

eastern United States literally hundreds of these scattered thundershowers may occur on a hot summer day. They are of great economic significance, because they produce much needed rain during the growing season.

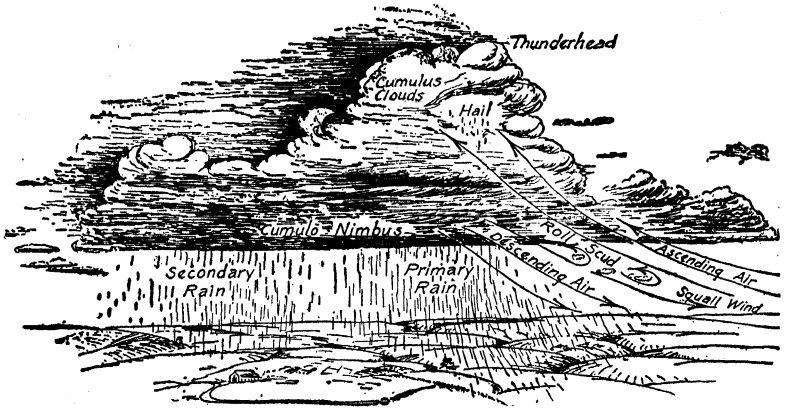


FIG. 77.—Structure of a local thunderstorm. In the United States such storms usually move in a general direction from west to east. (*Courtesy of A. K. Lobeck.*)

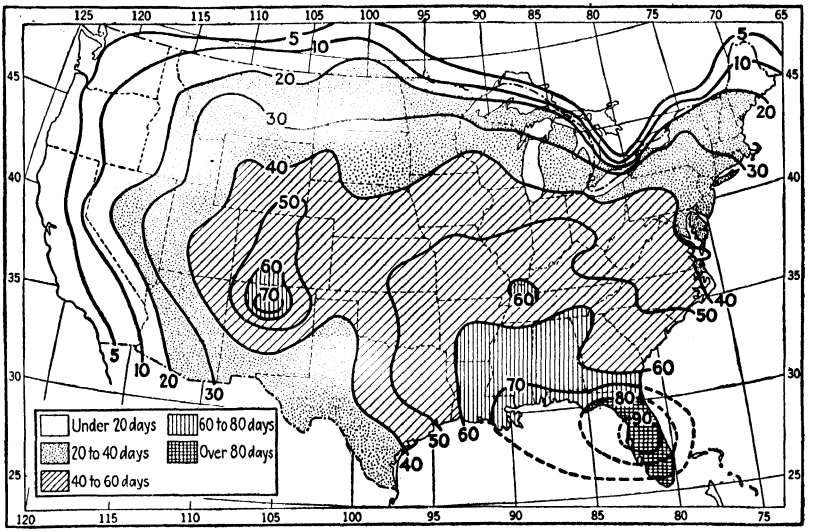


FIG. 78.—Average annual number of days with thunderstorms. (*After Alexander.*)

2. *Cold-front thunderstorms* often are more extensive and more severe than the local heat variety. They occur along the wind-shift lines of well-developed lows during the warm months. As previously explained, the wind-shift line marks the abrupt meeting place of warm- and cold-air masses. The warm-air mass,

which in central and eastern United States often comes from the Gulf of Mexico, may carry much water vapor. As it is suddenly uplifted by the advancing, underrunning cold front of the polar air mass, dark cumulo-nimbus clouds may form. The resulting thunderstorm may be extremely violent, accompanied by heavy rain, lightning, strong winds, and sometimes hail. Such storms may occur at any time of day or night. Because of the dangers involved, these disturbances are avoided by aviators whenever possible. Such a storm usually is followed by cool, clear weather.

High temperatures and stagnant, humid air in the doldrums furnish ideal conditions for thunderstorm formation. Thunder is



FIG. 79.—Unusually large hailstones. (*Courtesy of S. D. Flora.*)

heard in some doldrum regions 75 to 150 days per year. Deserts in the tropics, however, may have fewer than 5 days with thunder, because of low humidity. In the United States the Gulf states rank highest, and the Pacific Coast lowest, in the number of thunderstorms (Fig. 78). In the middle latitudes such storms are more numerous over land than over sea.

Characteristics of Thunderstorms. *Hail,* the most destructive form of precipitation (see page 92), sometimes accompanies thunderstorms. When convection is most violent, and air currents are ascending at the rate of 25 to 30 miles per hour, raindrops are carried up into regions of extreme cold. They mix with snow and form cloudy globules of ice. Moving downward, this ice is covered with a layer of water and is then shot upward again, and the film of water freezes. This process may continue

until the hailstone, formed of concentric layers of clear ice and snow, like the layers of an onion, reaches considerable size (Fig. 79). When the upward-moving air currents weaken, the hailstones fall to earth. They make dents in automobiles and shatter the glass of greenhouses. Destructive hailstorms often do tremendous damage to growing crops. Many farmers carry insurance to cover such damage.

Lightning is a huge electric spark, caused by the discharge of electricity between clouds or between a cloud and the earth.

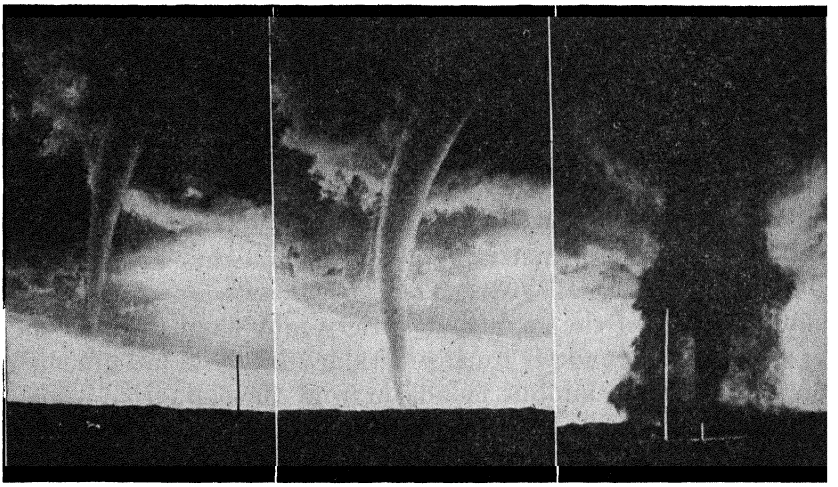


FIG. 80.—Three stages in a tornado that occurred near Gothenburg, Neb., in 1930. In the picture at the left, the tornado's cone is seen as it formed in the clouds; in the center, the fully developed cone as it reached the earth. At the right, the cone strikes a farmhouse, which appears to explode. (*Courtesy of U.S. Weather Bureau.*)

Perhaps you have amused yourself at one time or another by dragging your feet on a rug and then touching someone on the ear. The tiny electric spark that you saw between your finger and the ear was lightning. The faint popping sound was thunder.

Clouds are charged with electricity. The water particles in one cloud may carry a positive charge of electricity, whereas those in another may carry a negative charge. One part of a single cloud may be charged positively; another part, negatively. The electrical discharge caused by these opposite charges usually appears as lightning. Sometimes the electrical discharge takes place between a low cloud and the earth. However, most lightning occurs between clouds. Probably not more than 1 per cent

of the lightning flashes go to the earth. In the United States 700 to 800 persons lose their lives each year as a result of lightning, and double as many are injured. Fire losses due to lightning amount to over 12 million dollars annually.

Thunder is produced by the violent expansion of the air caused by the tremendous heat of lightning. Light waves travel about 187,000 miles per second; sound waves, about 1,000 feet per second. Thus the sound of thunder is heard after the flash of lightning is seen. By counting the seconds between the time the flash is seen and the time the thunder is heard, it is possible to estimate the distance between the observer and the lightning. Sometimes a lightning flash may occur behind a cloud so that the entire cloud is illuminated. This is referred to as *sheet* lightning.

Tornadoes

What They Are and Where They Occur. Tornadoes are the most violent and destructive of all storms, but they are rare and do damage over small areas. They are closely associated with thunderstorms of the cold-front variety in V-shaped lows. The approach of a tornado is usually heralded by dark and greenish masses of cumulo-nimbus clouds in wild turmoil, from which descends the funnel-shaped tornado cloud (Fig. 80). Upper-air currents carry the storm in a general northeasterly direction. The rate of travel averages 25 to 40 miles per hour. Tornadoes occur chiefly in spring and early summer. Destruction of property and life is due mainly to high wind velocities of 100 to 500 miles per hour. Vertical air currents within the tornado are thought to reach velocities ranging from 100 to 200 miles per hour. These storms are typically American. In the United States they are most frequent over the Central and Southeastern states east of the Rocky Mountains. Tornadoes at sea often are called *water spouts.*

Summary

In this chapter we have learned that storms are of tremendous importance because they are the earth's principal generators of precipitation. Thunderstorms are most numerous in the doldrum belt. Cyclones, or lows, and anticyclones, or highs, travel from west to east in the two belts of westerly winds. A

knowledge of storms and of the movements of air masses about lows and highs is of great importance to the weather forecaster. Tornadoes, hurricanes, and typhoons are extremely energetic storms which often cause much loss of life and do enormous damage to property.

Having considered air temperature, pressure, wind belts, humidity, precipitation, and storms, we are ready now to study climate, by which we mean the generalized weather conditions over the earth. There are a number of distinct types of climate to be found on the various continents. The next two chapters deal mainly with descriptions of these climatic types.

Questions

1. Why are storms of special importance over the lowlands of the earth?
2. What is a cyclone? An anticyclone?
3. On a weather map, how is a cyclone shown? An anticyclone?
4. How does pressure change from the center to the edge of a cyclone? An anticyclone?
5. How should you reduce to sea level the barometer reading at a place having an elevation of 1,800 feet? Of 5,850 feet?
6. How do summer cyclones differ from winter cyclones?
7. Why do lows travel in a general easterly direction?
8. What is the speed of lows in summer? In winter?
9. What is the wind direction in the front, or east quadrants, of a low? In the rear, or west quadrants?
10. Why are easterly winds an indication of unsettled weather?
11. Why is the wind-shift line also called the cold front?
12. Why is warm, humid air often forced upward along the surface cold front?
13. Along the wind-shift line of a V-shaped low, what atmospheric disturbances may be experienced?
14. Discuss the wind system of an anticyclone, or high.
15. Why do some lows fail to bring precipitation?
16. Why is there generally little precipitation at the center of a high?
17. Contrast the nature of cyclonic and thunderstorm rainfall.
18. Describe cyclonic weather, especially in the cool months.
19. Why do violent thunderstorms sometimes occur along the cold front? Mention several reasons why aviators avoid severe thunderstorms.

20. What causes a cold wave? A blizzard?

21. What causes a hot wave? What is its effect on evaporation?

22. Contrast temperature conditions in the southeast and northwest quadrants of a low. What temperature change takes place as the storm passes? Why?

23. In which quadrant of a low is humid, "sticky" weather most noticeable?

24. Why does a barometer fall as a storm approaches? Why does it rise as the storm retreats?

25. Name and locate the two tracks along which most lows travel across North America.

26. Write five weather-forecasting rules that, in your opinion, are most important.

27. If wind direction is east and the barometer is falling, from what direction is the storm probably approaching?

28. Explain veering and backing of the wind.

29. What would be the forecast if the barometer was 29.75 inches and falling, and the wind northeast? If the barometer was 30.20 inches and steady, and the wind west?

30. In the study of air masses, what four things are of special interest?

31. What is a radio-meteorograph? An isentropic chart?

32. How are wind velocity and direction aloft ascertained?

33. What is meant by the cloud ceiling?

34. Why is a low cloud ceiling a hindrance to aviation?

35. State two or three facts about each of the following air masses: Polar Pacific, Polar Continental, Tropical Gulf.

36. What does the letter *N* indicate when it precedes the symbol of an air mass?

37. Why is a two-way radio of considerable value on board an airplane?

38. If a well-developed low was in your path, should you fly north or south of the center? Why?

39. Where and when do hurricanes occur? Typhoons? How do these storms differ from tornadoes?

40. What are the characteristics of a thunderstorm?

41. Name the two types of thunderstorm. Briefly describe each.

42. Why are thunderstorms numerous in the doldrums?

43. Where in the United States are thunderstorms most common? Why? Where uncommon? Why?

44. Explain how hail is formed.

45. What is lightning? Explain the cause of lightning.

46. What causes thunder? How can you estimate the distance to a lightning flash?

47. Describe the tornado cloud. What is the wind velocity in a tornado?

48. Where and when do tornadoes occur? Toward what direction do they usually travel?

Suggested Activities

1. Keep a daily weather record. Using a barometer of some kind and a wind vane, make daily forecasts of the weather. Score your forecasts as *correct*, *partly correct*, or *wrong*. If possible, secure the daily weather map from the nearest weather bureau. Make good use of the map to increase the accuracy of your forecasts.

2. Draw a weather map on an outline wall map of the United States. Discuss the forecast for various parts of the country.

3. Secure several copies of the *Monthly Weather Review*, published by the U.S. Weather Bureau, Washington, D.C., and for sale by the Superintendent of Documents. These will give you an idea of the amount of detailed work done by the Weather Bureau.

4. If it is possible to secure the daily weather maps, keep them posted so that the movements of lows and highs can be observed for several days at a time.

5. Study cloud types. They often aid in weather forecasting.

6. Visit a weather bureau or airport, and observe the method of drawing the weather map.

7. Study a map showing air lines. Make inquiry as to the number of weather men employed by the various air-transport companies.

8. If daily weather maps are published in your local newspaper, cut them out, and paste them in a notebook. Paste the official forecast below each map.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Radio-meteorographs
2. Recent Developments in Air-mass Analysis
3. Distribution of Tornadoes in the United States
4. Hurricanes and Typhoons
5. Weather Service of Transcontinental Air Lines
6. Additional Rules for Forecasting Weather
7. The Value of Weather Forecasting
8. The U.S. Weather Bureau
9. Weather Forecasting on the Pacific Coast

References

BLAIR, THOMAS A.: *Weather Elements*, Prentice-Hall, Inc., New York, 1937.

BYERS, H. R.: *Synoptic and Aeronautical Meteorology*, McGraw-Hill Book Company, Inc., New York, 1937.

"Instructions for Airway Meteorological Service," Circular N of the Aerological Division, U.S. Weather Bureau, Washington, D.C.

Meteorology, Special Text 193 of the Army Extension Courses, Government Printing Office, Washington, D.C.

NAMIAS, JEROME: "An Introduction to the Study of Air Mass Analysis," Bulletin of The American Meteorological Society, Milton, Mass., 1940.

TREWARTHA, GLENN T.: *An Introduction to Weather and Climate*, McGraw-Hill Book Company, Inc., New York, 1937.

"Weather Forecasting," *Bulletin* 42 of the U.S. Weather Bureau, Government Printing Office, Washington, D.C.

Chapter VI. Climates of the Tropics and the Dry Middle Latitudes

Sometimes we hear interesting conversations on the subject of climate. Especially is this true when people from widely separated parts of the country get together. The northern Minnesotan can be heard telling about cool summers and cold, invigorating winters, with plenty of snow and ice for winter sports. The Floridian describes his climate as always warm and moist and points to the fact that thousands of tourists spend a part of the winter in Florida in order to avoid the cold of more northerly regions. The southern Californian tells of warm, dry summer days and cool nights and of a winter that really is not winter but instead is a moderately cool season, with snow almost unknown.

The variety of climates over the earth is indeed great. Some, like the tropical deserts, are hot and dry the year round; others, like the coast of southern Alaska, are cool and moist. Some, like much of the United States, have distinct changes of seasons; others, like the equatorial lowlands, have little change during the year. One type of climate may be favorable for the production of bananas; another, for citrus fruits; another, for cereals; and still another, for magnificent forests. Some climates are so severe that people avoid them. Witness, for example, the sparse population of the intensely hot, dry Sahara Desert in northern Africa and of the arctic shores of northern Russia which are bitterly cold much of the year.

Climate, therefore, is a most important element of environment. It has much to do with peoples' daily work habits and with the occupations that they follow.

What about Your Local Climate? Before beginning a study of the principal types of climate that are to be found on the

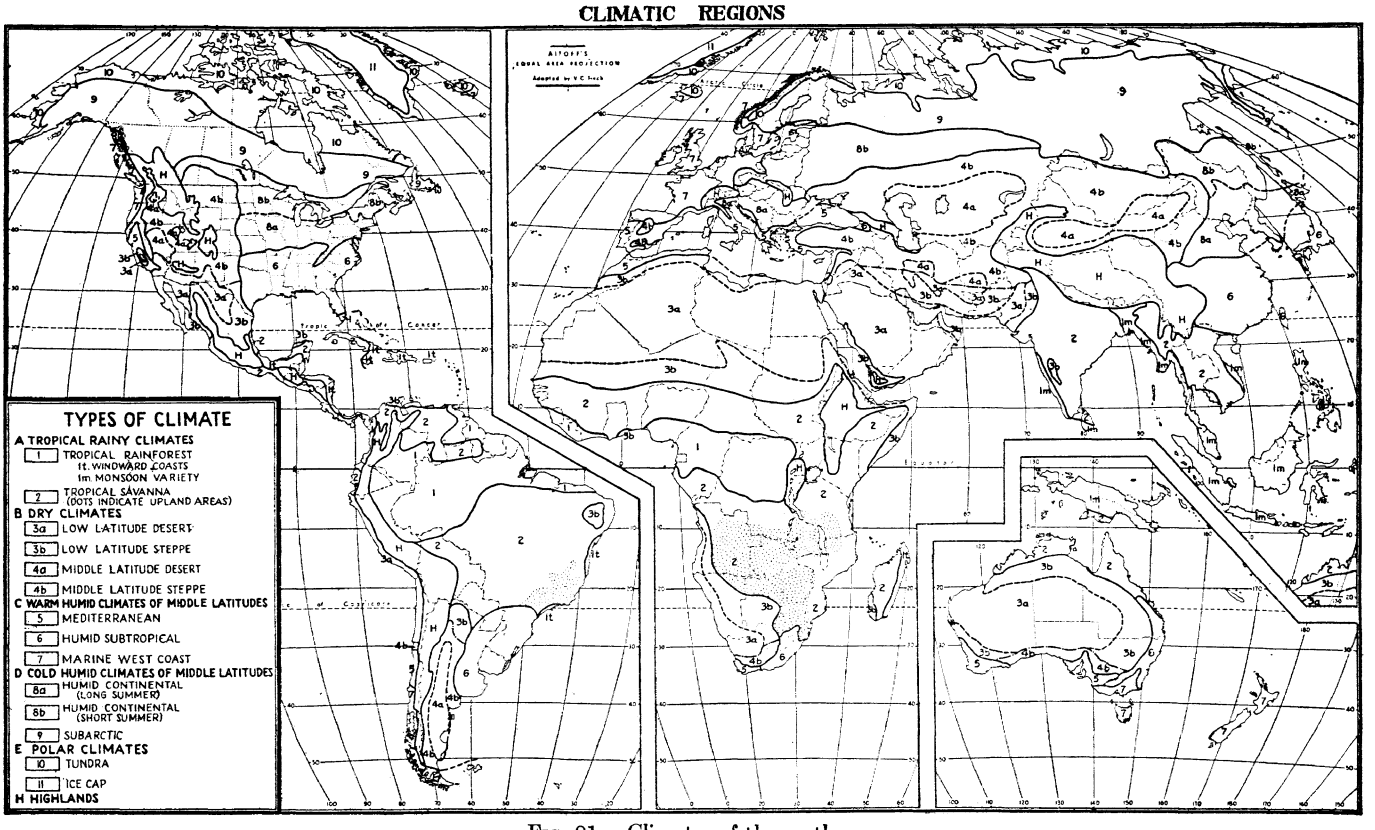


FIG. 81.—Climates of the earth

earth's surface, you should fix in mind certain facts about your local climate. This knowledge will help you to compare climates in other parts of the world with your own. Such comparisons enable us to understand better the environmental conditions in other localities.

The two most important elements of climate are *temperature* and *rainfall.* What are the temperature and rainfall characteristics of your own local climate? Using data from the nearest weather bureau, learn the answers to the following questions:

1. Which month is the warmest? Coldest?
2. What is the *average* temperature of the warmest month? Of the coldest month?
3. What is the annual range of temperature? The daily range of temperature?
4. What is the highest temperature recorded during the year? The lowest?
5. What is the average annual rainfall?
6. Which season has the most rain? Which month? Which month has least rain?

With these facts in mind for the purpose of comparison, we may give our attention now to the various types of climate on the earth.

Climatic Regions. It is possible to divide the continents into regions, called *climatic regions*, each of which has a certain type of climate (Fig. 81). The location of these regions is made possible by the numerous records of temperature and rainfall that have been kept for many years in many places. (For examples of such records, see Appendix B.) It is important that the information on the seasons given in Appendix A be kept in mind during the study of world climatic regions. Our survey of these regions begins with the tropical climates of the low latitudes (equator to 20° or 30°).

Tropical Rainy Climates

General Considerations. The humid tropics form a somewhat interrupted and irregular "belt" 20° to 40° wide around the earth and straddling the equator. This region differs from all other humid regions of the earth by reason of the fact that it is constantly warm; in other words, it lacks a winter. Within this

climatic group, even the coolest month has an average temperature of 64° or more.

Annual rainfall is rarely less than 30 inches and often exceeds 100 inches. Much of the precipitation is of the convectional, or thunderstorm, type, the heavy showers often being accompanied by severe thunder and lightning. Especially in the wet, tropical lowlands, high relative humidity tends to increase human discomfort. Since the rainfall is mainly convectional in origin, it tends to be greatest at, or soon after, the season of high sun, when the sun is most nearly overhead. On the other hand, rainfall tends to decrease during periods of low sun, or when the sun's rays are more oblique. It is well said, therefore, that in the tropics rainfall follows the sun.

The abundance and intensity of light, both direct and reflected, in the low latitudes are distressing to the eyes. The bright sunlight is also dangerous. To expose the uncovered head to the direct rays of the tropical sun is to invite illness.

The two principal climatic types within the humid tropics differ from each other mainly in the seasonal distribution of precipitation. They are

1. *Tropical rainforest*, having ample rainfall throughout the year.
2. *Savanna*, having distinct wet and dry seasons.

Tropical Rainforest Climate

Characteristics. Hot, humid weather, luxuriant vegetation, buzzing insects, the chattering of numerous monkeys—these brief expressions enable us to picture the tropical rainforest. Here, in places, are to be found great jungles, where trees, vines, and dense undergrowth form a vegetation cover difficult to penetrate. Much of the tropical rainforest, however, is not true jungle.

The two most distinguishing characteristics of tropical rainforest climate are

1. Uniformly high temperature
2. Heavy precipitation distributed throughout the year, so that there is no marked dry season (Fig. 82).

Location. For the most part, this climate is found astride the equator and extending out 5° to 10° on either side. On the

eastern sides of continents, however, where trade winds come from warm oceans, this climatic type may be found 15° or even 25° from the equator. In general tropical rainforest climate coincides reasonably well with the equatorial belt of calms and variable winds, or the doldrums. The principal regions having this type of climate are (1) the Amazon Basin, (2) the Congo Basin, (3) the East Indies and Malay Peninsula, and (4) Panama and the eastern lowlands of Central America.

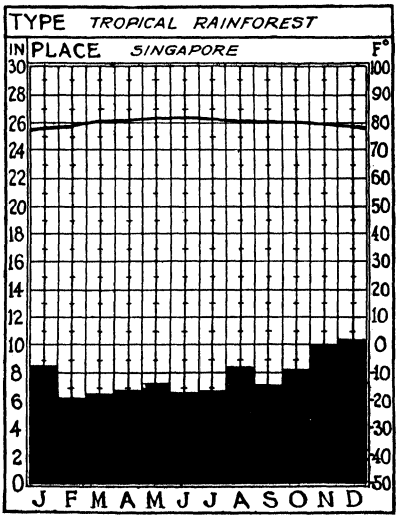


FIG. 82.—Average monthly temperature and precipitation for a representative tropical rainforest station. Monthly temperatures are much more uniform than monthly precipitation.

Temperature. Lying as it commonly does on each side of the equator, and consequently in the belt of greatest insolation, it is to be expected that temperatures in the tropical rainforest climate will be uniformly high (Fig. 83). Annual average temperature usually falls between 77° and 80°. There is little seasonal variation in temperature, because (1) the altitude of the sun is high throughout the year and (2) there is little difference in the length of day and night from one part of the year to another. The annual range of temperature, or difference between the averages of the warmest and coolest months, is usually less than 5°. Thus the annual range at Pará, Brazil, is 3°; Equatorville, central Africa, 2°; and Singapore in southern Malaya, 3.2°. Over oceans in these latitudes the range is still less. A remarkable example is shown by Jaluit in the Marshall Islands, which has a range of only 0.8°. It is evident that an outstanding characteristic of this type of climate is the uniformity and monotony of continuous hot weather.

The daily, or diurnal, range of temperature, or the difference between the warmest and coolest hours of the day, is usually 10° to 25°, or several times greater than the annual range (Fig. 83). During the afternoon the thermometer commonly rises to

temperatures varying from 85° to 93° and at night sinks to 70° or 75°. The highest temperature of the day seldom exceeds 96°, whereas in many midwestern cities of the United States it may reach 105° or more in the summer months. Sensible temperatures are excessively high in the tropical rainforest as the result of high humidity. The weather is sultry and oppressive.

Precipitation. Rainfall is both heavy and well distributed throughout the year, there being no dry season. It is estimated that the average annual rainfall throughout much of the doldrum belt is in the neighborhood of 100 inches. In this region close to the equator, conditions are ideal for rain formation. The trades from northeast and southeast rise above the earth's surface as

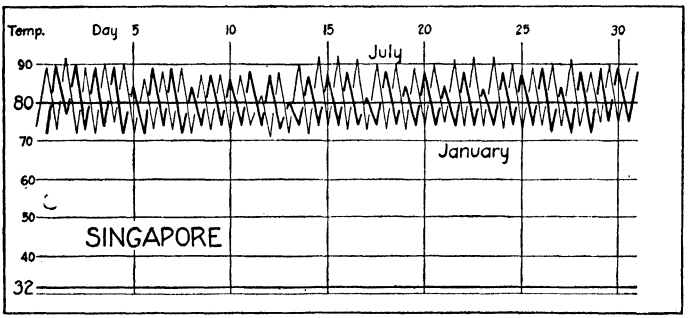


FIG. 83.—Daily maximum and minimum temperatures for the extreme months at a representative tropical rainforest station. The thinner line is July.

they near the equator, leaving a belt of variable winds and calms between them. In this belt of hot, stagnant, moist air, weak tropical cyclones are developed. Local convection produces towering cumulo-nimbus clouds and heavy thundershowers. Mornings are often relatively clear; but as the heat of day increases, cumulus clouds begin to appear. On an average, about 2 days per week have thunderstorms, and several in a single afternoon are not unusual. It is true that there is no genuinely dry season in tropical rainforest climate, yet it should not be inferred that the rainfall is evenly distributed throughout the year. Certain seasons are less wet than others, the variation being due partly to the north-south movement of the sun.

Daily Weather. The following description by an eyewitness is taken from *The Naturalist on the River Amazon* by Henry Walter Bates:

The heat increased rapidly toward two o'clock (92° and 93° Fahr.), by which time every voice of bird or mammal was hushed. . . . The leaves, which were so moist and fresh in early morning, now became lax and drooping; the flowers shed their petals . . . The approach of the rain-clouds was after a uniform fashion very interesting to observe. First, the cool sea-breeze, which commenced to blow about 10 o'clock, and which had increased in force with the increasing power of the sun, would flag and finally die away. The heat and electric tension of the atmosphere would then become almost insupportable. Languor and uneasiness would seize on everyone; even the denizens of the forest betraying it by their motions. White clouds would appear in the east and gather into cumuli, with an increasing blackness along their lower portions. The whole eastern horizon would become almost suddenly black, and this would spread upwards, the sun at length becoming obscured. Then the rush of the mighty wind is heard through the forest, swaying the tree-tops; a vivid flash of lightning bursts forth, then a crash of thunder, and down streams the deluging rain. Such storms soon cease, leaving bluish-black motionless clouds in the sky until night. Meantime all nature is refreshed; but heaps of flower-petals and fallen leaves are seen under the trees. Toward evening life revives again, and the singing uproar is resumed from bush and tree.[1]

Life in Tropical Rainforest Regions. Dense, shady forest with little undergrowth is the typical vegetation cover of much of the virgin tropical rainforest. In old clearings, along streams, and in other places where the sunlight can get through is a jungle growth of trees and underbrush so dense that its penetration is a difficult task. It is here that men make good use of rivers and streams for transportation. The rapid growth of vegetation is a handicap in the construction and maintenance of railroads.

Rainforest climate of the tropics, however, is ideal for the growth of certain economic crops of great value which are native to this type of climate. Especially in the Malay Peninsula and East Indies thousands of square miles are planted in rubber trees. A few rubber plantations are located in the Amazon Basin (Fig. 84). In the eastern lowlands of Central America are to be found great banana plantations (Fig. 85). Lowlands of the Gold Coast, Brazil, and Ecuador contain considerable areas

[1] Bates, Henry Walter. *The Naturalist on the River Amazon*, pp. 31–32, John Murray, London, 1910.

devoted to the growth of cacao trees (Fig. 86). The fruit of this tree is a large pod which contains many beans. These beans, after being dried, are used in making cocoa and chocolate. Sugar cane is an important crop in many parts of the tropics. The cane grows rapidly and can be cut several times per year. A plant of growing importance is the coconut tree. The milk of the coconut is a wholesome food. The dried meat, called *copra*, is shipped to many parts of the world. Coconut oil is valuable not only as



FIG. 84.—Rubber trees in the Amazon Basin. Some of the trees are being tapped. (*Courtesy of Ford Motor Co.*)

a food but also in the manufacture of fine soaps. Tropical rain-forest agriculture in many places, however, is handicapped by poor soil. Many soils are badly leached, meaning that the heavy and continuous rains dissolve and carry away certain valuable plant foods in the soil.

Some kinds of animal life, especially insects, flourish in this type of climate because of the abundant food supply and lack of a winter season. Crocodiles and alligators infest many streams. Among the insects are mosquitoes which act as carriers of malaria and yellow fever. Attacks by hordes of ants often make travel

through the jungle a miserable experience. Monkeys by the thousands chatter in the tree tops.

The natives who inhabit these regions live for the most part from the products of crude and primitive agriculture and from the fish of the streams. Their homes are often small huts with



FIG. 85.—Banana tree in the tropical rainforest climate of Central America. The humid lowlands along the eastern coast of Central America and the island of Jamaica are the heaviest producers of bananas. (*Courtesy of United Fruit Co.*)

steep roofs which quickly shed the heavy rain (Fig. 87). In certain regions these natives are employed on the huge banana, rubber, sugar, or cacao plantations. Density of population throughout tropical lowlands varies but in general is sparse. The great Amazon Basin is one of the most sparsely populated regions of the world. In contrast to Amazonia, however, is the densely populated island of Java.

White men are able to endure the tropical rainforest climate after a fashion. They wear light-weight, white clothing and a

sufficient head cover to provide protection against the blazing heat of the sun. Long-continued physical exertion is distasteful,

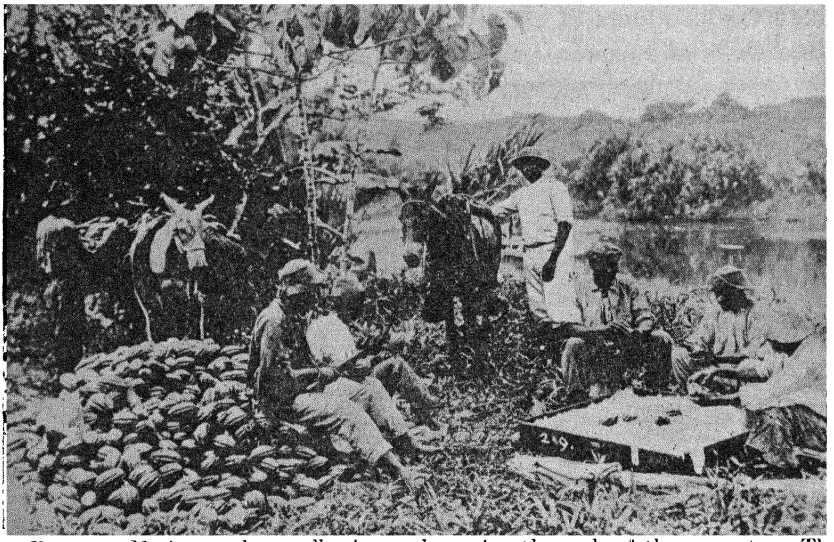


FIG. 86.—Native workers collecting and opening the pods of the cacao tree. The pods are 8 to 12 inches long and about 4 inches in diameter. Each pod contains 20 to 40 beans, which resemble large shelled almonds. (*Courtesy of Hershey Chocolate Corp.*)

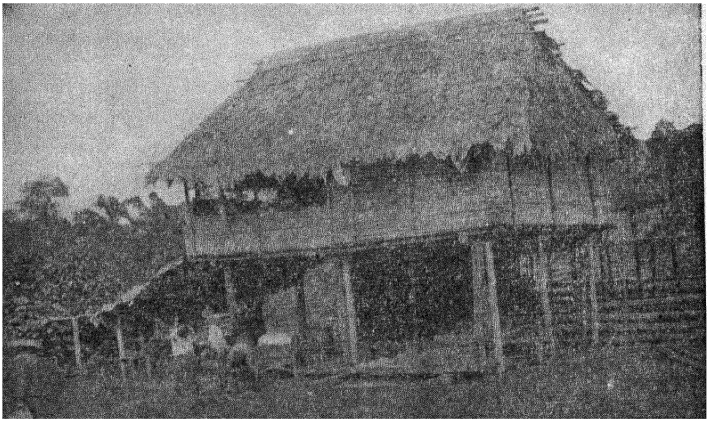


FIG. 87.—A native house in the tropical rainforest of Ecuador. The living quarters are elevated above the ground in order to protect against floods and animals and to give better underventilation. (*Courtesy of Rau Art Studios.*)

however, and the hard work of the plantations is left to the natives, the few white men being employed principally as

overseers and managers. There is the ever present danger of contracting one of the numerous tropical fevers. These must be combated by the frequent use of quinine. Air conditioning of homes and improved sanitary conditions are making life in the tropics more pleasant. In spite of these favorable developments, however, there are few large white settlements within this climatic type.

CLIMATIC DATA FOR REPRESENTATIVE TROPICAL RAINFOREST STATIONS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Singapore, Malay Peninsula							
Temp.	78.3	79.0	80.2	80.8	81.5	81.1	81.0	80.6	80.4	80.1	79.3	78.6	80.1	3.2
Precip.	8.5	6.1	6.5	6.9	7.2	6.7	6.8	8.5	7.1	8.2	10.0	10.4	92.9	
							Paró, Amazon Valley							
Temp.	77.7	77.0	77.5	77.7	78.4	78.3	78.1	78.3	78.6	79.0	79.7	79.0	78.3	2.7
Precip.	10.3	12.6	13.3	13.2	9.3	5.7	4.9	4.3	3.2	2.5	2.3	5.1	86.7	
							New Antwerp, Belgian Congo							
Temp.	79.2	80.1	79.2	78.1	79.2	78.4	76.5	76.3	77.0	77.4	77.9	78.1	78.1	3.8
Precip.	4.1	3.5	4.1	5.6	6.2	6.1	6.3	6.3	6.3	6.6	2.6	9.3	66.9	

SAVANNA CLIMATE

Location and Boundaries. Savanna climate differs from the tropical rainforest in two respects: (1) it usually has less rainfall, and (2) there are distinct wet and dry seasons. Savannas lie on the poleward sides of the tropical rainforest, between the doldrums on one side and the trades and subtropical highs on the other. They range in latitude from about 5° to 15°. As the vertical rays of the sun move north and south during the year, savannas are alternately influenced by doldrums and trades. Since trades tend to produce deserts, it is evident that savannas occupy a position between constantly wet and constantly dry climates. The llanos of the Orinoco Valley in Colombia and Venezuela and adjacent parts of the Guiana highlands, the campos of Brazil, the Sudan of north Africa, the veldt of south Africa, and portions of northern Australia are all representative savanna lands. Such lands are characterized by tall grass and open forest. Tree growth is heavier on the equatorward side. Poleward we find trees giving way entirely to grassland as the desert is approached. The savanna lands of India, Burma, and French Indo-China are under the influence of monsoon wind systems instead of doldrums and trades.

Temperature. Since the noon sun is never far from a vertical position, constantly high temperatures are the rule in savanna lands. The annual range is usually about 10° or 15°, slightly more than in the tropical rainforest (Fig. 88). In some savanna regions, the inhabitants recognize three temperature periods: (1) the cooler dry season at the time of low sun; (2) the hotter dry season just preceding the rains; and (3) the hot, wet season during the rains. During the cooler dry season, or the period of low sun, day temperatures are high, reaching 80° to 90° in the afternoon. Humidity is low so that the heat is not oppressive. Nights are inclined to be pleasantly mild, the temperature dropping to 60° or 70°. During the hot, dry period, temperatures rise above 90° and often over 100°. The hot, wet season is one of high sun and doldrum influence. It is similar to the tropical rainforest. Daily range of temperature is less than in the dry season, and high humidity makes the weather sultry.

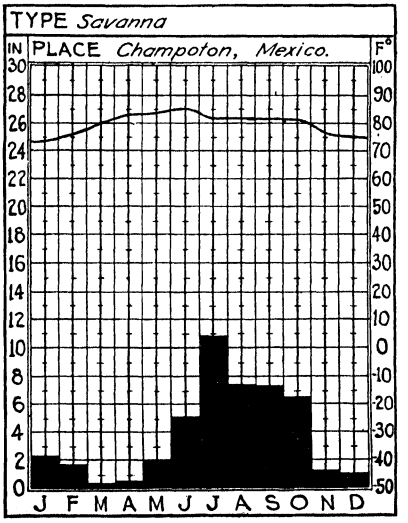


FIG. 88.—Average monthly temperature and precipitation for a representative savanna station.

Precipitation. Savanna lands, with annual rainfall ranging from 40 to 60 inches, receive less precipitation than the tropical rainforest. In contrast to the rainforest, savannas have distinct wet and dry seasons. The Sudan of Africa, which lies just north of the tropical rainforest, may be used to illustrate seasonal distribution of precipitation. As the vertical rays of the sun move north of the equator in April and May, thunderstorms over the Sudan become more frequent. Rainfall continues to increase in amount until July or August, when the doldrums have reached their most northerly position. With the southward retreat of the doldrums, following the sun, rainfall decreases; and by October or November the trades are again in control, and drought again grips the Sudan.

One should keep in mind that south of the equator the period of high sun includes December, January, and February. The period of low sun includes June, July, and August. It is obvious, therefore, that when a Northern Hemisphere savanna is having its rainy season, a drought prevails in the Southern Hemisphere savanna, and vice versa.

SAVANNA CLIMATE

	June to August	*Season*	*December to February*	*Season*
N. Hemisphere	High sun	Wet	Low sun	Dry
S. Hemisphere	Low sun	Dry	High sun	Wet

The hot, wet season is ushered in by violent thunderstorms and severe winds which in Africa are called *tornadoes*. In the dry season, weather is like that of the desert. Humidity is so low that the skin often becomes parched and cracked. In spite of the aridity, the dry weather furnishes relief from the sultry weather of the wet season. As the dry season advances, the landscape becomes brown in color, the trees lose their leaves, the rivers are low, the soil cracks, and all nature appears dormant. Dust and smoke from grass fires often fill the air. The coming of the wet season brings a startling change. Nature responds rapidly to the copious rains of violent thunderstorms. Grasslands are soon green, and the forests clothed with leaves and flowers.

Especially in South Africa and southern Brazil, the savanna lands experience cooler weather because of the higher elevations of plateaus and highlands.

Monsoon Savannas. In India the savanna wet and dry seasons correspond with the periods of onshore and offshore winds, respectively. Winds blow toward land in the warm season, carrying vast amounts of moisture inland. Weak lows move up the Ganges Valley toward the northwest, causing abundant rains. As these onshore winds, loaded with moisture, approach the southern slopes of the snow-capped Himalaya Mountains, the rainfall resulting is the heaviest in the world. Cherrapunji, for example, averages over 400 inches of rain per year and holds the world's record of 905 inches. Over the savanna lands of India the annual rainfall decreases from the eastern coast toward the

northwest. During the period of low sun, winds blow from high-pressure areas over the land toward the sea. This is the dry season during which irrigation is used to provide moisture to growing crops, especially wheat.

Life in the Savannas. Largely as a result of the climatic conditions that prevail, the characteristic natural vegetation of savanna lands consists mainly of tall grass and trees. In some places the grasslands are suitable for the grazing of cattle. In general, however, grazing in the savannas suffers from several serious handicaps, *viz.*, (1) the dry season, (2) the coarse nature of the grass, (3) insect pests, and (4) tropical diseases.

The savanna lands of Africa are the big game regions. A list of wild animals that inhabit the tree and grasslands of Africa would indeed be a long one. Travelers often are astounded at their great numbers. Especially during the dry season, a regular parade of animals can be observed in the vicinity of favorite water holes dotted here and there throughout parts of these regions.

Man lives in the savannas mainly by agricultural and pastoral pursuits. For the most part, these regions in Australia, Africa, and South America are only sparsely populated. This is largely because of (1) the dry season, which in some cases lasts for several months and (2) the lack of dependable rainfall. On the other hand, the monsoon savannas of southeastern Asia support a very dense population. Portions of India are among the most densely populated regions of the world. Here the abundant rains during the wet season and irrigation during the dry season make it possible to produce a tremendous quantity of food, especially from such crops as rice, wheat, and sugar cane. The upland portions of peninsular India are well adapted to cotton production.

In parts of the savanna, man is able to utilize certain valuable trees. In the highlands of southern Brazil, around São Paulo, the coffee tree thrives. In the Gran Chaco, in northern Argentina and Paraguay, quebracho forests furnish not only good timber but also a valuable tanning extract. Commercially, teakwood is one of the most valuable of the savanna trees. This wood is extremely durable and has no equal as a shipbuilding material. It is found in certain highland regions of southeastern Asia.

CLIMATIC DATA FOR REPRESENTATIVE SAVANNA STATIONS

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Timbo, French West Africa (10°40′N.)														
Temp.	72	76	81	80	77	73	72	72	72	73	72	71	74	9.7
Precip.	0.0	0.0	1.0	2.4	6.4	9.0	12.4	14.7	10.2	6.7	1.3	0.0	64.1	
Calcutta, India														
Temp.	65	70	79	85	86	85	83	82	83	80	72	65	78	21
Precip.	0.4	1.1	1.4	2.0	5.0	11.2	12.1	11.5	9.0	4.3	0.5	0.2	58.8	
Cuyabá, Brazil (10°S.)														
Temp.	81	81	81	80	78	75	76	78	82	82	82	81	80	6.6
Precip.	9.8	8.3	8.3	4.0	2.1	0.3	0.2	1.1	2.0	4.5	5.9	8.1	54.6	

The Dry Climates

What Is Meant by a "Dry" Climate? The essential feature of a dry climate is that evaporation shall exceed precipitation. As a result of little rainfall, there is no surplus of water to maintain a constant water supply in the ground. Permanent streams, therefore, cannot originate in such areas. It may be possible for streams to cross them, as do the Nile and the Colorado, provided they have their sources in more humid regions.

Two subdivisions of dry climates are commonly recognized: (1) the arid, or desert, type and (2) the semiarid, or steppe, type. In general, the steppe is a transitional belt, or belt of gradual change, lying between the real desert and the humid climates beyond.

Temperature, Precipitation, and Winds. Temperature changes in the dry climates tend to be greater than in the humid. The daily range is usually large. Clear skies and low relative humidity permit rapid heating of the earth during the day and rapid loss of heat at night. The lack of vegetation in deserts also contributes to the more rapid heating and cooling of the earth's surface.

Rainfall in dry climates is always meager and varies from year to year. Dependability of rainfall usually decreases with decrease in yearly amount. For example, droughts are likely to be more frequent in a region having an annual rainfall of 20 inches than in one having 30 or 40 inches. No part of the earth, as far as is known, is absolutely rainless, although at Arica, on the Pacific Coast of northern Chile, the average yearly rainfall was only 0.02 inch over a period of 17 years. During the entire 17 years only three showers were heavy enough to be measured.

Relative humidity in the dry climates, with a few exceptions, is low, ranging from 12 to 30 per cent during the midday hours. The rate of evaporation is therefore high. The amount of sunshine is great, and cloudiness small. Direct as well as reflected sunlight from the bare, light-colored earth is blinding in its intensity.

Dry regions tend to be windy places. The sparse vegetation offers little resistance to air movement (Fig. 89). Strong convec-

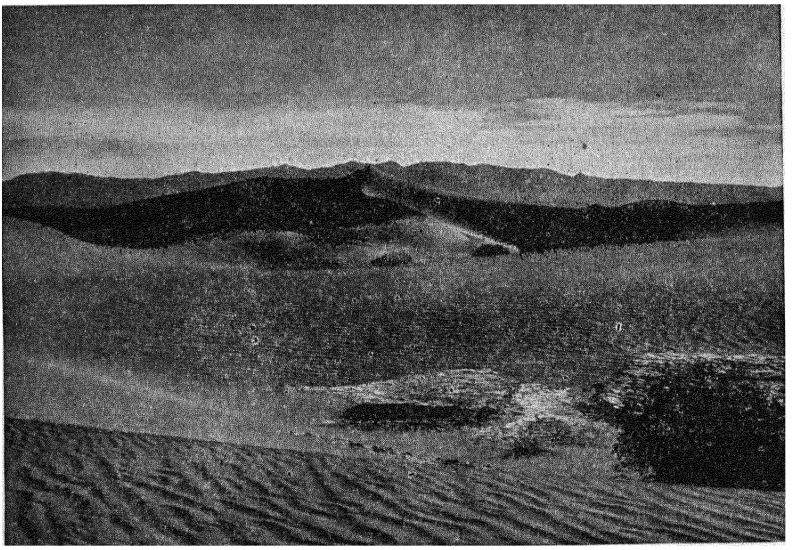


FIG. 89.—The billowing, wind-rippled forms of sand dunes in the American desert. Note the mud floor and some vegetation in the depressions, or pockets, where water has stood. The distant hills in this view are low mountains, not sand dunes. (*Ewing Galloway.*)

tion currents during the day increase the strength of horizontal winds. The air is quieter at night, which is an aid to radiation of heat. Desert air is often murky with fine dust which fills the eyes, nose, and throat, causing serious discomfort. Much of this dust is carried beyond the desert to form the *loess* (wind-blown soils) of bordering regions. Heavier sand and rock particles travel close to the earth's surface. Such wind-blown sand carves some of the peculiar landforms of deserts. The dry climates may be subdivided as follows:

1. Hot (low latitude)
   - *a.* Desert
   - *b.* Steppe

2. Cold in winter (middle latitude)
   a. Desert
   b. Steppe

Low-latitude Desert

Location. These tropical deserts at their extreme margins range from about 15° to 30° of latitude. They tend to occupy centers and western (leeward) sides of the continent in the trades and subtropical highs. It is well to remember that east coasts in the trades are humid and west coasts relatively dry. Cool ocean currents along such west coasts intensify the aridity. The reason for this is explained in a later chapter. The principal low-latitude deserts are (1) the Sahara in northern Africa, (2) Arabia, (3) Thar in northwestern India, (4) the Sonora in northwestern Mexico and southwestern United States, (5) the Kalahari in southern Africa, (6) the Australian desert, and (7) the Atacama-Peruvian Desert along the coast of Peru and northern Chile.

Temperature. The annual range of temperature in tropical deserts is relatively high. At Aswan, in the Sahara, the average July temperature is 95°, and the January temperature 61°, making a range of 34°. The large range is due to the extremely hot summer and not to severe winter cold, as is the case in middle and high latitudes. Daily range of temperature averages 24° to 45° and in rare instances reaches 60° or 70°. The temperature in a single day in parts of the Sahara has been known to range from near freezing to 80° or 90°.

During the months of high sun, scorching, dry heat prevails. The percentage of sunshine is high. Yuma, Ariz., receives 97 per cent of the possible sunshine in June. Midday temperatures of 105° to 110° are common at this season. At Yuma, in 1914, the temperature went above 100° for 80 consecutive days, except for 1 day. Night temperatures are by no means cool, the low readings usually being around 70° to 75°.

At the time of low sun the days are still warm, with the thermometer reaching 60° to 70°, but the nights are distinctly chilly, with minimum temperatures in the neighborhood of 40°. At Insalah, in the Sahara, extreme temperatures for the year have been known to go as high as 124° and as low as 26°. It is

possible, therefore, for light frosts to occur in parts of these low-latitude deserts.

Precipitation. Annual rainfall in the hot deserts averages possibly 5 to 10 inches, although over much of the Sahara it is less than 5 inches (Fig. 90). What rain does fall often comes in the form of violent convectional showers which do not cover a very great area. These heavy downpours may do more harm than good. Dry stream beds are soon filled with raging torrents of water which may damage roads, bridges, or railroads. The immediate runoff of water is excessive. Such dash rains are of little value to the oasis farmer, who uses water from springs and wells to irrigate his crops.

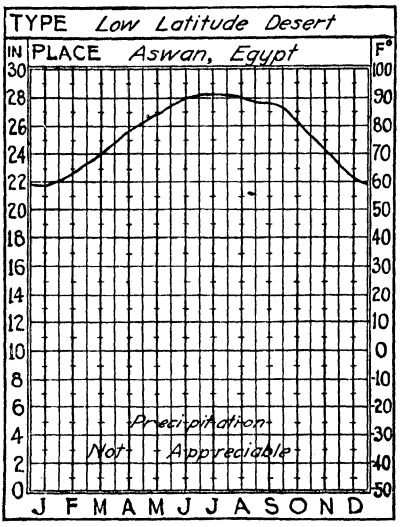


FIG. 90.—Average monthly temperature at a representative station in a low-latitude desert.

Evaporation, caused by high temperatures and low relative humidity, is high. If a pan of water is continuously exposed to the air, the amount evaporated from it may be more than twenty times the annual precipitation. At Yuma the average evaporation during the hot months is 55 inches; the average rainfall during the same period is not quite 1 inch. Relative humidities as low as 2 per cent, with temperatures over 100°, have been recorded in the Egyptian Sahara. It was the excessively dry air that allowed the Egyptians to mummify their dead.

West-coast Deserts in the Tropics. The usual characteristics of tropical deserts are modified somewhat in the west-coast deserts where cool ocean currents parallel the shore (see map of ocean currents, page 375). The presence of cool currents is especially marked along the desert coasts of Peru and northern Chile, the southwestern coasts of Africa, and to a lesser degree the northwestern coast of Mexico. Temperatures along such coasts are therefore lower than those of inland deserts at the same latitude. Rainfall is extremely low. Callao, Peru, has an

annual rainfall of 1.8 inches. However, heavy fogs often produce dew and mist. As the cool ocean air drifts landward, the heat of the coastal desert soon evaporates the fogs so that as a rule they do not extend very far inland.

It should be mentioned here that the high evaporation was partly responsible for the preservation of the deposits of sodium nitrate in northern Chile. Water, carrying the nitrate in solution, was evaporated from the desert surface, and the nitrates remain as surface deposits. These nitrates have been shipped from Iquique and Antofagasta to all parts of the world. They are

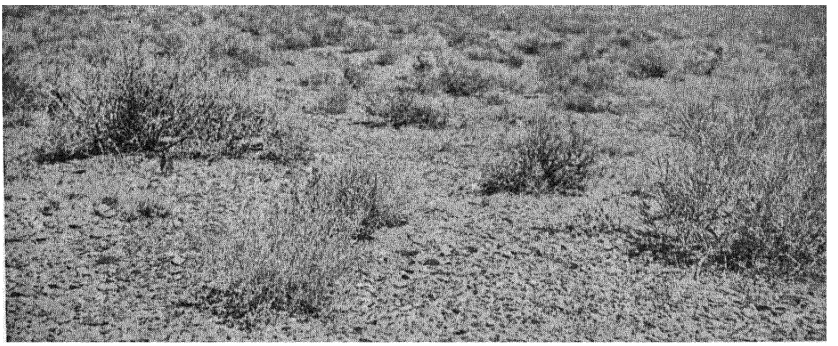


FIG. 91. The pebbles and rock fragments of a desert pavement in western Nevada. (*Photograph by John C. Weaver.*)

especially valuable in the manufacture of explosives and commercial fertilizers. The nitrate industry of Chile, however, has suffered from the increased manufacture of commercial nitrates in other parts of the world.

Desert Surface. The most characteristic and extensive arid land cover is one of coarse stony or pebbly material (Fig. 91). Loose, shifting sand, often in the form of dunes or hills, covers portions of the desert (Fig. 89). Oasis agriculture is found in limited areas where small deposits of water-carried or alluvial soil are available, provided there is a fairly reliable source of water near at hand.

Where drainage is poor, the rapid evaporation of ground waters may result in the formation of white, alkali soils. Ground water carries chemical matter in solution. As the water evaporates, the white chemical compounds accumulate in the topsoil. This is like boiling salt water. The water boils away, but the

salt remains in the pan. Alkali soils are worthless from the standpoint of crop production.

In general, desert features are sharp and bold. The more resistant rocks may protrude above the general surface, sometimes forming mesas or buttes (Fig. 92). Deep, steep-sided gullies are formed during the occasional torrential downpours of rain. Steep-walled gorges or canyons may be cut by larger streams, called *exotic streams*, which originate outside the desert in more

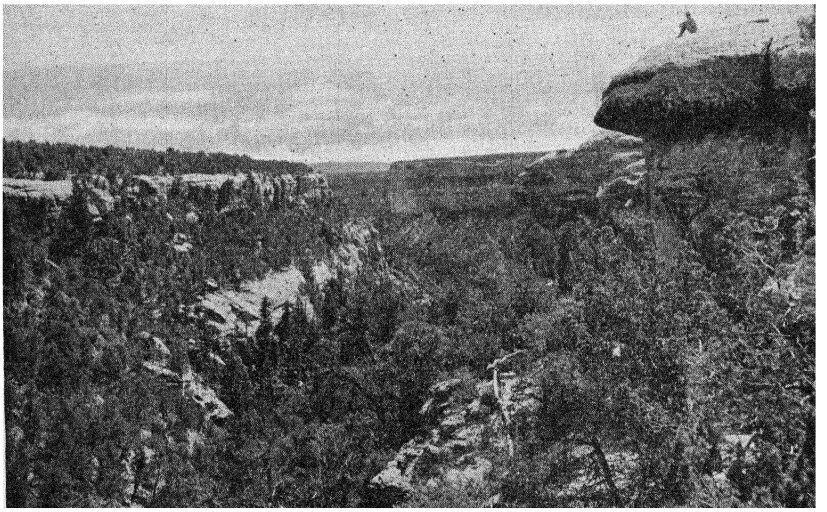


FIG. 92.—View down one of the canyons in Mesa Verde National Park, southwestern Colorado. "Mesa Verde" means "green tableland." The top of the mesa is 1,000 to 2,000 feet above the surrounding territory. The cap rock is red sandstone, underlain by shale. The famous cliff dwellings, used by Indians hundreds of years ago, are in the sandstone layer. (*Courtesy of U.S. Department of the Interior.*)

humid lands. Most arid lands are able to support a scattered vegetation. Desert shrubs such as sagebrush and creosote bush predominate over grassy or weedy plants. In places, various species of cactus form a considerable part of the vegetation (Fig. 93). These arid-land plants are equipped both to resist and to endure drought. Their feeding value is low, although in places goats and sheep are able to find sufficient forage.

Life in the true, tropical desert is indeed hard. Together with certain snow- and ice-covered lands of high latitudes, these are the most sparsely populated regions of the earth. The blistering sun, low humidity, high winds, and sandstorms are

factors that try the endurance of men. Caravans of camels are able to cross the larger deserts by carrying both food and water. Desert tribes in certain localities tend to be nomadic, moving

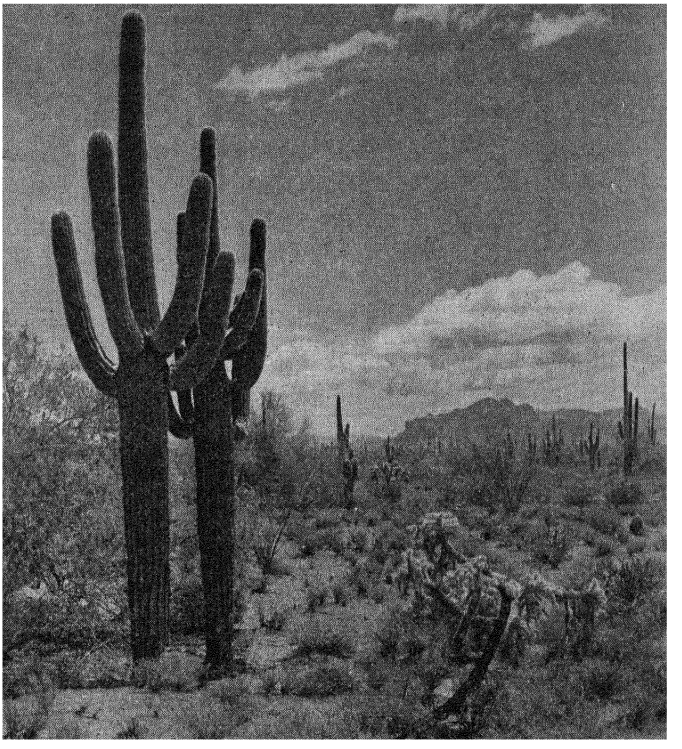


FIG. 93.—The weird but beautiful plants of the Arizona desert testify that this soil is good though dry. In the foreground is a giant cactus. (*Courtesy of U.S. Bureau of Reclamation.*)

from place to place, seeking the meager resources offered by the arid landscape.

CLIMATIC DATA FOR REPRESENTATIVE STATIONS IN LOW-LATITUDE DESERTS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Jacobabad, India							
Temp.	57	62	75	86	92	98	95	92	89	79	68	59	79	41
Precip.	0.3	0.3	0.3	0.2	0.1	0.2	1.0	1.1	0.3	0.0	0.1	0.1	4.0	
							William Creek, Australia							
Temp.	83	83	76	67	59	54	52	56	62	70	77	81	68	30.5
Precip.	0.5	0.4	0.8	0.4	0.4	0.7	0.3	0.3	0.4	0.3	0.4	0.3	5.4	
							Lima, Peru							
Temp.	71	73	73	70	66	62	61	61	61	62	66	70	66	12.8
Precip.	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.5	0.1	0.0	0.0	1.8	

Low-latitude Steppe

Low-latitude steppes are semiarid lands, located around the edges of the low-latitude deserts. In northern Africa the steppe lies between the Sahara and Mediterranean climates. On the south edge of the Sahara the steppe lies between the desert and savanna climates. The semiarid regions in northern Australia, southwestern Africa, and northwestern India lie for the most part on the equatorward side of the tropical deserts.

Rainfall in the steppes, like that in the deserts, is not only meager but also variable and not dependable. Humid years attract settlers who later suffer from a series of dry years. Agriculture is safe only under irrigation. Temperature conditions are much the same as in the adjacent desert, with the exception that those steppes on the poleward margins have somewhat lower temperatures during the cool season. These regions as a whole are sparsely populated except in isolated, irrigated spots. During favorable years the grazing of sheep and cattle may provide an occupation for a scattered population. Undependable rainfall and high temperatures are the serious handicaps in these localities.

Climatic Data for Benghazi, Tripoli
Low-latitude Steppe

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	55	57	63	66	72	75	78	79	78	75	66	59	69	24
Precip.	3.7	1.8	0.7	0.1	0.1	0.0	0.0	0.0	0.1	0.3	2.1	3.1	11.9	

Middle-latitude Dry Climates

Middle-latitude Desert

Location. Middle-latitude deserts range from about 30° to 45° in latitude. For the most part they lie in the deep interiors of the great continents, far from the oceans which are the principal source of water vapor for the earth's atmosphere. In these latitudes Asia has the largest area of dry climates, and North America is next in order. Aridity is due not so much to the influence of wind belts, as with the tropical deserts, as to location in the *interiors* of large landmasses. It is significant, also, that the middle-latitude deserts tend to occupy depressions, or basins, being surrounded or partially so by highlands or

mountains. Thus the arid Great Basin of Nevada is separated from the Pacific Ocean by the Sierra Nevada Mountains, and to the east lie the Wasatch and Rocky Mountains (Fig. 94). Much of the arid land of Asia is shut off from a possible source of water vapor from the Indian Ocean by the high Himalaya Mountains. Gobi, Tarim, Dzungaria, Russian Turkestan, and central Iran all are surrounded, in part at least, by highland rims.

These deserts, then, are regions of rain shadow and descending winds, so that great aridity is the result. Another result of enclosure, combined with low elevation, is the very high temperature of summer months, sometimes reaching 90° to 110°.

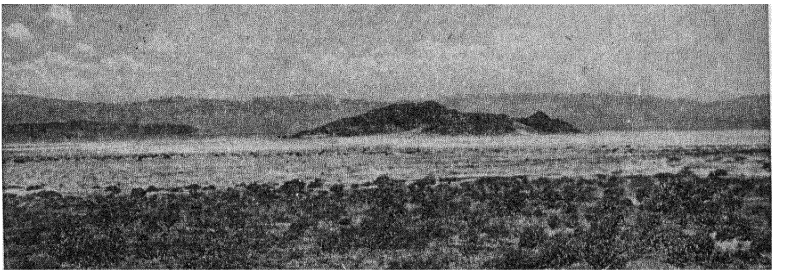


FIG. 94.—An arid basin in Nevada. Its deep alluvial filling has a glistening white crust of salt, and wind-blown salt clings to the rocky island included within it. (*Photograph by John C. Weaver.*)

Patagonia, in Argentina, does not correspond in some respects to the description given above for middle-latitude deserts. There the main cause of aridity lies in the fact that much of southern Argentina is in the rain shadow of the Andes Mountains. A cool ocean current lying offshore likewise induces aridity. Southern South America is so narrow that marine influence is more pronounced, and temperatures in dry Patagonia are by no means so extreme as in the deserts of central Asia or North America.

Temperature and Precipitation. Middle-latitude deserts have a much greater annual range of temperature than do the deserts of low latitudes. Summers are warm, and winters cold. In some places in the deserts of Asia the January average temperature is around 0°, and the July average above 80°. During most of the year the daily range of temperature is considerably

higher than in more humid regions at the same latitude. In winter, continental anticyclones with descending air are rather prevalent over the dry lands, producing cold, clear days with little precipitation. Winds blowing outward from these anticyclones carry low temperatures to localities situated farther south. In the United States a Great Basin high over Nevada, Utah, and Idaho may become anchored for two weeks or more in autumn or winter, warding off storms from the north and producing in the Central states a period of delightful, fair weather. Summer heat tends to develop a seasonal low over the dry interiors of the continents, causing a general inflow of

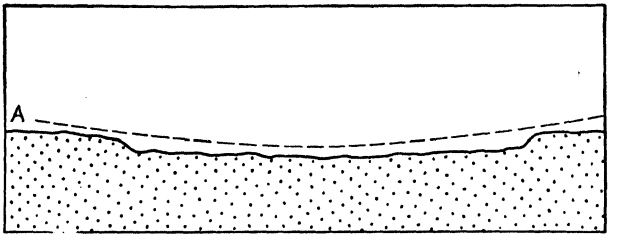


FIG. 95.—A mirage is due to refraction, or bending, of the light rays. An observer at *A* actually sees an image of the blue sky that comes to his eye along the path shown by the dotted line. This makes the basin appear to contain a lake. The same phenomenon often is seen when one looks down an automobile highway.

winds of monsoonal character. The continents are so vast in size, however, that moisture drawn inland is largely precipitated before it reaches the dry interiors. During the daylight hours in summer, winds are unusually strong in these deserts, a result of convection induced by high temperatures. As with the tropical desert, rainfall is meager. Occasionally in winter the middle-latitude desert is covered with snow. Annual precipitation, however, is usually less than 10 inches. Vegetation is necessarily scanty; and these regions, like the tropical deserts, are among the very sparsely populated portions of the continents.

Mirage. Although mirages have been observed in many parts of the world, they probably have been seen more often in desert and steppe lands than elsewhere. A mirage is due to the refraction, or bending, of light rays. In a flat, basinlike area, the air next to the earth may become much warmer than the air immediately above. The two layers of air, having different

temperatures, also have different densities. As light rays pass through these layers, they are refracted, or bent. A person looking toward the flat basin may be badly fooled. The basin



FIG. 96.—A field of kaffir corn in the semiarid steppe lands of western Kansas. This crop is well adapted to the light rainfall of these regions. It provides feed for several kinds of livestock. (*Courtesy of Kansas State College of Agriculture and Applied Science.*)

may appear to contain a large lake. Actually, because of the bending of light rays, he sees an image of the blue sky (Fig. 95).

CLIMATIC DATA FOR MIDDLE-LATITUDE DESERT

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Urga, Mongolia (3,800 Ft.)														
Temp.	−16	−4	13	34	48	58	63	59	48	30	8	−17	28	79
Precip.	0.0	0.1	0.0	0.0	0.3	1.7	2.6	2.1	0.5	0.1	0.1	0.1	7.6	
Fallon, Nev. (3,965 Ft.)														
Temp.	31	36	41	50	56	65	74	72	61	51	40	32	50.6	42.7
Precip.	0.6	0.5	0.5	0.4	0.6	0.3	0.1	0.2	0.3	0.4	0.3	0.6	4.7	

MIDDLE-LATITUDE STEPPE

Characteristics. Middle-latitude steppes are the semiarid lands between the middle-latitude deserts and adjacent, more

humid regions. Temperature conditions are not greatly unlike those of the desert. The steppes, however, receive more rainfall and are, therefore, somewhat better fitted for human settlement. Settlers are tempted to farm these semiarid lands (Fig. 96). A succession of humid years may bring them partial success, but invariably a series of dry years will follow with disastrous effects.

Location. In North America a considerable area of this type of climate extends from Texas to Canada, lying east of the Rocky Mountains (Fig. 97). Winters are much more severe in the north (eastern Montana) than in the south. This is the high-plains region. Because of the rather level nature of the land and the scarcity of trees, strong winds prevail during most of the year. In winter these high winds, together with near zero temperatures and snow, are elements of the "blizzards" that sometimes occur in the prairie states. In summer, hot south winds are extremely drying. The short grass that is the typical vegetation has added humus to the soil, so that over most of the region soils are fairly rich and, under irrigation, are very productive. As an illustration, the excellent sugar-beet region of eastern Colorado may be cited. The growth of grasses encourages the grazing of sheep and cattle. Wheat production in the region is a gamble with the weather elements.

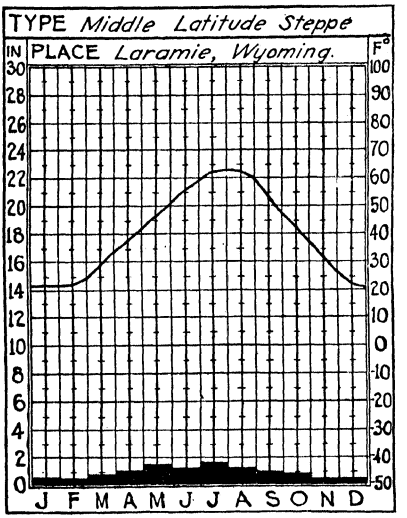


FIG. 97.—Average monthly temperature and precipitation for middle-latitude steppe station.

Two unique features of this climate in North America should be mentioned. One is the *duststorms* which originate in the "dust bowl" in southwestern Kansas and southeastern Colorado, the dust being carried by southwest winds over the Central states (Fig. 98). These storms are not troublesome except during a series of dry years. The other is the *chinook* wind, a warm wind that descends the eastern slopes of the Rocky Mountains and,

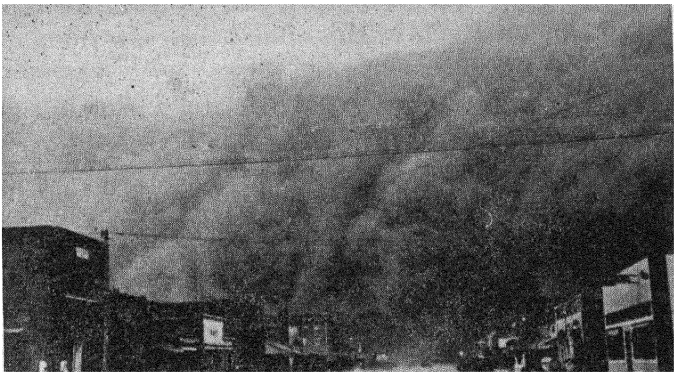


FIG. 98.—A duststorm at Ulysses, in extreme southwestern Kansas. (*Photograph by R. L. Gray, Courtesy of S. D. Flora, U.S. Weather Bureau, Topeka, Kans.*)

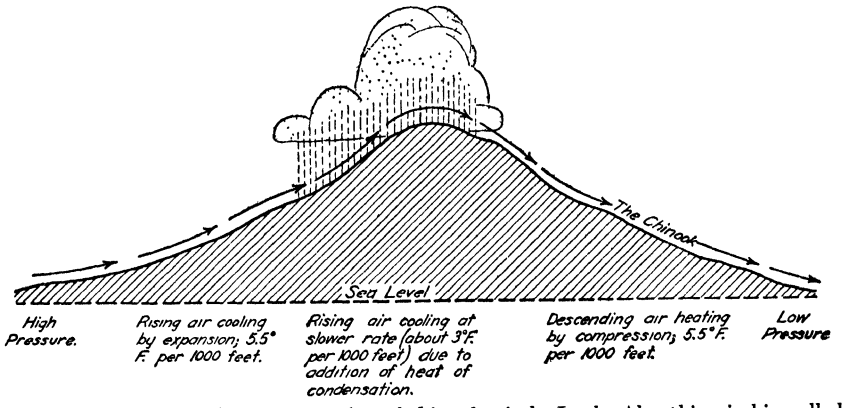


FIG. 99.—Diagrammatic representation of chinook winds. In the Alps this wind is called the foehn.

especially in winter, causes a rapid rise in temperature (Fig. 99). Mainly because of the uncertainty of rainfall, the region as a whole is rather sparsely populated.

CLIMATIC DATA FOR WILLISTON, MONT.

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	6	8	22	43	53	63	69	67	56	44	27	14	39.2	62.7
Precip.	0.5	0.4	0.9	1.1	2.1	3.2	1.7	1.7	1.0	0.7	0.6	0.5	14.4	

Summary

Tropical rainforest climate is hot and humid. There is no cool season. Average monthly temperatures differ little during the year. Convectional rainfall in the form of thunderstorms totals

in many places 80 to 100 inches per year. Among the more important economic products of this climate are raw rubber, cacao beans, bananas, coconuts, and cane sugar.

Savanna lands are characterized by a wet season during high sun and a dry season during low sun. Native vegetation consists mainly of coarse grass and scattered trees.

Low-latitude deserts have no winter. At high sun they are extremely hot; at low sun, warm. Middle-latitude deserts have a winter season and therefore a much higher annual range of temperature than do those of low latitudes.

The difference between savanna and steppe is shown in the following chart:

	Annual Rainfall Inches	*Vegetation*
Savanna	30–60	Tall grass and scattered trees
Steppe	10–20	Short grass

The following chapter continues with a discussion of the types of climate to be found in those parts of the world which are farther from the equator than the tropical rainforest or the trade-wind desert.

Questions

Tropical Rainforests

1. How is tropical rainforest climate distinguished from other humid climates?
2. What is the average annual temperature in tropical rainforests? Why is the annual range of temperature so low?
3. Compare the daily range with the annual range of temperature.
4. Make a statement concerning the amount and the seasonal distribution of rain in the tropical rainforest.
5. Why are conditions ideal for rain formation? What is the type of the rainfall?
6. Discuss the daily weather in regions of tropical rainforest climate.
7. What types of clouds predominate in rainforest regions?

8. What is the typical rainforest vegetation? Effect on transportation?

9. Mention a few economic crops and the areas of production.

10. Discuss life in the tropical rainforest.

11. How do white men combat tropical heat? Fever? What is meant by enervating?

12. What problem does the high humidity of the air in the rainforest regions introduce into the practice of air conditioning?

SAVANNA LANDS

13. How does savanna rainfall differ from that of the rainforest?

14. Savannas are influenced by what two wind belts? What is the effect of each?

15. What and where are llanos? Campos? Sudan? Veldt?

16. What three temperature periods are recognized in savannas? Which resembles the tropical rainforest?

17. When does the wet season in the Sudan occur? Why? What is the type of the rainfall?

18. What months constitute the wet season and the dry season in the savannas of the Northern Hemisphere? Southern Hemisphere?

19. What is the effect of the dry season in savannas?

20. Locate the principal upland savannas.

21. Explain the cause of monsoon winds in southeastern Asia.

22. Why does rainfall decrease from Calcutta toward the northwest? It is heaviest during what months?

23. Why does Cherrapunji have such heavy rain?

24. What is the typical vegetation of savannas?

25. Mention several handicaps to the grazing of livestock in the savannas.

26. Name a few economic products of savannas and at least one producing region for each.

DRY CLIMATES

27. What is the essential feature of a dry climate?

28. In general, how does latitude affect rate of evaporation?

29. What are the two subdivisions of dry climates?

30. Why is the daily range of temperature large in deserts?

31. What is a general rule relating to dependability of rain?

32. Locate Arica. What is the annual rainfall there?

33. What are the characteristics of humidity, sunshine, and winds in dry climates?

34. Name and locate the principal low-latitude deserts.

35. Discuss annual and daily range of temperature in low-latitude deserts.

36. What temperature extremes have occurred at Insalah?

37. What is the character of most desert rainfall?

38. How much does evaporation exceed precipitation in some deserts?

39. What peculiar characteristic has the climate of a west-coast tropical desert?

40. How has climate probably contributed to formation of sodium nitrate deposits in northern Chile?

41. Describe the desert surface. What is an oasis?

42. What is meant by an exotic stream? Give an example.

43. Describe desert vegetation.

44. Locate the low-latitude steppes. Why are they sparsely populated?

45. What is the main cause of aridity in middle-latitude deserts?

46. Where is the Great Basin? It is bordered by what mountains?

47. Name the desert regions of Asia.

48. Where is Patagonia? Why is it arid?

49. Contrast annual range of temperature in high-latitude and low-latitude deserts.

50. What is the effect of an anticyclone over the Great Basin?

51. Describe the climate of the Great Plains of North America. Are soils in general rich or poor? Where is the dust bowl? What are chinook winds?

52. Where would evaporation be more severe, in the steppes of Montana or in the steppes of New Mexico? Why? What would be the effect on crop production?

Suggested Activities

1. Display in the classroom three maps of the world, one showing relief, another the planetary winds over the oceans, and a third the annual rainfall of the continents. Discuss as many relationships as possible. Note particularly the regions of orographic rainfall and rain shadow.

2. Plot rainfall and temperature curves for selected places throughout the world. Paste these curves on a large outline wall map of the world with arrows pointing to the exact location of each place.

3. If possible, purchase several large outline wall maps of the United States. Use them to illustrate various climatic conditions throughout the country.

4. Place a pan of water outside a window, and observe the rate of evaporation. Repeat at different seasons of the year. Use coarse screen to keep out birds. At the same time keep a record of sun altitude at noon and the approximate percentage of cloudy and clear weather.

5. Choose one climate among those so far discussed in which you would like to live. Then write a short discussion of this climate, giving reasons for your choice.

6. Paste or pin on a world map the names of tropical economic products in those regions where they are produced in great quantities.

7. Draw a rough outline map of the United States, and superimpose it on a map of the Sahara Desert drawn at the same scale.

8. Summarize the causes of aridity.

9. Label the great deserts on a climatic map of the world.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Products of the Tropical Rainforest
2. Life in the Amazon Basin
3. The Belgian Congo
4. Plantation Rubber of Malaya and the East Indies
5. Sugar-cane Production in Cuba
6. Cacao
7. Central American Banana Plantations
8. Egyptian Sudan
9. Coffee Production in Brazil and Central America
10. Distribution of Population in India
11. The Use of Savanna and Steppe Lands in Australia
12. The Llanos of Colombia and Venezuela
13. Irrigation Projects in the Steppe Lands of North America
14. Dry Farming in the High Plains of North America

REFERENCES

Atlas of American Agriculture, Part II, "Climate," three sections, *viz.*, Frost and the Growing Season; Temperature, Sunshine, and Wind; Precipitation and Humidity, Government Printing Office, Washington, D.C.

JAMES, PRESTON E.: *An Outline of Geography*, Ginn and Company, Boston, 1935.

KENDREW, W. G.: *Climates of the Continents*, Oxford University Press, New York, 1937.

WARD, R. DEC.: *Climates of the United States*, Ginn and Company, Boston, 1925.

Chapter VII. Climates of Middle and High Latitudes

"Rain changing to snow; much colder." Thus reads the weather forecast in February. A day or two later comes this warning:

"Florida fruit growers should be prepared to protect trees against freezing weather."

Meanwhile, in California, the news stories tell of unusually heavy rains.

Then comes spring, and we read, "Much warmer tomorrow; thunderstorm probable in afternoon."

Summer arrives, and there are occasional rains. Then, throughout much of central United States, a "spell" of hot, dry weather sets in, and much damage is done to growing crops.

All kinds of weather! Such is the nature of the middle latitudes, or intermediate zones, which extend approximately from the 30th to the 65th parallel. Such variety is in sharp contrast with the monotonous, warm, humid weather of the tropical rainforest. In the tropics, seasons are designated as *wet* and *dry;* in the middle latitudes, as *summer* and *winter.* In the tropics, plants are dormant during the dry season; in the middle latitudes, during the cold, or winter, season.

Cyclones and anticyclones move from west to east in the middle latitudes. They are largely responsible for the changeableness of the weather. It is in these regions that the science of weather forecasting is best developed and most useful.

Our study of these latitudes begins with that type of climate which is found around the shores of the Mediterranean Sea.

Mediterranean Climate

General Features and Location. Blue skies, abundant sunshine, mild winters, and few rainy days are outstanding

features of Mediterranean climate. With such an environment usually is associated a great variety of fruits and flowers at all seasons. World regions having this type of climate are widely known for their numerous resorts and playgrounds.

Mediterranean climate, also called *subtropical dry-summer* climate, in its simplest form, has three principal characteristics:

1. The precipitation is moderate to low in amount, and much of it falls in the winter season, the summer being nearly rainless (Fig. 100).

2. The winter temperatures are mild, but the summers are warm to hot.

3. There is much sunshine in all the seasons, but especially in the summer.

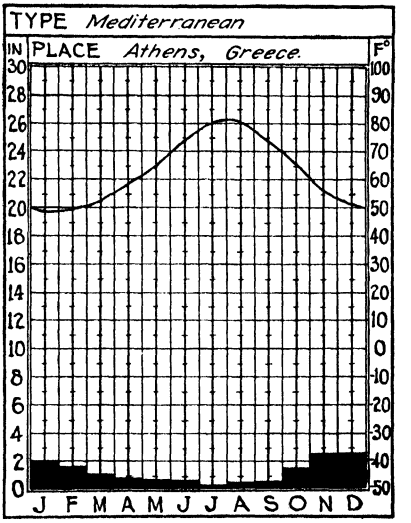


FIG. 100.—Average monthly temperature and precipitation for a representative station with Mediterranean climate.

This type of climate is located on the tropical margins of the middle latitudes. Especially is it found on the western sides of continents, in approximately the latitude of the subtropical highs. This climate, therefore, lies between the dry trades and subtropical highs on the one hand and the humid westerlies with their cyclonic storms on the other. In summer, tropical dry weather is in control; in winter, the changeable weather of the westerlies is the prevailing influence. This, then, is a transition climate between low-latitude steppes and deserts and the cool, marine, west-coast climate farther poleward.

The major regions of Mediterranean climate are (1) the borderlands of the Mediterranean Sea, (2) central and coastal-southern California, (3) central Chile, (4) the southern tip of South Africa, and (5) parts of southern Australia. These areas lie roughly between 30° and 40° of latitude. In central Chile, mountains near the ocean shore confine this climate to a narrow coastal margin. Africa and Australia do not extend southward far enough to have any large areas of Mediterranean climate.

Only in the region of the Mediterranean Basin does this climate extend far inland. In winter, the paths of cyclones move equatorward so that they cross southern Europe. This probably is due to the relative warmth of the Mediterranean Sea. Over this sea there forms an elongated low-pressure area, or "trough." This trough attracts the cyclones which penetrate eastward to Palestine and beyond, bringing cyclonic weather and winter rainfall with them.

Temperature. In a region having Mediterranean climate, more pleasant temperatures throughout the year are likely to be found *along coasts* than farther inland. Summer weather along shore is distinctly cooler. This is caused (1) by the marine influence of ocean winds and (2) in some cases by a cool ocean current that parallels the coast, *e.g.*, in California and Chile. Thus the average temperature of the warmest month at San Francisco is 60°, whereas at Red Bluff in the Sacramento Valley it is 80°. Winters along such coasts are unusually mild, frost being practically unknown. The cold months have average temperatures around 50° to 55°. Annual range of temperature is uncommonly small, approximately 10° at San Francisco and 11° at Valparaiso, Chile. Fogs are frequent, just as they are along desert coasts toward the equator.

Farther inland, Mediterranean climate is somewhat different. Winters are still mild, but summers are distinctly hotter than in coastal regions. At Sacramento, in 1931, there were 27 days in July and 16 in August with maximum temperatures above 90°, highest readings sometimes reaching 105° to 110°. At night, however, the thermometer may record 55° to 60°, showing a great daily range. The relatively cool nights are greatly appreciated by the inhabitants of these regions. In summer the arid heat and glaring sunshine, together with hot, desertlike winds and the parched condition of the vegetation, are disagreeable elements of the landscape.

It is for the mild, bright winters, with delightful living temperatures, that Mediterranean climates are justly famed. People from more severe climates seek them as winter playgrounds and health resorts. Even interior locations have average cold-month temperatures 10° to 20° above freezing. (Sacramento 46°, Marseilles 43°, and Rome 44°.) In southern Cali-

fornia, in January, midday temperatures rise to 55° or 65° and at night drop to 40° or 45°. The growing season is not quite the whole year, because *frosts* occasionally occur during the three winter months, especially in valleys into which cold air sinks. Sensitive crops such as citrus fruits (oranges, lemons, grapefruit) are therefore planted on hillsides. Although severe frosts are rare, there have been instances when freezing temperatures have resulted in widespread disaster to orchardists. For that reason various methods of combating low temperatures are employed when necessary during the cold months. Prominent among such methods is the use of orchard heaters mentioned in Chap. II (see page 38).

Precipitation. Mediterranean climate is unique among world climates in that it is the only one of the humid climates that has a summer drought. Annual rainfall averages 15 to 25 inches. There is a pronounced maximum during the *cooler* months, summer being nearly, if not absolutely, dry. The yearly amount increases with latitude. Thus San Diego has 10 inches of rain per year on the average; Los Angeles, 16; and San Francisco, 23. In all Mediterranean regions snow is so rare that it is a matter of considerable comment when it does fall. It is rather fortunate that the rains occur in the cool season. If they fell during the hot season, much more moisture would be lost by evaporation and thus would not be available for plant growth.

The winter rainfall is due largely to the influence of cyclones which move farther equatorward at that season of the year. There are "spells of weather" when dull, gray skies prevail. Showers fall at intervals. Occasionally the rain becomes a downpour for a short period, sometimes causing floods which do great damage. Thunderstorms seldom occur except possibly in the mountains or hills, two to four a year being the usual number in southern California. The winter rains brighten the landscape, the growth of vegetation changing the prevailing color from brown to shades of green.

Seasonal Weather. Summer weather changes little from day to day. It is characterized by clear skies, drought, brilliant sunshine, high daytime temperatures, rapid cooling at night, and, except near the coast, low relative humidity. Certain regions

in Mediterranean climates are famous for sea breezes, winds that blow from sea to land and have a moderating effect on the intense heat. In autumn and winter the days are bright except for the occasional periods of cloudy, rainy weather. Along coasts, fogs appear in the morning, but the sun evaporates them by nine or ten o'clock. The coast of California is one of the foggiest areas in the United States. Spring is a delightful season, fresh and yet warm. On the whole it is cooler than autumn.



FIG. 101.—Orchards in the Sacramento Valley. (*Courtesy of Sacramento Chamber of Commerce.*)

This is the time when many grains are harvested. As the season advances, rainy spells become rare, and the heat more intense.

A low-pressure area crossing Europe may draw hot winds northward from the Sahara Desert. These winds, called *siroccos*, with temperatures of 100° or more and humidities of 10 to 20 per cent, may do serious damage to vegetation.

Life in Mediterranean Climate. Native plants in this climate are of necessity drought resistant. Trees tend to be widely spaced, not tall, and covered with a thick bark which serves to retard evaporation. Leaves are small and leathery, characteristics that prevent rapid loss of water. Among these drought-resistant trees is the valuable cork oak. Produced

mainly in Portugal and western Spain, the bark of this tree furnishes the world's principal supply of cork.

In some localities the vegetation cover consists principally of a mixture of shrubs and bushes. This is the chaparral of California. Such a vegetation cover is not capable of supporting abundant animal life. However, the meager forage seems to be sufficient in many places for the needs of sheep and goats; and Mediterranean lands, especially in southern Europe, are noted for their large numbers of these animals.

Man combats the semiarid nature of Mediterranean climate by means of irrigation. Under the bright sun, vineyards and citrus-fruit orchards flourish (Fig. 101). In California the rich soils that have accumulated at the base of mountain slopes are so utilized. The hot sun and dry air of the interior valleys are climatic factors that are largely responsible for the development of the fruit-drying industry in certain localities, *e.g.*, around Fresno, Calif. The exporting of enormous quantities of wine from countries bordering the Mediterranean Sea is a direct result of a climate favorable to grape production.

CLIMATIC DATA FOR REPRESENTATIVE MEDITERRANEAN STATIONS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Red Bluff, Calif. (Interior)							
Temp.	45	50	54	59	67	75	82	80	73	64	54	46	62.3	36.3
Precip.	4.6	3.9	3.2	1.7	1.1	0.5	0.0	0.1	0.8	1.3	2.9	4.3	24.3	
							Santa Monica, Calif. (Coast)							
Temp.	53	53	55	58	60	63	66	66	65	62	58	55	59.5	13.6
Precip.	3.5	3.0	2.9	0.5	0.5	0.0	0.0	0.0	0.1	0.6	1.4	2.3	14.78	
							Perth, Australia (Coast)							
Temp.	74	74	71	67	61	57	55	56	58	61	66	71	64	19
Precip.	0.3	0.5	0.7	1.6	4.9	6.9	6.5	5.7	3.3	2.1	0.8	0.6	33.9	

Humid Subtropical Climate

General Features and Location. Humid subtropical climate differs from *dry* subtropical, or Mediterranean, climate in three respects:

1. It usually is located on the east sides of continents.
2. It has more abundant rain.
3. The rainfall is either well distributed throughout the year or concentrated in the warm season.

These two subtropical types of climate have about the same latitudinal location, the humid east-coast type ranging from 25°

to 40°. West coasts in the intermediate zones feel the marine influence of westerly winds from the ocean. East coasts also experience westerly winds. However, east coasts are subject to winds having a monsoon tendency, *i.e.*, winds blowing from sea to land in summer and from land to sea in winter. The larger the continent the greater the extremes of temperature near its center. The greater the extremes of temperature the more pronounced will be the monsoon winds, because great temperature differences mean great pressure differences. Thus Asia and North America are continents in which the monsoon tendency is relatively well developed. The stronger the monsoon tendency the greater the concentration of precipitation in the warm season.

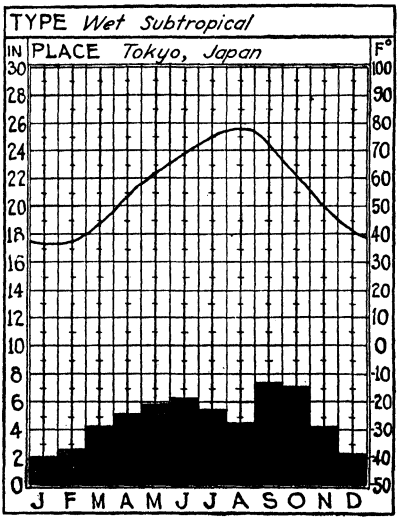


FIG. 102.—Average monthly temperature and precipitation for a representative station in the humid, or wet, subtropics.

The larger areas of humid subtropical climate are (1) southeastern United States; (2) Japan and eastern China; and (3) northern Argentina, Uruguay, and extreme southern Brazil. Smaller areas are found in southeastern Africa and Australia.

Temperature. The temperature characteristics of humid subtropics are somewhat similar to those of Mediterranean climates, since they occupy about the same latitudes. However, warm ocean currents along east coasts prevent such cool, foggy weather as that of San Francisco and other west-coastal locations.

Summers are warm to hot, typical average temperatures for the warmest months being 75° to 80° (Fig. 102). Relative humidity, as well as temperature, is high, producing a sultry, oppressive condition. Sensible temperatures, therefore, especially in summer, are higher in Florida than in California. Summer heat in the American Gulf states closely resembles that of the tropical rainforest. In the subtropical regions of China and

Japan, Europeans and Americans frequently quit their usual places of residence during the summer and go to high-altitude stations, as they do in the genuine tropics. Nights are hot and humid in contrast to the drier and cooler nights of Mediterranean climate.

Winters in the humid subtropics are relatively mild. Cool-month temperatures average 40° to 55°. The annual range of temperature is, therefore, usually not great, ranging from 20° to 30°. Nights may be uncomfortably chilly because of high humidity and a temperature around 40°.

The growing season, or period between killing frosts, is long, ranging from 7 months up to nearly, if not quite, the entire year. Freezing temperatures occur on only a relatively few nights in winter. The cold spells do serious damage to sensitive crops such as citrus fruits and sugar cane. Cold waves are more severe in the American Gulf states than in southeastern China. This is because (1) winter cyclones and anticyclones of North America are well developed and (2) the level nature of the land surface permits the cold air from northern Canada to flow southward toward or even to the Gulf of Mexico (Fig. 103). The extreme southern tip of Florida is the only place in the United States where the thermometer has never been known to reach 32°.

Precipitation. Rainfall is relatively abundant within the humid subtropics, annual amounts ranging from 30 to 65 inches. Rain falls throughout most of the year but in general is heavier in the summer months.

Summer rainfall is mainly convectional, accompanied by thunder and lightning. The humid subtropical region of southeastern United States ranks high in thunderstorms, the annual number ranging from 60 to 90. Hurricanes and typhoons are late summer and early autumn storms characteristic of this climate. They bring torrential rains and floods, which, with high winds, may do tremendous damage. In the Swatow typhoon of August, 1922, it was estimated that 40,000 Chinese lost their lives, chiefly by drowning.

Winter rainfall is mainly cyclonic in origin. It is usually associated with a general and persistant cloud cover extending over wide areas. Because of more numerous cyclones, winters

are cloudier than summers. Gray, overcast days are unpleasantly chilly. Snow falls occasionally but melts within a day or two.

Humid Subtropics Are Highly Productive. Without doubt these regions possess the most productive climate of the middle latitudes. There is little restriction upon the kinds of crops that can be grown. Winter cropping is nowhere prohibitive.

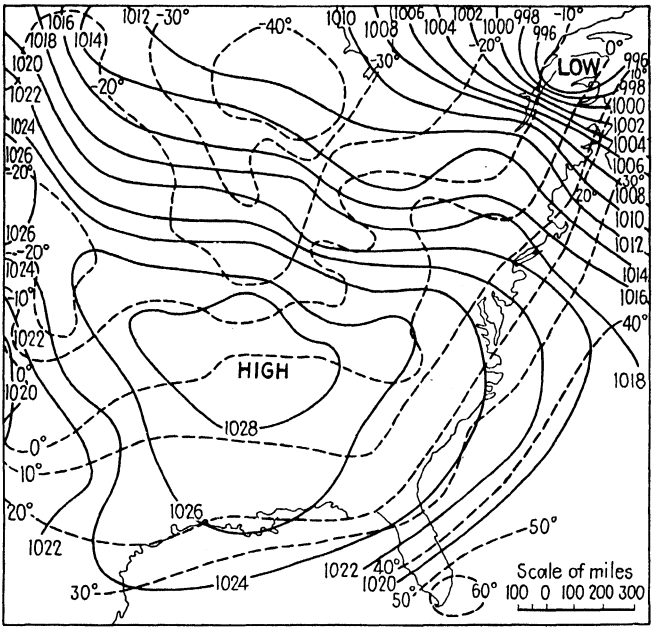


FIG. 103.—Weather controls giving rise to killing frosts in the American humid subtropics. A well-developed anticyclone advancing from the northwest as a mass of polar continental air produced minimum temperatures of 20° at New Orleans and 8° at Memphis. The isotherm of 20° fairly well parallels the Gulf and South Atlantic Coasts.

In southern China and Japan, many of the fields are in use the entire year. The lack of a cold season, however, tends to increase crop losses from injurious fungus and insect pests.

The abundant warmth and moisture cause an equally abundant vegetation cover, usually of forests; although in regions of more moderate rainfall, grasses may replace trees. Grasslands, for example, predominate in the pampa of northern Argentina. In China, the forests have been cut to such an extent that soil erosion and floods are serious problems. The South

Atlantic and Gulf states of America possess considerable forest resources, although the stand of pine trees has rapidly diminished. Much of the land from which southern pines are being removed is so poor that it is unfit for agriculture.

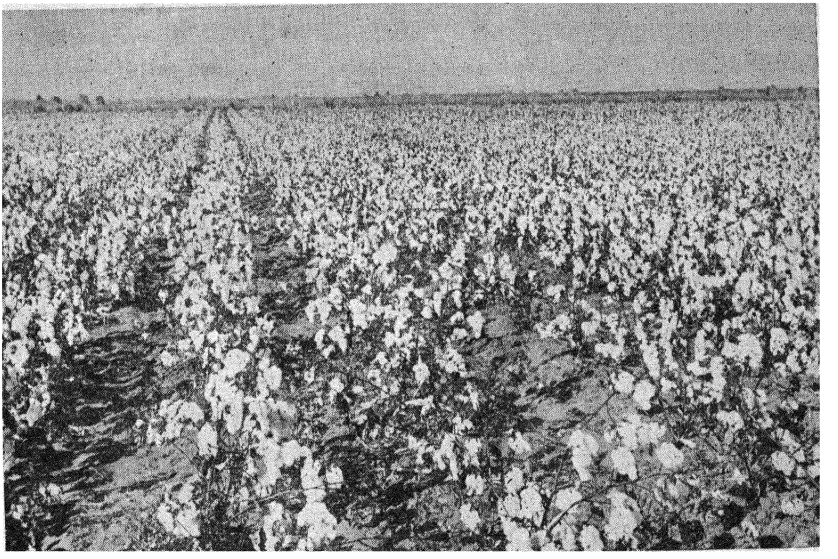


FIG. 104.—Cotton growing on the flat coastal plain of Texas. (*Courtesy of Agricultural Experiment Station, A. and M. College of Texas.*)

In general, the forest soils of the Gulf states are not of high fertility. This is due largely to the solution and removal of soil materials by abundant rains.

It needs to be emphasized, however, that in those areas where soils are fairly rich, humid subtropical climate is capable of tremendous agricultural production (Fig. 104). This is shown by the rice-producing delta regions of China and the black soils

CLIMATIC DATA FOR REPRESENTATIVE HUMID SUBTROPICAL STATIONS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Charleston, S. C.								
Temp.	50	52	58	65	73	79	82	81	77	68	58	51	66.1	31.4
Precip.	3.0	3.1	3.3	2.4	3.3	5.1	6.2	6.5	5.2	3.7	2.5	3.2	47.3	
						Shanghai, China								
Temp.	38	39	46	56	66	73	80	80	73	63	52	42	49	42.8
Precip.	2.8	2.0	3.9	4.4	3.3	6.6	7.4	4.7	3.9	3.7	1.7	1.3	45.8	
						Sydney, Australia								
Temp.	72	71	69	65	59	54	52	55	59	62	67	70	63	20
Precip.	3.6	4.4	4.9	5.4	5.1	4.8	5.0	3.0	2.9	2.9	2.8	2.8	47.7	

of the cotton belt of the United States. The supplying of northern markets with citrus fruits and off-season vegetables and the operation of winter resorts for tourists illustrate other opportunities for human occupation in the American Gulf states.

Marine West-coast Climate

Location. Marine climates occupy positions on *western*, or *windward*, sides of middle-latitude continents, poleward from about 40°. Onshore westerly winds import to them conditions from the oceans. In their general atmospheric characteristics, therefore, they are like the seas from which the imported air is arriving. Where land areas are relatively narrow, as with Great Britain, New Zealand, and Tasmania, the marine influence is felt inland as well as along the coast.

Because of higher latitude, marine coasts are *not* subject to the very dry seasons found in Mediterranean climates. Moreover, marine coasts are usually paralleled by relatively warm ocean currents. Evaporation of water from these currents increases the moisture content of the winds that move from sea to land in these regions.

The depth to which marine west-coast climates penetrate inland depends upon the nature of the land surface. Where mountains closely parallel the west coasts as in North America, South America, and Scandinavia, oceanic conditions are confined to relatively narrow coastal strips. But where extensive lowlands prevail, as in parts of western Europe, the effects of the sea are carried well inland.

Temperature. Summers are moderately cool and, although more or less ideal for human efficiency and comfort, are on the other hand somewhat too cool for the best growth of many cereal crops. These cool summers are in severe contrast to the hot summers of Mediterranean and humid subtropical climates. In these cloudy, rainy regions the daily range of temperature is small. In Seattle the highest temperatures of the day in July average 73°, and the lowest average 51°. Occasional hot days occur, but prolonged hot waves are very few.

Winters, on the whole, are abnormally mild for the latitude. Especially is this true in western Europe where a great mass of warm water, known as the *North Atlantic Drift*, a continuation

of the Gulf Stream, lies offshore. Thus most marine parts of western Europe are 20° to 30° too warm in January for their latitudes. Hammerfest, on the coast of Norway, 71°N., is an ice-free port, yet ice-breakers are required to keep open the harbor of Hamburg, 54°N. but considerably inland from the Atlantic. It is rare for London to have a temperature below 15°. The frost-free, or growing, season is unusually long for the latitude, being 180 to 210 days in the American North Pacific Coast region.

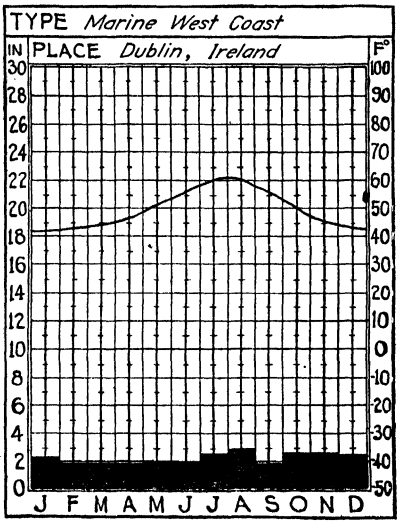


FIG. 105 —Average monthly temperature and precipitation for a representative station in marine west-coast climate.

Precipitation. Marine west coasts generally have adequate rainfall at all seasons (Fig. 105). The total amount varies, depending much upon the surface features of the land. Over the lowlands of western Europe, the rainfall is only moderate, usually 20 to 40 inches. On mountainous coasts, however, the total may reach 100 to 150 inches. Europe is the only continent where marine rainfall extends inland to any great distance. In North America heavy precipitation on the west side of the Cascades is counterbalanced by arid to semiarid conditions to the east.

Rainfall on marine west coasts has two outstanding characteristics: (1) It is reliable, droughts being of rare occurrence, and (2) it is adequate for plant growth at all seasons. Usually there is no marked dry season. In some places, especially along mountain coasts, winter precipitation is much heavier than that of summer. Snowfall is not abundant over the lowlands of northwest Europe because of temperatures that are prevailingly above freezing. On the western slopes of the Cascades, however, 300 to 400 inches of snow fall on the average each year. Snowfall is likewise heavy in the southern Andes, in the mountains of New Zealand, and along the coast of British Columbia and southern Alaska.

Marine coasts are well known for cloudy weather. The Puget Sound region has the highest cloudiness and least sunshine of any part of the United States. Over western Europe, cloudiness over wide areas is greater than 70 per cent, the sun sometimes

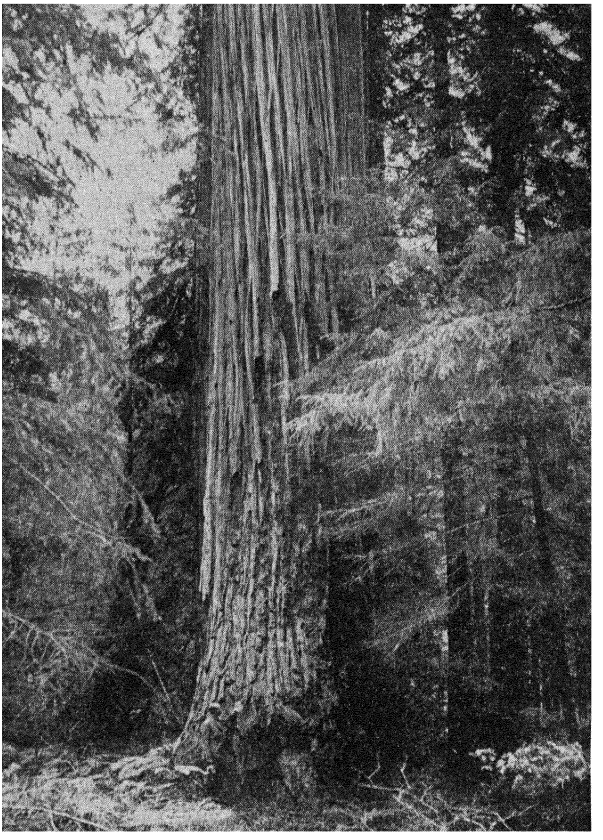


FIG. 106.—This large California redwood tree (*Sequoia sempervirens*) is over 12 feet in diameter, measured 5 feet above the ground. (*Courtesy of U.S. Forest Service.*)

being hidden for several weeks in succession. Evaporation, therefore, is very low, so that small amounts of rainfall are very effective for plant growth. Relative humidity is almost always high.

Productivity of Marine West Coasts. In this mild, humid climate, forests and pasture lands are of excellent quality. The finest stand of timber in the United States is found along the northern Pacific Coast. In northern California, occupying

the foggy, western slopes of the Coastal Ranges, are the great redwood forests (Fig. 106), but pines and cedars prevail inland. Farther north, in Oregon, Washington, and southern British Columbia, Douglas fir is the outstanding tree, being the most important timber tree of the Pacific Coast forests. North of about latitude 50°, in British Columbia and Alaska, fir is less abundant, and spruce and western cedar become the dominant timber trees. Of the remaining stand of saw timber in the United States, about 60 per cent is in the Pacific Coast forests.

The cool, damp climate of marine west coasts is well suited to the growth of many grasses. The excellent pasture lands that abound in some regions have encouraged livestock production. Thus most of the breeds of fine livestock have been developed in the countries of western Europe.

Soils in regions of marine west-coast climate vary considerably but in general are only moderately fertile. The various types of soil are responsible to some extent for the variety of agricultural crops produced. The forest soils in general are superior to those of the tropical rainforest. In many places the soils have been influenced considerably by past glaciation. Especially in Oregon and Washington, many of the more fertile valleys are important fruit-producing regions, an example being the Rogue River Valley.

CLIMATIC DATA FOR REPRESENTATIVE MARINE WEST-COAST STATIONS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Seattle, Wash.							
Temp.	40	42	45	50	55	60	64	64	59	52	46	42	51.4	24
Precip.	4.9	3.8	3.1	2.4	1.8	1.3	0.6	0.7	1.7	2.8	4.8	5.5	33.4	
							Paris, France							
Temp.	37	39	43	51	56	62	66	64	59	51	43	37	50.5	27
Precip.	1.5	1.2	1.6	1.7	2.1	2.3	2.2	2.2	2.0	2.3	1.8	1.7	22.6	
							Hokitika, New Zealand							
Temp.	60	61	59	55	50	47	45	46	50	53	55	58	53	16
Precip.	9.8	7.3	9.7	9.2	9.8	9.7	9.0	9.4	9.2	11.8	10.6	10.6	116.1	

Humid Continental Climate

Location. Humid continental climates are limited to North America and Eurasia. There is no landmass in the south intermediate zone sufficiently large to have this type of climate. In Europe marine climate extends to eastern Germany, where it gradually changes to humid continental. In North America

mountain barriers that parallel the western coast cause arid to semiarid conditions over much of the western half of the continent. Therefore humid continental climate is found mainly in the eastern half of North America, extending roughly from southern Missouri to southern Canada and from central Kansas to the Atlantic.

This severe climate is land controlled. It is carried to the east margin of the continents by westerly winds. The east coasts do not experience quite so severe temperature changes as do the mid-continental areas, but their climate is, nevertheless, much more continental than marine. A third segment of this climatic type is found in North China, Manchuria (Manchukuo), and southeastern Siberia.

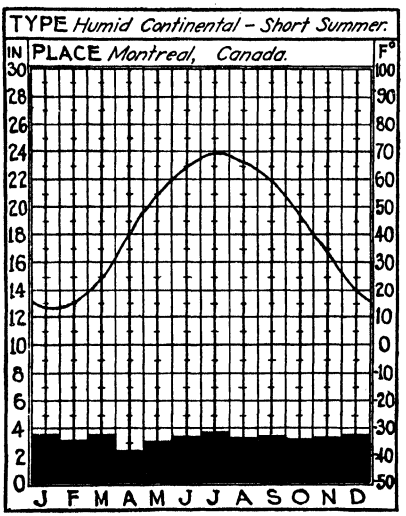


FIG. 107.—Average monthly temperature and precipitation at a station in the humid continental climate with short summers. The absence of a marked summer maximum in precipitation results from the very abundant winter snowfall.

Temperature. Warm to hot summers and cold winters are characteristic of the regions mentioned above. The annual range of temperature is, therefore, large (Fig. 107). The monsoon tendency, with southerly winds in summer and northerly winds in winter, tends to increase the extremes of temperature. In general, the severity of the climate increases from south to north and from coast to interior. Higher humidity along the Atlantic seaboard causes summer heat to be more oppressive and sultry and the winter cold more raw and penetrating than are the drier extremes of the interior. Temperature contrasts from south to north are much greater in winter than in summer. Between St. Louis and Winnipeg the January contrast amounts to 34°; in July it is only 13°.

Precipitation. In humid continental climates, the maximum precipitation usually occurs in the summer, although winters are not necessarily dry (Fig. 108). The summer maximum is due to

(1) the monsoonal tendency, as a result of which southerly winds blowing from sea to land carry great quantities of water vapor inland, (2) the resulting increased absolute humidity in summer, and (3) strong convection due to high temperatures. The warm-season rainfall is mainly convectional, a considerable percentage falling as the heavy downpours of thunderstorms. In winter, in addition to low absolute humidity, anticyclones with winds blowing from land to sea check the importation of water vapor from the ocean and sometimes retard the passage of lows across the continent.

The economic importance to agricultural production of having the year's rainfall relatively concentrated in the growing season cannot be overestimated. As these climates have a pronounced winter season, it is highly essential that periods of sufficient warmth and sufficient rainfall coincide. The great American Middle West is a highly productive agricultural region. This would not be the case if its rainfall were like that of southern California.

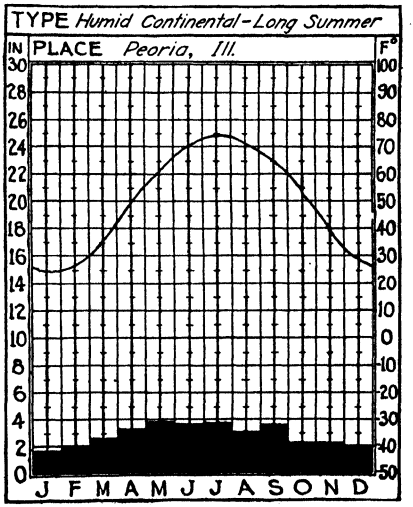


FIG. 108.—Average monthly temperature and precipitation for a representative humid continental climate with long summers.

Winters in humid continental climates are characterized by periods of cloudy, cyclonic weather. Precipitation may be in the form of rain or snow and occasionally sleet (Fig. 109). It takes 5 to 15 inches of snow to equal 1 inch of rain. A snow cover is of economic importance on fields planted to winter wheat, because (1) it adds moisture to the soil and, (2) owing to its low conductivity, it prevents the ground from becoming excessively cold. The snow, acting as a sort of blanket, helps to prevent winter freezing of the wheat.

Another effect of a snow cover is, of course, to reduce winter temperatures. The sun's heat is reflected from the white surface during daylight hours, whereas, in contrast, a field of black soil absorbs much heat. Night temperatures drop noticeably because

the snow has prevented the warming of the earth's surface during the day. In those parts of northeastern United States and Canada where winter cyclones are particularly numerous and well developed, such as the Upper Great Lakes Region, the St. Lawrence Valley, New England, and the Canadian maritime provinces, snow becomes excessively deep. Thus northern New York and parts of New England have more than 7 feet of snowfall during an average winter, and the snow cover remains on the ground for more than 4 months. In parts of the Adirondack Mountains 150 inches or more of snow falls annually. Over the American Great Plains, on the other hand, the fall of snow amounts to only 20 or 30 inches.

Seasonal Weather. In no other climate are rapid and irregular weather changes so characteristic as in the humid continental. These "spells of weather," caused by the passage of lows and highs, are numerous on marine west coasts, but in those locations temperature changes are not so severe. In eastern United States in particular, storm control is especially strong.

It is in the cold season, when storm tracks move south, that extreme weather changes occur. At that season sun control is much less dominant than that of moving cyclones and anticyclones. Changes in barometric pressure and wind velocity are greater than in summer. Daily temperatures often depend upon the direction of the wind. Thus a north wind one day with near zero weather may be followed next day by a south wind with temperatures 20° to 30° higher, and vice versa. Both lows and highs tend to move faster and to be larger, more frequent, and better developed in winter than at any other season. In the United States there is a distinct concentration of winter storm tracks over the Northeastern states, so it is this region which experiences the most frequent weather changes. In far continental interiors, strong highs tend to develop, causing steady cold weather and checking the activity of moving cyclones. Mixed with clear weather are periods of gray days with a stratus cloud covering from which little or no precipitation falls.

A blizzard is a severe winter storm which occurs in central North America and in Russia. It is not merely a heavy snow-

storm. It is a combination of strong winds, zero cold, and drifting, powdery snow. Actually, there may be no precipitation falling at the time, yet the air is filled to a height of several hundred feet by swirling masses of dry, finely pulverized snow, whipped up from the freshly fallen cover. Sometimes the sun can be seen shining wanly through the shroud of flakes. These storms are dangerous to both man and beast who may be caught long distances from shelter. On the weather map of the United States this type of storm is associated with a well-developed



FIG. 109.—Winter snow scene on a typical farm in the American corn belt.

low over the Central states followed by a high from western Canada and Montana. The bitter cold of the polar continental air mass in the high may be 20° to 40° below zero or even lower. The cold front advances over the country from west to east, the strong northwest winds often reaching the Gulf states. More frequent and widespread is the cold wave of winter in the United States. The temperature usually drops some 20° in 24 hours and remains near zero for several days. The sharp drop in temperature, which is the cold wave, occurs when the wind shifts from an easterly direction to the northwest.

Summer weather is dominantly under the influence of the sun. Storm tracks move northward. Weather is more uniform from day to day than in winter. Temperatures are much the

same over wide areas. Cyclones and anticyclones are weaker and less frequent. Clear, windy days are followed by hot, stagnant nights. On days of weaker winds and higher humidity, heat thunderstorms may develop during the warmer hours. Hot waves result from southerly winds combined with high sun and clear skies which drive midday temperatures to 100° or above over vast areas. Such conditions are brought about by a stagnant high in the south and a slow-moving, weak low, with little cloudiness, to the north. Anticyclones with cool, northerly winds are indeed welcome following such trying periods of blistering heat. Long, hot spells of summer weather without rain constitute the dreaded drought of central and eastern United States. The damage done by these dry periods to agricultural crops and livestock may run into millions of dollars.

Spring and autumn are transition seasons. Spring especially is noted for "fickle" weather. It is the season when the sun is trying to reestablish its control over cyclones, and the struggle results in sharp and peculiar changes in weather. In February or March, owing to abnormally warm weather, the buds of fruit trees may swell and then be killed by a later period of freezing temperatures. Autumn witnesses some of the loveliest days of the year but likewise some of the rawest, gloomiest weather. A temporary return of warm, sunny days with cool nights in October and early November brings the much cherished Indian Summer.

Humid continental climate is divided into two subtypes: long-summer subtype and short-summer subtype.

Long-summer Subtype. This long-summer phase (Fig. 108) is sometimes called *corn-belt climate*, because much of the world's commercial corn crop is grown in regions having its imprint. It is also called the *oak-maple-hickory climate*, because such trees dominate the hardwood forests found over much of these areas. In the United States this subtype covers a tier of states from central Kansas and Nebraska to the Atlantic Coast, including, in addition to the two states mentioned, Iowa, Missouri, Illinois, southern Wisconsin and Michigan, Indiana, Ohio, Pennsylvania, southern New York, and the coast states from southern New England to about Maryland. The American corn belt lies within its borders. In Europe this climate prevails only in the south-

central portions of the continent: the Danube and Balkan States and the Po Valley of Italy. It is on the plains of the Danube and in the Po Valley that much of Europe's corn crop is grown. The third principal region is in eastern Asia, including northern China, southern Manchuria, most of Chosen, and northern Japan. In this Asiatic area, monsoon winds and rainfall are particularly well developed.

Since these regions occupy the southern portions of the areas having humid continental climate, they experience a relatively long growing season of 5 to 7 months and only moderately severe winters. At St. Louis, Mo., the thermometer seldom records zero. Summers are likely to be hot and humid, resembling very much the tropical rainforest climate of the Amazon Valley. Because the wind dies with the sunset, nights tend to be warm and humid, making sleep indoors a difficult matter. In the crowded tenement districts of large cities, people abandon the hot, sultry air inside their homes and seek the open parks, where they spend the night. This is the season during which many inhabitants enjoy their vacations in the north woods or on the cool slopes of the Rocky Mountains.

CLIMATIC DATA—LONG-SUMMER SUBTYPE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Peoria, Ill.							
Temp.	24	28	40	51	62	71	75	73	65	53	39	28	50.8	51.6
Precip.	1.8	2.0	2.7	3.3	3.9	3.8	3.8	3.2	3.8	2.4	2.4	2.0	34.9	
							New York City							
Temp.	31	31	39	49	60	69	74	72	67	56	44	34	52.1	43.0
Precip.	3.3	3.3	3.4	3.3	3.4	3.4	4.1	4.3	3.4	3.4	3.4	3.3	42.0	
							Bucureşti (Bucharest), Rumania							
Temp.	26	29	40	52	61	68	73	71	64	54	41	30	50.7	47.5
Precip.	1.2	1.1	1.7	2.0	2.5	3.3	2.8	1.9	1.5	1.5	1.9	1.7	23.0	
							Peiping, China							
Temp.	24	29	41	57	68	76	79	77	68	55	39	27	53	55
Precip.	0.1	0.2	0.2	0.6	1.4	3.0	9.4	6.3	2.6	0.6	0.3	0.1	24.9	

Short-summer Subtype. This more severe phase of humid continental climate lies north of the long-summer subtype and between it and subarctic climate. It is sometimes referred to as the *spring-wheat* type, because of the prevalence of this cereal in certain areas (Fig. 110). In North America this climate extends from southern Alberta, North Dakota, and Minnesota eastward to the Atlantic. In Eurasia it includes most of Poland,

eastern Germany, the small Baltic States, and a large part of the central Russian Plain between 50° and 60° of latitude. A

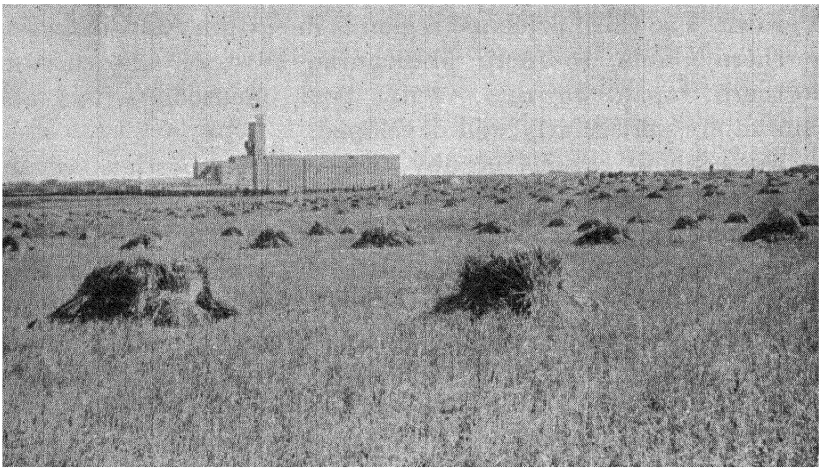


FIG. 110.—Harvest of wheat near Saskatoon, Sask., Canada. This was planted in the spring. Winter wheat, in localities such as Kansas, Missouri, and Illinois, is planted in early autumn.

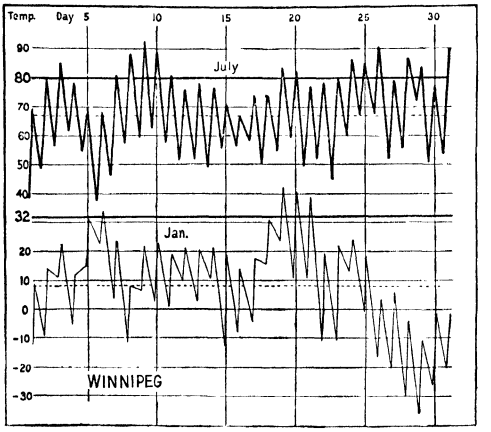


FIG. 111.—Daily maximum and minimum temperatures for the extreme months at a representative station in humid continental climate with short summers. (*Courtesy of Mark Jefferson and Geographical Review.*)

third area appears in northern Manchuria and southeastern Siberia.

Summers are usually warm for a few months, but the climate is handicapped by the short duration of the growing season of

3 to 5 months. Long summer days of these high latitudes somewhat offset this disadvantage. The cooler summer weather of these regions is an asset in one respect, *viz.*, in that it attracts thousands of tourists from more southerly localities. The long winter is the dominant season. In January and February, temperatures hover in the neighborhood of zero much of the time. At Winnipeg in January, daily maximum temperatures average 6°, and minimum temperatures −14° (Fig. 111). Annual precipitation in these regions is usually less than in the long-summer subtype, owing partly to greater distance from the sea. Because of continuous low winter temperatures, the snow cover remains on the ground for long periods of time.

CLIMATIC DATA—SHORT-SUMMER SUBTYPE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
							Madison, Wis.							
Temp.	17	20	31	46	58	67	72	70	62	50	35	23	45.8	55.5
Precip.	1.5	1.5	2.1	2.6	3.7	3.9	3.8	3.2	3.6	2.4	1.8	1.6	31.6	
							Moskva (Moscow), U.S.S.R.							
Temp.	12	15	23	38	53	62	66	63	52	40	28	17	39.0	53.8
Precip.	1.1	1.0	1.2	1.5	1.9	2.0	2.8	2.9	2.2	1.4	1.6	1.5	21.1	
							Harbin, Manchuria							
Temp.	−2	5	24	42	56	66	72	69	58	40	21	3	37.9	73.8
Precip.	0.1	0.2	0.4	0.9	1.7	3.8	4.5	4.1	1.8	1.3	0.3	0.2	19.3	

Productivity of Humid Continental Climate. This climate at present is one of the greatest producing climates of the earth. The original natural vegetation consisted mainly of a mixture of tall-grass prairie and deciduous woodlands. Tree growth was more pronounced in the more humid areas and along streams. In the virgin state, the prairies provided some of the finest natural grazing lands on the earth. Most of the grasslands, however, have long been under cultivation, because they are excellent producers of field crops, especially the cereals, such as corn, wheat, oats, barley, and rye. The production of corn, together with certain hay and forage crops, early encouraged the fattening of livestock, which in turn brought into existence the huge meat-packing industry.

Formerly, excellent forests existed in this type of climate in both Europe and North America. The northern part of the central hardwood-forest belt of the United States lies in the long-summer subtype of this climate. Oak, maple, hickory, and

birch are a few of the abundant and valuable deciduous trees of this belt, which extends from western Missouri northeastward to Pennsylvania. Large parts of this forest were destroyed in the process of early settlement of the Central states. Excellent forests of Norway pine, white pine, spruce, fir, hemlock, and other trees originally extended from New England to Minnesota. Lumber companies early attacked these fine forests, the cutting gradually advancing from east to west. The remaining stand of pine in Michigan, Wisconsin, and Minnesota today is less than 2 per cent of the original extent. In the Lake states alone there are 25 to 30 million acres of cut-over country, much of it of little value except as potential forest or resort land.

Some of the richest soils in the world are found in regions of humid continental climate. These excellent soils have resulted largely from the annual growth and decay of grasses over a long period of time. In general, grassland soils are richer than those of forested areas. Probably the richest soils in North America are found in the so-called *black-earth belt* which occupies the tier of states from North Dakota to Texas. Similar soils are found in parts of Russia, especially in the region north of the Black Sea. More noticeably in the northerly portions of this climatic type, the soils show the effects of the great continental glaciers which moved southward from certain northern parts of Europe and North America.

Subarctic Climates

General Features and Location. Subarctic is the extreme in continental climates, having the largest annual range of temperature on the earth. It is found only in the northern parts of North America and Eurasia, largely because of the fact that these great landmasses undergo greater changes in temperature with the change of seasons than do large water bodies at similar latitudes. The poleward boundary of subarctic climate is approximately the isotherm of 50° for the warmest month (usually July), which closely coincides with the northern limit of tree growth. Beyond this isotherm, in the tundra, lowly vegetation forms such as mosses, lichens, and bushes predominate. To the subarctic lands of Eurasia, with their extensive coniferous forests, the Russians have given the name *taiga* (tī′-ga).

At Yakutsk, Siberia, nearly 62°N., representing the extreme in subarctic climate, the warmest month, July, has an average temperature of 66° which is higher than the same month at Berlin, London, or San Francisco. Midday temperatures often reach 80° to 90°. This is due largely to the long summer days, long twilight, and very short period of real darkness. For example, at latitude 55°N., June days average 17 hours of possible sunshine; and at 65°N., 22 hours. In the more northerly portions of the subarctic lands at the time of the summer solstice, one can read a paper out-of-doors even at midnight.

Winter follows rapidly on the heels of summer, so that the length of the growing season is only 50 to 75 days. Even in July and August, freezing temperatures sometimes occur. A shift of the wind to the north brings with it the chill of the ice-laden arctic. Such conditions are serious handicaps to agricultural development and have contributed largely to slow permanent settlement within subarctic regions.

Siberia holds the record for low temperatures at low elevations. Verkhoyansk, in the northeastern part, boasts an average January temperature of −59°, with an absolute minimum of −90° recorded in February, 1892. This, of course, is an extreme case. At Yakutsk, where July averages 66°, January averages −46°, making an annual range of 112°. Concerning the Siberian winter, Hann writes:

> It is not possible to describe the terrible cold one has to endure; one has to experience it to appreciate it. The quicksilver (mercury) freezes solid and can be cut and hammered like lead; iron becomes brittle, and the hatchet breaks like glass; wood, depending upon the degree of moisture in it, becomes harder than iron and withstands the axe so that only completely dry wood can be split.

Winter weather in similar latitudes of North America, however, is not quite so severe as that of Siberia.

Subarctic Eurasia and North America are largely covered by taiga, softwood forests which rank among the most extensive and least known wildernesses of the earth (Fig. 112). Conifers, mainly spruce, fir, larch, and pine, occupy in the neighborhood of 75 per cent of the area. Although the extent of these forests is very great, their economic value is not to be overemphasized.

Trees are not closely spaced, and even in the southern portions of the region their diameters rarely exceed 1¼ feet. These forests are the home of many of the earth's most important

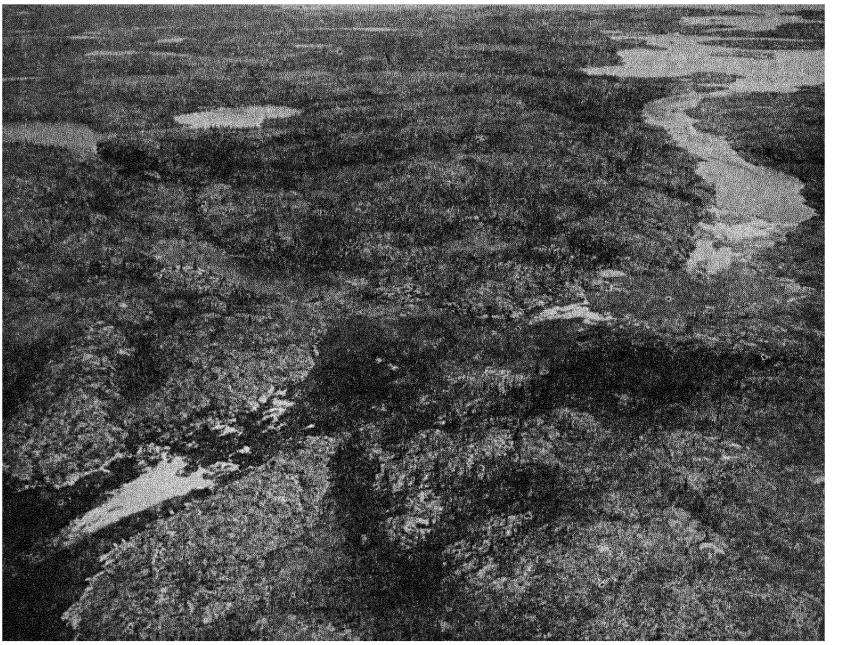


FIG. 112.—Taiga in the ice-scoured region of Canada. The meager soil cover permits only a thin stand of trees. (*Courtesy of Royal Canadian Air Force.*)

fur-bearing animals, many of which are being killed at an alarming rate. In general, the subarctic is a region of inferior soils, because the long, cold winters retard many of the processes of soil formation.

CLIMATIC DATA—SUBARCTIC CLIMATE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Fort Vermilion, Alberta, Canada														
Temp.	−14	−6	8	30	47	55	60	57	46	32	10	− 4	26.7	74.3
Precip.	0.6	0.3	0.5	0.7	1.0	1.9	2.1	2.1	1.4	0.7	0.5	0.4	12.3	
Moose Factory, Ontario, Canada														
Temp.	−4	−2	10	28	42	54	61	59	51	39	22	5	30.4	65.6
Precip.	1.3	0.9	1.1	1.0	1.8	2.2	2.4	3.3	2.9	1.8	1.1	1.1	21.0	
Yakutsk, Siberia, U.S.S.R.														
Temp.	−46	−35	−10	16	41	59	66	60	42	16	−21	−41	12	112
Precip.	0.9	0.2	0.4	0.6	1.1	2.1	1.7	2.6	1.2	1.4	0.6	0.9	13.7	

Tundra Climate

Location. The most extensive tundra areas are the Arctic Sea margins of North America and Eurasia. Most of the islands north of Canada and the coastal fringe of southern Greenland are likewise included. There is very little tundra in the Southern Hemisphere.

Long, bitterly cold winters and very short, cool summers are the rule (Fig. 113). Along the arctic coasts of Siberia, *average* January and February temperatures are in the neighborhood of −35° or −40°. Winter temperatures are not so severe along the northern coast of North America. Raw and chilly, the warmest months of the tundra, which average around 35° to 45°, resemble March and April in midwestern United States. Usually only 2 to 4 months have average temperatures above freezing, and killing frost is likely to occur at any time. Because of the unusually long, cold season, the subsoil is permanently frozen. Fog sometimes lasts for days at a time. The snow cover begins to disappear in May, and the lakes are usually rid of their ice cover in June. Bog- and swampland dominate the landscape. Myriads of mosquitoes and black flies make life almost unbearable for man and beast alike during the summer period of wet earth. Precipitation is not over 10 or 12 inches for the year and shows a summer maximum.

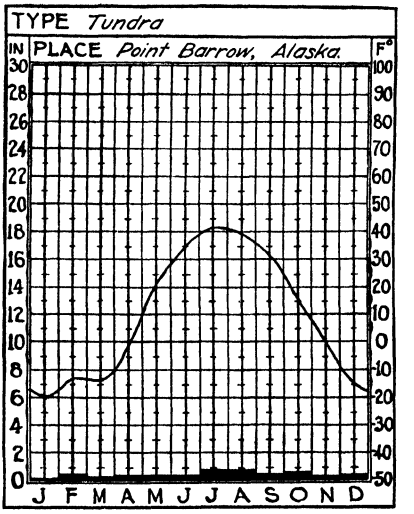


FIG. 113.—Average monthly temperatures and precipitation for a representative tundra station.

The reindeer, or caribou, is to the arctic tundra what the camel is to the tropical desert. These animals, together with the musk ox, feed upon certain forms of native vegetation which consists of mosses, lichens, sedges, and in some localities flowering and bushy plants, together with stunted birches, willow, and aspen. For the arctic peoples, the reindeer provides food, cloth-

ing, transportation, and shelter. The herds, sometimes numbering several hundred, are migratory, covering extensive areas in their search for food. Eskimos, who inhabit the coasts of tundra lands and who live mainly upon sea foods, are being taught to tend reindeer herds in parts of Alaska. Some of the reindeer meat is exported to Pacific Coast ports of the United States.

Ice-cap Climate

General Features and Location. This is the least known of the world's climatic types. It is found over the permanent continental ice sheets of Antarctica and Greenland and over the frozen ocean in the vicinity of the North Pole. Only limited climatic data are available from these deserts of snow and ice where the average temperature of no month is above 32°. The average temperature of an entire year in the tropical rainforest is 75° to 80°, but that of the interior of the Greenland ice cap is estimated at −25° and at the South Pole probably colder. December and January, two of the warmest months at the South Pole, have been found to have averages of about −10°.

Precipitation is meager and almost entirely in the form of snow, much of which consists of dry, sandlike particles. Expeditions of Admiral Richard E. Byrd into the antarctic have shown that this region has the coldest warm season on earth. Especially toward the edges of Antarctica, severe blizzards with winds having velocities of 50 to 75 miles per hour are features of the climate that mean death to any man or animal not adequately protected.

Mountain Climates

General Features and Location. Almost endless varieties of local climates exist within a mountain mass. Atmospheric conditions differ with altitude and exposure and, of course, with latitude. It cannot be said that there is a definite mountain type of climate.

A notable characteristic of high-altitude climate is the intensity of insolation. This is largely due to the cleaner, drier, and thinner air. The great relative intensity of the sun's rays

attracts the attention of nearly all persons going to high elevations. Insolation is not only more intense, but it is also richer in the shorter wave lengths of energy, the violet and ultraviolet rays. One therefore burns and tans quickly in the mountains. Because of the brilliant sunshine and pure air, many sanitariums are established at high elevations. Temperature decreases with altitude on the average about 3° per 1,000 feet. Climatically, this decrease is of great importance in tropical lands. Quito, Ecuador, on the equator, at an elevation of 9,350 feet, has an average annual temperature of 54°, which is 25° lower than that of the adjacent Amazon lowland. Mexico City, with an elevation of 7,400 feet and situated about 4° south of the Tropic of Cancer, has an average January temperature of 54° and a July average of 62°. White people in the tropics seek high elevations where cool and uniform temperatures are to be found. Mountain climate is similar to that of the California coast in this respect—in the sun, one feels warm; in the shade, cool. During the day, owing to convection, a warm wind blows up a mountain valley; at night, a cool wind descends from higher elevations. Cool evening breezes and low humidity are the principal climatic assets of the many summer resorts of the Colorado Rockies.

Winds that ascend mountain slopes are cooled by expansion. Condensation of water vapor results in the formation, especially during midday, of huge cumulus and cumulo-nimbus clouds. Precipitation in the mountains of arid lands creates "islands" of vegetation. Where a mountain system lies at right angles to the prevailing wind, the windward slopes are likely to receive frequent rains. Opposite the wet side is the rain shadow. The abundant precipitation in mountains is of much importance. It furnishes a source of water for springs, rivers, irrigation, and artesian wells. It is responsible for the existence of many excellent forests and grazing lands. Occasionally, terrific downpours may result in floods. Glaciers and snow, especially in the Alps, are scenic attractions of many summer resorts.

Summary

In this chapter and the preceding one we have learned that there are many types of climate on the earth's surface. These climates may be classified as follows:

The low-latitude, or tropical, climates are of three types:

1. Tropical rainforest:
    a. Windward coasts.
    b. Monsoon variety.
2. Tropical savanna.
3. Low-latitude dry climate:
    a. Deserts.
    b. Steppes.

The climates of the middle latitudes, or intermediate zones, are also of three types:

1. Middle-latitude dry climates:
    a. Deserts.
    b. Steppes.
2. Warm, humid climates:
    a. Mediterranean.
    b. Wet subtropical.
    c. Marine west coasts.
3. Cold, humid climates:
    a. Humid continental (long summer and short summer).
    b. Subarctic.

The high latitudes, or polar caps, are the regions where the two types of polar climates prevail:

1. Tundra.
2. Ice cap.

Our study so far has been concerned mainly with the atmosphere—temperature, pressure, wind belts, precipitation, storms, and climate. Precipitation causes rivers to form. Abundant snowfall, especially in mountains, may cause glaciers to form. Rivers and glaciers, together with wind-blown sand, carve many of the features of the earth's surface. Our study, therefore, shifts now to the solid earth's crust, or lithosphere, and considers, first, its composition and, second, how its surface features are made.

Questions

Mediterranean climate

1. What are the three principal features of this climate?
2. Regions in this climate are alternately influenced by what wind belts?

3. Name the five major regions having this climate.

4. Contrast the temperatures of San Francisco and Red Bluff. Explain.

5. Why is this climate famed for its winter weather?

6. What is the outstanding characteristic of the Mediterranean type of rainfall?

7. Why is rainfall heavier at San Francisco than at San Diego?

8. Why are thunderstorms rare in southern California?

9. When are grains harvested in regions of Mediterranean climate?

10. Explain the cause and effects of a sirocco.

11. Describe the vegetation typical of this climate. What is chaparral?

12. Where is the cork oak found? Why does this tree produce a thick bark?

13. Why has fruit drying become an important industry in the vicinity of Fresno, Calif.?

HUMID SUBTROPICAL CLIMATE

14. In what three respects does this climate differ from Mediterranean climate?

15. Why does the size of a continent influence the monsoon tendency?

16. Locate the three larger regions having humid subtropical climate.

17. What is the average length of the growing season in regions having this climate?

18. Compare "sensible" temperatures in Florida and California.

19. Why are cold waves more severe in the Gulf states than in southeastern China?

20. Where do hurricanes and typhoons occur? When?

21. Contrast summer and winter rainfall.

22. Why is the humid subtropical climate the most productive climate of middle latitudes?

23. Discuss native vegetation in this type of climate.

24. What agricultural crops are produced in this climate?

MARINE WEST-COAST CLIMATE

25. Why are marine climates located on west coasts? At what latitudes?

26. Locate the principal world regions having marine climate.

27. Why does this climate penetrate farther inland in Europe than in North America?

28. Discuss summer and winter temperatures. How long is the growing season?

29. What are the two outstanding characteristics of marine rainfall?

30. Contrast snowfalls in western Europe and the Cascades.

31. What is the nature of rainfall?

32. How do these regions rank in cloudiness?

33. Where are the finest forests in the United States? What trees predominate?

34. Why are some regions in this climate noted for livestock production?

HUMID CONTINENTAL CLIMATE

35. Name and locate the world regions having this climate.

36. Why is the annual range of temperature large?

37. Summer maximum in rainfall is due to what three causes?

38. Why is maximum summer rainfall of great economic importance?

39. What is the value of snow on winter wheat land?

40. Why are weather changes rapid and irregular? Why more so in winter?

41. Where is snowfall heavier, in Kansas or in New England? Why?

42. Discuss the blizzard. The cold wave.

43. What causes a hot wave? A drought?

44. Why is spring a season of fickle weather? What is Indian Summer?

45. Name the states in the long-summer subtype. What cereal is typical of this climate? What trees? What is the chief objection to the summer climate?

46. What regions have the short-summer type of climate? What cereal is important in some of those areas?

47. In the short-summer subtype, what is the length of the growing season?

48. In what respect are cool summers of northern Minnesota and Wisconsin an asset?

49. What cereals are produced in humid continental climate?

50. What are deciduous trees? Conifers? Name several species of each. Where are they found in humid continental climate? Which are hardwood?

SUBARCTIC CLIMATE

51. In what two ways is the poleward boundary determined?

52. Why is the July average at Yakutsk more than that of San Francisco?

53. How many possible hours of sunlight are there at the time of summer solstice at 55°N.? 65°N.?

54. What is the lowest temperature ever recorded at Verkhoyansk?

55. Discuss the forests and soils of this climate.

TUNDRA CLIMATE

56. Locate the principal tundra regions.

57. Describe the climate and vegetation of the tundra.

58. In what ways is the reindeer of value to the inhabitants of these regions?

ICE-CAP CLIMATE

59. Where are the two principal regions having this climate? Describe the temperature conditions.

MOUNTAIN CLIMATE

60. What are two characteristics of insolation in mountains?

61. Why are many cities located at high elevations in the tropics? Give examples.

62. What are the two principal climatic assets of the Colorado Rockies?

63. What type of clouds is common in summer in many mountains? At what time of day? Why? What is the rain shadow? Give an example.

64. In what ways is the abundant precipitation in mountains of much importance?

Suggested Activities

1. Study three maps of the world, one showing annual rainfall, another the types of climate, and a third the density of population. Suggest as many relationships as possible, learned from the study of these three maps.

2. Chicago and Rome are in about the same latitude. Contrast the climates of the two cities.

3. On a large wall outline map of North America, color the climatic regions. Paste or pin labels on the map showing economic products of the different regions.

4. Outline on a map the spring- and winter-wheat regions of North America. Contrast the two regions climatically.

5. Compare the climate of Fairbanks, Alaska, with that of Bergen, Norway. They are not greatly different in latitude.

6. Choose a definite location in the regions discussed in this chapter, and write a short paper on why you would prefer to live in that particular place.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Economic Products of Mediterranean Countries
2. Climatic Contrasts within the State of California
3. Florida versus California as a Winter Resort State
4. Citrus-fruit Production in the Gulf States
5. The Climate of India
6. Great Deserts of the World
7. A Comparison of the Climates of Seattle and New York
8. The Pacific Coast Forests of the United States
9. The Climate of Spring- and Winter-wheat Regions

REFERENCES

KENDREW, W. G.: *Climate*, Oxford University Press, New York, 1938.

KOEPPE, CLARENCE: *Weather and Climate*, McKnight and McKnight, Bloomington, Ill., 1939.

RIDGLEY, D. C., and S. E. EKBLAW: *Influence of Geography on Our Economic Life*, Gregg Publishing Company, New York, 1938.

Chapter VIII. Composition and Changes of the Earth's Crust

Walk out into any stretch of open country. What do you see? Rocks, soils, hills, valleys, rivers, lakes, seas, plains, mountains, plateaus. These features, in endless combinations, help to distinguish the regions of the earth quite as much as do the factors of climate discussed in preceding chapters. What features distinguish your own locality?

In our study of the earth's crust, or *lithosphere*, we shall consider

1. The materials of which it is composed.
2. The general nature of the agents, forces, and processes that are concerned in changing the earth's crust.
3. The characteristics of various surface features or landforms that make it possible for us to recognize them.

Earth Materials

Important Earth Elements. The earth's crust is composed mainly of rocks. A *rock* is a group of two or more minerals, although some rocks consist almost entirely of one mineral. Minerals are combinations of chemical elements.[1] Of the 93 known chemical elements, many are very rare. Of the more abundant elements, *oxygen* is most important. In combination with other elements it comprises about 46 per cent of the known crust of the earth. *Silicon* is next in importance. In its combination with oxygen (SiO_2) it forms quartz which, when broken into fine particles, makes sand. In many combinations with various elements, silicon comprises nearly 28 per cent of the lithosphere. Six other elements together make up 24 per cent of the total. They are, in the order of their abundance, aluminum,

[1] A list of chemical elements and their symbols is given in Appendix H.

iron, calcium, potassium, sodium, and magnesium. The remaining 2 per cent of the lithosphere includes a long list of elements, some of which are of great importance in human affairs but exist in very small quantities. Among these are radium, platinum, gold, silver, and various precious minerals, such as the diamond.

Minerals. A *mineral* is an inorganic substance found in nature, having a definite chemical composition and sometimes a

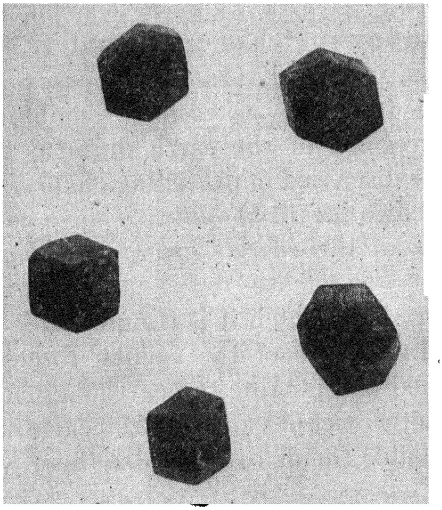


FIG. 114.—Minerals sometimes crystallize into definite forms. The crystalline form is often used in identifying the mineral. Pictured here are several crystals of garnet. This mineral is deep red in color and has a glassy appearance. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

crystalline form (Fig. 114). Some minerals consist of one element, such as pure gold or copper. Iron, in combination with oxygen and water, forms a yellow-brown mineral called *limonite*, commonly known as *iron rust*. The list of known minerals numbers several hundred. Of them, quartz is the most abundant (Fig. 115).

Rocks. Most rocks are composed of mineral crystals, each mineral retaining its own characteristics.[1] Since there are hundreds of minerals that can be locked together in many different combinations, it is obvious that numerous kinds of rocks must exist in the earth's crust. Just as some chemical elements and

[1] A more detailed treatment of rocks and minerals is given in Appendix F.

some minerals are more abundant than others, so it is with rocks. Using principally the method of formation as a basis,

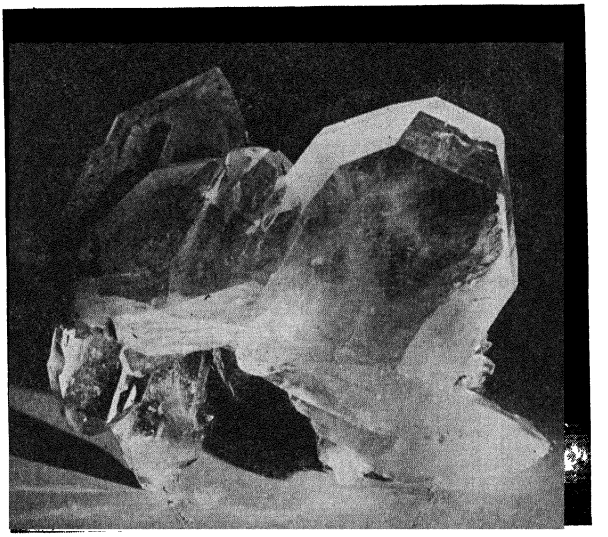


FIG. 115.—Quartz is one of the most abundant minerals. It exists in many forms. Sand consists of quartz grains. Crystalline quartz, shown in this picture, is hexagonal. Many excellent specimens of crystalline quartz come from a region near Hot Springs, Ark. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

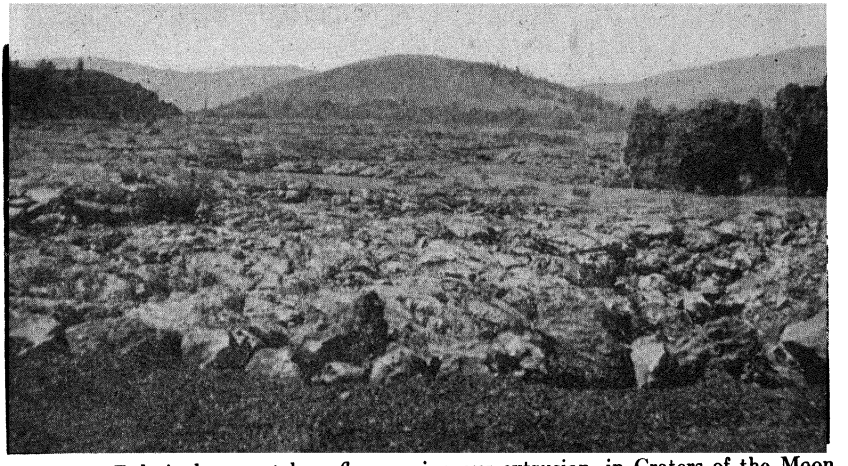


FIG. 116.—Relatively recent lava flow, or igneous extrusion, in Craters of the Moon National Monument, southern Idaho. (*Photograph by Della Junkin.*)

rocks are divided into three general classes. These are called (1) igneous, (2) sedimentary, and (3) metamorphic.

Igneous Rocks. Igneous rocks are those which have been solidified from a molten state. Lava pours forth from a volcano and cools, forming solid rock on the earth's surface. Such are called *extrusive* igneous rocks (Fig. 116). Deep in the earth, molten rock may fill a crevice or cavity. When it cools, the

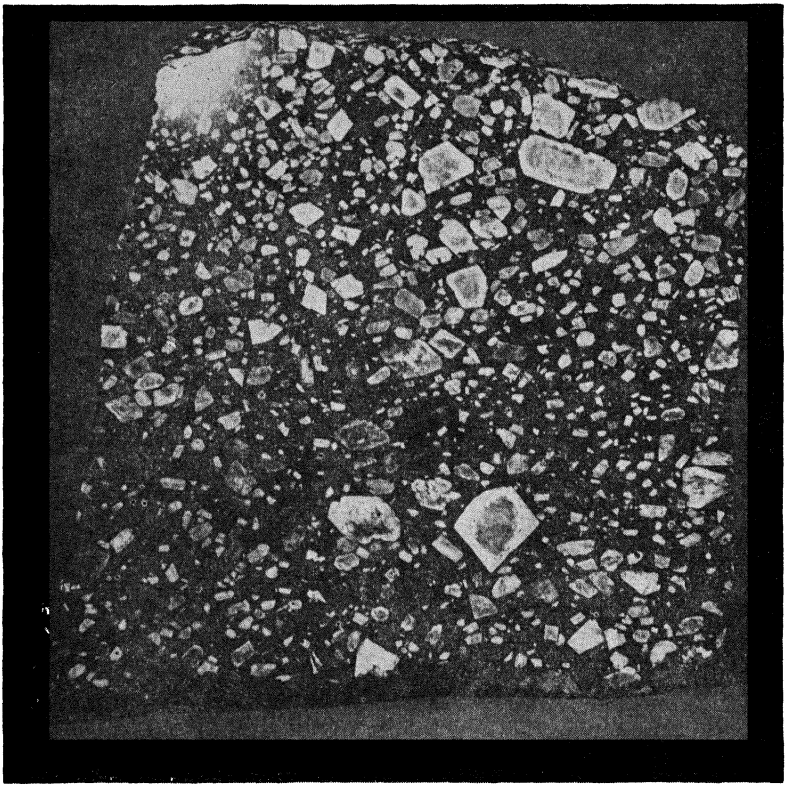


FIG. 117.—Some rocks are composed of many mineral crystals imbedded in some kind of ground mass. The rock shown here, called a *porphyry*, is igneous and illustrates such a formation. In some specimens of granite, the minerals quartz, mica, and feldspar can be easily recognized. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

igneous rock formed is called *intrusive*. As the earth's surface is eroded away, these intrusive rocks come to light. Extrusive rocks cool quickly, allowing little time for crystals of minerals to form. They are, therefore, known as *fine-grained crystalline* rocks. In some cases no crystals form at all, and the resulting material is volcanic glass, or *obsidian*. Deeply buried intrusive rocks, on the other hand, may not become entirely cooled for

hundreds of years. In that lapse of time the various chemical elements of like kind combine to form distinct and often large mineral crystals (Fig. 117). Such are called *coarse-grained crystalline* rocks. A good example is granite (Fig. 118), in some specimens of which it is easy to see three different minerals.

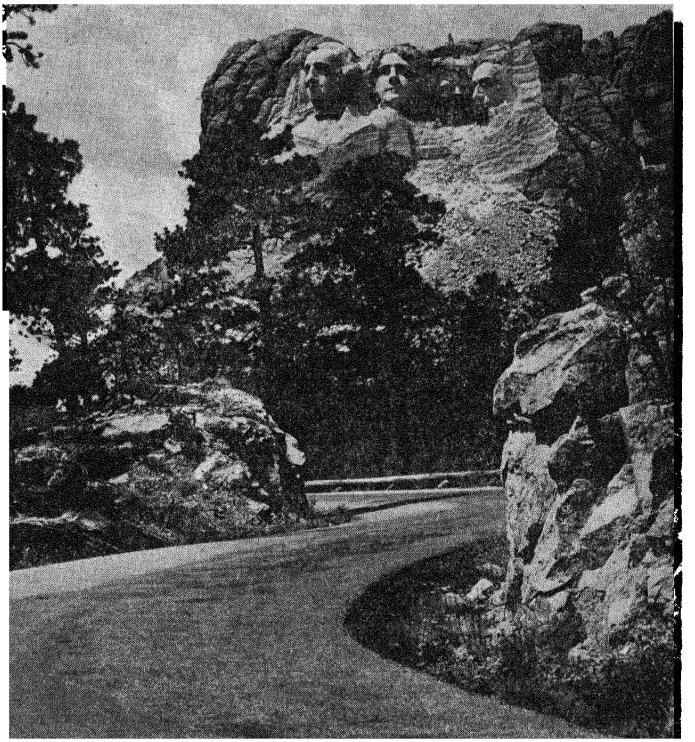


FIG. 118.—The Mt. Rushmore National Monument is carved in the resistant granite of the Black Hills of South Dakota. Numerous joint planes show in the uncarved rock. These 60-foot likenesses of George Washington, Thomas Jefferson, Theodore Roosevelt, and Abraham Lincoln will be destroyed by weathering over a period of hundreds of years. (*Courtesy of Bell Studio.*)

Sedimentary Rocks. Sedimentary rocks are composed of sediments which collect mainly at the bottoms of large bodies of water. Many materials are carried to the sea by rivers. Some, such as salt and lime, are carried in *solution*. Others, such as fine clay and sand, are carried in *suspension* and cause river water to appear very muddy. Upon reaching the sea, these sediments are deposited on the sea floor. The processes and condi-

tions of deposition appear to have been interrupted many times, so that different materials were laid down at different times. The sediments usually appear in distinct layers, or *strata*, and for that reason sedimentary rocks often are called *stratified* rocks (Fig. 119). Most stratified rocks are deposited in a horizontal position, or nearly so. When they are observed in positions greatly inclined from the horizontal, it is an indication that there has been a disturbance of the strata after their deposition.

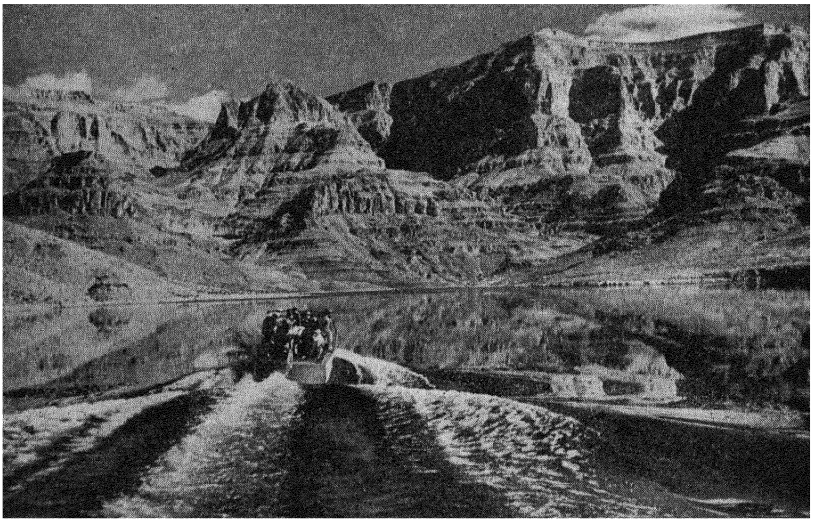


FIG. 119.—Layers, or strata, of sedimentary rock can be seen close to Lake Mead. This immense lake, which has been formed by Boulder Dam, is located in the Black Canyon of the Colorado River on the boundary line between Arizona and Nevada. (*Courtesy of Transcontinental and Western Air, Inc.*)

Kinds of Sedimentary Rocks. The most important sedimentary rocks are (1) *sandstone*, (2) *shale*, and (3) *limestone* (Fig. 120). The distinction between them is not always sharp. Mixing of sediments may produce a sandy limestone, a limy shale, or other combination.

Sandstone is composed mainly of sand particles cemented together. Coarse sand forms a coarse-grained sandstone, which, if poorly cemented, is easily broken. Fine sand, if firmly cemented, may form a fine-grained sandstone valuable as a building stone. At times the sand layers may be colored with lime, and at others with red or yellow iron oxide. The result is

colored sandstones or those having a banded appearance. Many sandstones are very resistant to the processes of rock wear and form protruding features on the earth's surface. Economically, sandstone is valuable as a building stone. Also, it is a *porous* rock, or one through which water can seep. Thus layers of this rock supply the source of water for many deep wells which provide water for farms and towns.

Shale is formed when sediment consists of clay and mud. The dominant color is gray, although shades of red, green, and purple often are observed. Since shale is composed of such fine material, it is an extremely fine-grained rock, so fine that it strongly resists the seepage of water. For that reason it is called an *impervious* rock, although it seldom is hard. If shale underlies sandstone, water will seep through the sandstone along the top surface of the shale. On the other hand, shale is more easily weathered and washed away by running water or rain than is either sandstone or limestone. Soil resulting from the weathering of shale is usually of a heavy clay nature. This rock splits into thin layers, is easily scratched with a knife, and when moistened has a distinct clay odor.

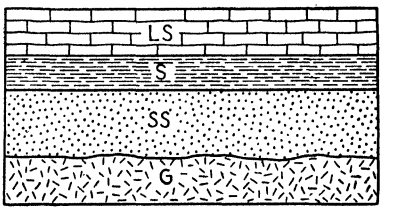


FIG. 120.—Conventional symbols for different rocks: *LS*, limestone; *S*, shale; *SS*, sandstone; *G*, granite or other igneous rock. Which of the sedimentary rocks is impervious? Which, porous?

Limestone is formed by the compacting of limy deposits or the shells of small marine animals. In some places are found thick deposits of nearly pure limestone (calcium carbonate). More commonly they contain admixtures of other materials, especially sand, clay, and limonite. Sometimes bodies composed mainly of quartz are found in limestones and are recognized as bands or masses of *chert* or *flint* (Fig. 121). Some limestones are compact and hard; others, soft and porous. The latter are called *chalk*. Unlike most rocks, limestones are readily soluble in ground water. Long-continued solution may cause the development of interior cavities or even great caverns such as Mammoth Cave of Kentucky and the Carlsbad Caverns of southeastern New Mexico. Limestone can be recognized by (1) the color.

usually ranging from buff or light gray to white; (2) effervescence, or bubbling, in acid; and (3) fossils of small marine animals, which ordinarily are more numerous than in shale or sandstone.

Limestone is a most abundant and valuable rock. It is mixed with shale, heated and pulverized or powdered to form the all-important Portland cement. Limestone alone when heated loses carbon dioxide, and the remaining material is commercial *lime*, or calcium oxide, a substance having many uses. Limestone

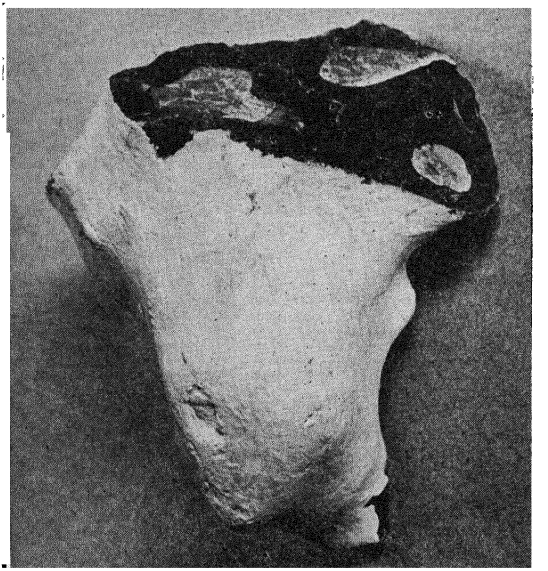


FIG. 121.—A dark, gray-black flint covered with a coating of soft, white mineral matter. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

is crushed to the size of fine gravel and is used in building roads. It is used also in the smelting of iron ore, a process by which iron is separated from other materials in the ore. In many places limestone is employed as a building stone. Two notable American regions of building limestone are worthy of mention. The one located at Bedford, Ind., has supplied gray stone for hundreds of large buildings in American cities. The other, at Carthage, Mo., markets a fine limestone which approaches marble in texture. Many of the great buildings in London are made of limestone obtained from the Isle of Portland on the south coast of England.

Not all sedimentary rocks were deposited in seas or oceans. Some were formed in shallow, coastal bays or marshes. The accumulation of vegetation in swamps ultimately resulted in the formation of a sedimentary rock called *coal.* Other organic deposits, containing considerable iron, formed bog iron ore or limonite and other iron formations. Still others are believed to have resulted from deposits in the evaporating waters of interior

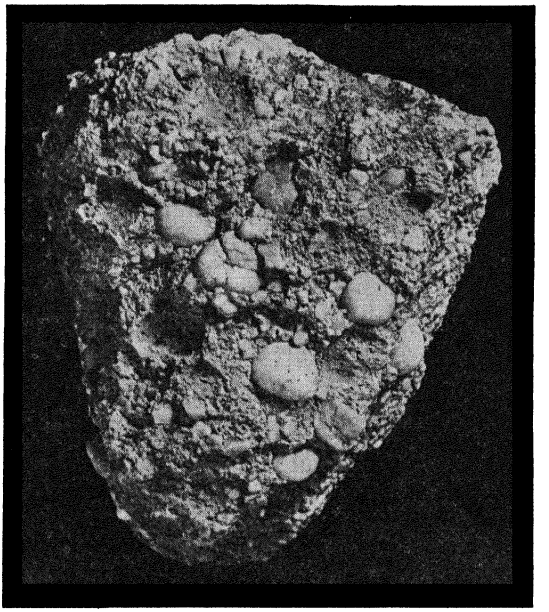


FIG. 122.—Conglomerate is a sedimentary rock. In this specimen many individual pebbles are clearly visible. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

basins or coastal swamps in arid climates. Such are *rock salt* and *gypsum.*

Conglomerate is a sedimentary rock composed of rounded pebbles cemented together (Fig. 122). It resembles man-made concrete.

Metamorphic Rocks. Metamorphose means to "change form." Metamorphic rocks are derived from rocks of any other sort by processes of change. The most common causes of change are pressure, heat, and the cementing action of underground waters. Great pressure and heat may be produced in two ways:

(1) by the warping and bending of great layers of rocks and (2) by the introduction of molten lavas into older rocks. At times, both processes may take place together. Other rocks are changed by the extremely slow process of alteration or replacement of minerals by underground water. Metamorphism in some rocks has involved a change so great as to produce minerals not present in the parent rock.

Both igneous and sedimentary rocks may be metamorphosed into rocks of different kinds. Under the influence of pressure and heat, the minerals of granite arrange themselves in rough bands, forming *gneiss* (pronounced *nice*). Thus the layers of mica, quartz, and feldspar may be plainly visible. Sandstone changes to a more compact, hard rock called *quartzite*, which is sometimes misnamed granite. Shale becomes harder, splits into thin layers, and is familiar as black *slate*, quarried especially in Pennsylvania and Vermont. It is used as roofing, as blackboards in schoolrooms, and as the "floor" in billiard tables. A pure limestone becomes somewhat harder, sometimes takes on a translucent or waxy appearance, and is called *marble*. When polished, this is a most beautiful stone and is used for ornamental building purposes. Important marble quarries are located in Vermont, Georgia, and Tennessee. Metamorphosed bituminous coal becomes *anthracite*. The outstanding region producing pure anthracite coal is located in northeastern Pennsylvania. If the metamorphosis of coal is carried far enough, the resulting material may be *graphite*, which is pure carbon. Graphite when mixed with certain amounts of clay forms the "lead" of lead pencils.

In several parts of the earth are vast areas of rocks of great age. Some, doubtless, were igneous; others, sedimentary. Whatever their original nature, they have been subjected, during the long progress of geological time, to processes of change. In some regions these processes have been repeated on a vast scale more than once. As a result, the rocks generally are metamorphosed to a high degree. Regions of that kind are sometimes broadly characterized as "areas of ancient crystalline rocks."

Rock and Mantle Rock. Over most of the land surface of the earth the solid rock of the earth's crust is buried beneath a covering layer, thin or thick, of broken-up and decomposed rock

fragments. This material is named *mantle rock*, or *regolith*, the upper part of which includes the soil. Not everywhere is the mantle rock sufficiently thick to cover the underlying rock. On many steep slopes, and in some regions over large areas generally, the bare and solid rock may be seen. These exposures of solid bedrock are called *outcrops*. Through the nature and attitude of the rocks displayed in widely scattered outcrops, geologists are able to form intelligent opinions as to the kind, distribution, and extent of the rocks buried beneath the mantle rock.

Bedrock of the United States. The importance of the kind of bedrock is shown by its influence on (1) the relief features of the earth's surface, (2) the kind of soils that overlie certain rocks, and (3) the occurrence of natural resources, such as deposits of valuable ores. Maps showing underlying bedrock often are very complex. However, a few general statements can be made about the distribution of the principal kinds of rock in the United States. Some parts of New England and the Appalachian Mountains are formed of ancient crystalline rocks; others, of stratified rocks. The vast interior lowlands from the Appalachians to the Rockies are for the most part underlain by sedimentary rocks. The Rocky Mountains are composed of mixed types, granite and gneiss forming extensive areas. The Colorado Plateau consists mainly of sedimentary rocks, and the Columbia Plateau and the Cascade and Sierra Nevada Mountains are largely igneous (Fig. 370).

Forces That Mold the Earth's Surface

Principal Landforms. The major subdivisions of the earth from the standpoint of relief or inequality of surface elevation are the great depressions which contain the *oceans* and the broad elevations which are the *continents*. Upon the continents there are many features of a smaller order of size with which people have daily and intimate concern. These are the high *mountain* masses, the broad *plateaus*, rough *hill* regions, and extended *plains*. Of a still smaller size are numerous low hills interrupted by many valleys.

What Causes Landforms? Landforms are made by forces that act upon the earth's surface through longer or shorter periods of time. Some of the forces may be described as earth

forces, some as climatic, and still others are produced by plants and animals. They accomplish their various kinds of work by means of processes that will be considered later. Forces and processes of different kinds, acting upon rocks of varying hardness, produce the interesting features of the land surface. So remarkable are these features in certain localities that they are set aside as national parks.

Landform Changes Involve Great Lengths of Time. As we study landforms and the processes by means of which they have been made, we must adopt a different conception of time from that employed in considering the events of human history. Although some of the processes of nature are sudden and violent, accomplishing notable results in a short space of time, such are the exception rather than the rule. Most of the landforms have been produced by the slow and long-continued operation of forces and processes still at work. The earth-changing forces produce little effect in the span of human life. Instead, they require thousands of years.

It is estimated by earth scientists that the age of the earth exceeds $1\frac{1}{2}$ billions (1,500,000,000) of years. Of this vast length of time the record of the first two-thirds is so ancient that it is vague and nearly lost. More is known of the last third of earth history, which is about 500 million years. But even that time is so long that it makes the many years of human history seem but a moment by comparison. In the study of earth history, the fossils of plants and animals are of much importance. These fossils have been preserved in the sedimentary rocks. They are the principal means by which the relative ages of different rocks in the later third of earth history are determined.

Forces Responsible for the Surface Molding of the Earth. The various forces involved in the production and alteration of landforms may be grouped into (1) *tectonic*, those which originate within the earth, and (2) *gradational*, those which originate without or beyond the earth.

Tectonic forces derive their energy mainly from changes occurring in the earth's interior. These changes are caused by (1) heating, (2) expansion or contraction, and (3) the moving of liquid material from one place to another. These tectonic forces are subdivided into two general groups.

1. *Diastrophism*—the warping, folding, or bending and breaking of the earth's crust.

2. *Volcanism*—the action of volcanoes in the movement or expulsion of molten rock from the interior.

The tendency of the tectonic forces and their processes is to produce differences in elevation on the earth's surface. In some places rock layers are bent up; in others, down. Molten rock may pour from an opening in the earth's crust, greatly increasing the elevation of the land in that locality.

Gradational forces operate largely through the work of agents such as wind, running water, moving snow and ice, and living organisms. The tendency of these forces is to level the earth's surface by reducing land to uniform slopes or grades. The processes of gradation are subdivided into

1. *Degradation*—those processes which operate to wear away or reduce land elevations to the final level, or grade.

2. *Aggradation*—those which tend to fill the sea margins and depressions of various kinds and thus to build them up.

Degradation involves rock decay and the transportation of rock materials from higher to lower elevations. Aggradation is the deposition of sediment in low places.

The two great groups of forces, tectonic, on the one hand, and gradational, on the other, are at work continuously and, therefore, are in endless conflict. The one causes earth features having differences in elevation; the other tends to reduce them to low and uniform plain. The hills, valleys, and other relief features that now exist are the present, but temporary, expression of the state of this perpetual battle.

Diastrophism: A Tectonic Process

Breaking of Surface Rocks. It is well known that any rock, under sufficient strain, will break. Terrific strains are placed on the outer shell of the earth by the expansion or shrinkage of the earth as a whole. Strains also are produced by the removal of molten rock or surface sediments from place to place. As a result, surface rocks everywhere are characterized by many cracks, called *joints* (Fig. 123). These are so numerous that the hard ex-

terior of the earth must resemble the cracked glaze on a piece of antique china. However, the joints become smaller and fewer with depth and below a dozen miles or so are believed not to exist. This cracked surface zone is called the *zone of fracture.* The joints permit the water of the ground to circulate more freely within the rocks and enable the agents of gradation to work more readily.

Sometimes rocks not only break but also actually move along the plane of breakage. The change in position of rock layers due to such breaking and slipping is called a *fault* (Fig. 124). The

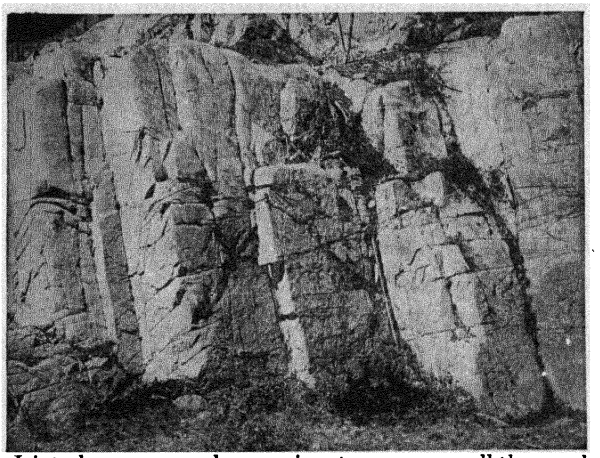


FIG. 123.—Joint planes commonly occur in sets, or groups, all the members of which trend in the same direction. The sets may be vertical, inclined, or horizontal. (*Courtesy of U.S. Geological Survey.*)

motion that produces the dislocation often is sudden but usually is limited in amount to fractions of an inch or a few feet. If the displacement is vertical, the rocks on one side may be elevated enough to produce a cliff which is called a *fault scarp.* The rock movement, however, may be horizontal as well as vertical.

When many successive faults occur along the same plane at intervals during thousands of years, the resulting fault scarp may attain the size of hills or even mountains. Most of the basin ranges in Nevada are a result of faulting where great masses of rock have been uptilted. The towering east face of the Sierra Nevada Mountains in California is a huge fault scarp, and so is the Lewis Range in Montana, in Glacier National Park. These giant displacements required a tremendous length of time during

which the agents of degradation carved the highest segments into mountain peaks.

In a few places in the world, parallel faults of great length have permitted the blocks of earth between them to drop (Fig. 125). These become broad valleys, flanked on either side by fault scarps, and are known as *rift valleys*, or *graben*, from the German word meaning "trough." Of this origin are such famous valleys as the Lowlands of Scotland, the upper Rhine Valley, the depression in which the Dead Sea lies, and those vast trenches in East Africa which are occupied in part by Lakes Tanganyika and Nyassa. In some places the land between parallel faults has been uplifted. The result is the formation of a blocklike mountain uplift called a *horst*.

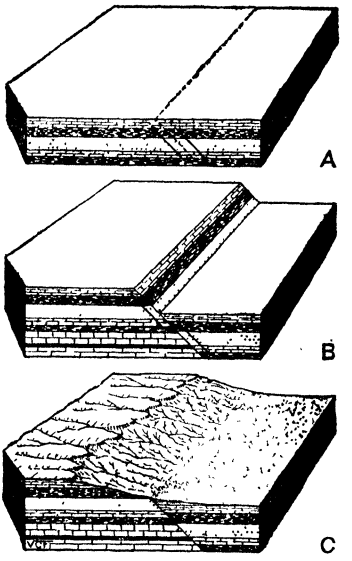


FIG. 124.—This diagram shows the development of a fault in sedimentary rock: *A*, the strata before faulting; *B*, fault, showing direction of displacement and the fault scarp; *C*, the reduction of the fault scarp by erosion to a dissected fault-line scarp.

Folding or Bending of Surface Rocks. Just as a board warps and bends, so does the earth's surface. The close bending of rock layers is called *folding* (Fig. 126). The folds may be very small or large enough to form mountains. They may be simple or complex. In some mountain regions, sedimentary rock strata have been under such enormous pressure that they have been

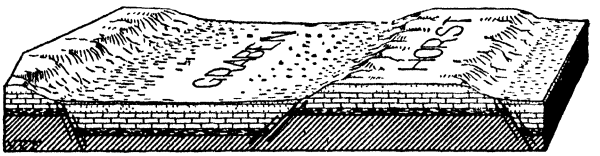


FIG. 125.—Block faulting and the formation of a graben and a horst are illustrated in this diagram. The arrows indicate direction of relative displacement.

pushed up into a series of wavelike folds. The arch, or crest, of one of these folds is called an *anticline*, and the trough of the wave a *syncline* (Figs. 127, 128). In the Alps and some other

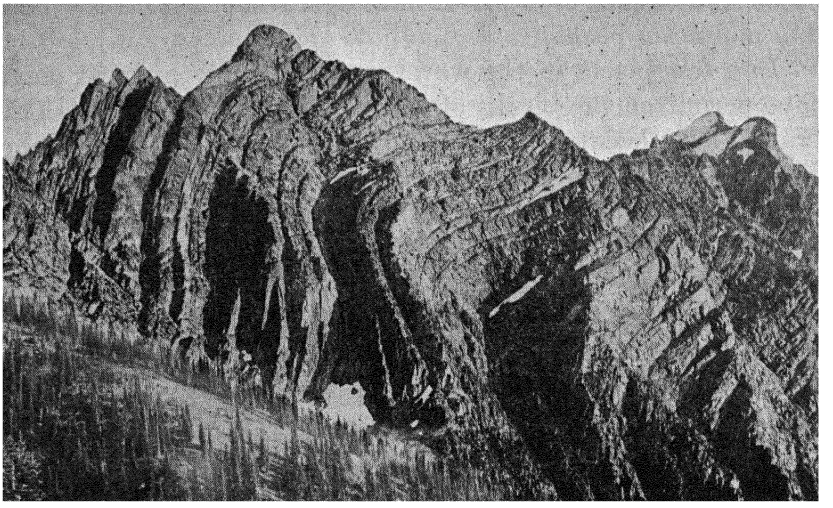


FIG. 126.—An example of the folding or bending of rock strata, Glacier National Park. (*Courtesy of U.S. Geological Survey.*)



FIG. 127.—Synclinal and anticlinal mountains. The complicated folds and faults of some mountains have been studied, and from the eroded remnants that make up the present mountains great structures have been projected. These probably never existed, because they were eroded as they were formed.

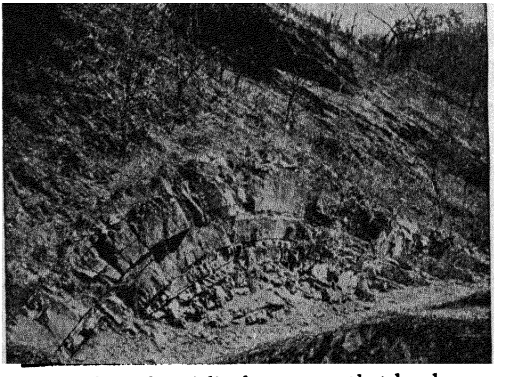


FIG. 128.—A portion of a buried anticlinal structure that has been exposed in a stream valley. (*Courtesy of U.S. Geological Survey.*)

mountains, the upward bends have been closed and tipped over. Such mountain formations are further complicated by faulting and in some cases the intrusion of molten rocks. Seldom do anticlines and synclines appear as corresponding ridges and valleys, because the agents of degradation have greatly altered their general appearance.

Similar to folding in nature, less intense but no less important, are those broad bends in the earth's crust which may be called *warping*. Such changes in crustal shape probably are continuously in progress but require thousands of years to produce notable results. Through warping, broad areas of lowland, such as the North Sea Basin, have been lowered slowly a few feet or a few scores of feet and added to the shallow sea bottoms. By the same process, shallow sea bottoms have been elevated slowly and added to the areas of the continents. Most of the state of Florida is a relatively recent addition to the area of North America. This process accounts for the great areas of sedimentary rocks with their thousands of fossils of marine animals, now located far in the interior of the continents. There are evidences that some areas were alternately elevated above and depressed below sea level.

From the foregoing, it is evident that the positions and arrangements of the rocks are subject to the greatest variation. Sediments, put down horizontally, do not always remain so. Likewise, igneous rocks, long after their formation, are subject to bending and fracture. The position and arrangement of rock formations with respect to one another is called the *rock structure*. This structure often plays a most important part in the evolution of landforms.

The records of the rocks seem to indicate that all parts of the earth have been subjected to warping, folding, or faulting at one time or another. Perhaps that still is the case, but certainly these processes seem to be more vigorously active in certain regions, or zones, than in others. Most important of these are the borders of the Pacific Ocean. Offshore are several notable ocean deeps; onshore are systems of mountains, such as those of Japan, the Philippines, the Andes of South America, and the Coast Ranges of North America. The constant strain in the rocks between these deeps and mountains has resulted in numerous

faults, geologically recent. Other areas of diastrophism are (1) the region of the West Indies and (2) a long zone extending from Spain across southern Europe and Asia and through the East Indies.

Volcanism: A Tectonic Process

Volcanism is the term applied to all those processes by means of which molten rock is transferred from deep-seated sources to or toward the surface of the earth (Fig. 129). This molten rock is of considerable environmental significance, since it is the direct or indirect cause of several classes of landforms.

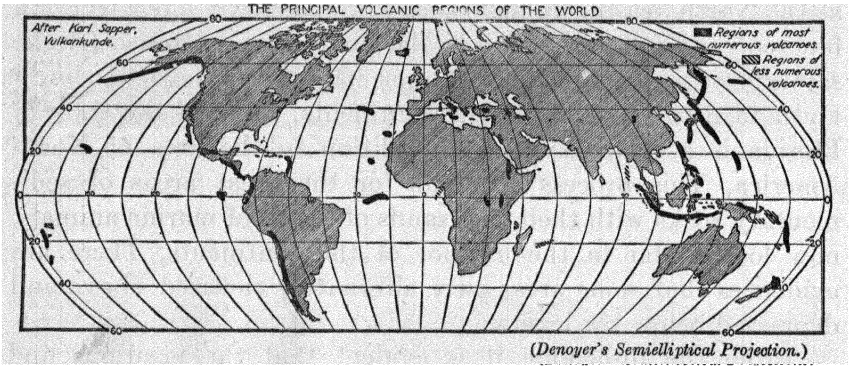


Fig. 129.

Volcanic Products. The principal product of volcanic extrusion is lava, or molten rock. Certain lavas are accompanied by poisonous gases and steam. In addition are various other products such as pumice stone, volcanic dust, ashes, cinders, and slag. A typical volcano is a cone-shaped mountain with an opening, or crater, at the top (Fig. 130). Minor eruptions in the vicinity of the main volcano may form a number of cinder cones. Following a volcanic outburst near the ocean, floating pumice stone sometimes covers the water.

Types of Volcanic Eruptions. Two main types of volcanic eruptions are recognized, although some eruptions are intermediate; *i.e.*, they seem to fall between the two main types.

Explosive Type. This type of volcano is the most violent and destructive. Explosions of pent-up gases, mainly steam, cause enormous quantities of gas and dust to be thrown into the air to form great clouds.

Krakatao, a volcano in the Strait of Sunda, near Java, became violently active in August, 1883, after a repose of two centuries. Following on the premonitory outrushes of gas, great explosions occurred, which blew into the air more than 4 cubic miles of dust, ash, and rock fragments. A vast dark cloud rose 17 miles into the atmosphere, by its density completely hiding the sun over an enormous area, and the finest part of the dust eventually attained a height of 30 miles and traveled around the world several times, causing brilliant red sunsets during three years after the eruption. The ejected material rained down on an area of 320,000 square miles. The noise of the

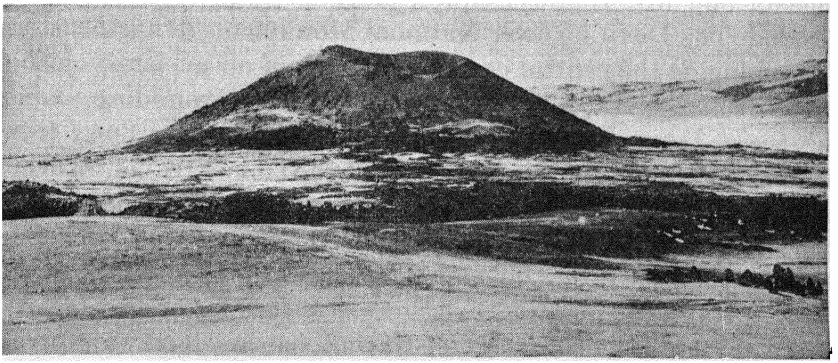


FIG. 130.—Mt. Capulin, an extinct volcano in northeastern New Mexico. This cone is of relatively recent origin and consists of volcanic cinders, or scoria. It rises about 1,500 feet above the surrounding plain and about 8,000 feet above sea level. From the top other small cones can be seen. Volcanic dust from the volcanoes of New Mexico is found in parts of Kansas. (*Courtesy of U.S. Geological Survey.*)

terrific detonations was heard as far as Australia, 1,750 miles distant; and the disturbance in the atmosphere was registered by barometers over the whole world. Huge waves, up to 100 feet above tide, were generated in the sea and rushed along the low-lying coasts of Java and Sumatra, sweeping far inland and destroying towns, villages, and the lives of 36,000 people; these waves were perceptible 3,000 to 4,000 miles away.[1]

Other explosive volcanoes may be mentioned. Mt. Pelée is located on the island of Martinique, northeast of Venezuela. In 1902 it completely destroyed the city of St. Pierre. Vesuvius, near Naples, Italy, which probably has been studied more than any other volcano in the world, has periods of activity. In A.D. 79 it destroyed the towns of Pompeii and Herculaneum.

[1] Longwell, C. R., A. Knopf, and R. F. Flint, *Physical Geology*, p. 254, John Wiley & Sons, Inc., New York, 1932.

On the Alaskan Peninsula and Aleutian Islands are many active volcanoes. In 1912 Katmai, a volcano in this region, gave vent to a most violent eruption. The great cone of Mt. Etna, on the eastern end of the island of Sicily, rises over 10,000 feet above the Mediterranean Sea and from time to time is subject to explosive eruptions. In Mexico, Central America, and the Andes are a number of volcanoes that occasionally become active. Many volcanoes of past centuries are now extinct, and their cones exist today as high, snow-covered peaks. Such are Mt. Shasta and Mt. Rainier. Other, older cones have been greatly eroded. The Devil's Tower National Monument, in northeastern Wyoming, is the central core, or "neck," of an ancient volcano, which rises several hundred feet above the surrounding plains.

Quiet Type. In this type of volcano, lava overflows from the crater and flows down the sides of the cone. Steam and other gases escape, but there is no violent explosion. Hawaiian volcanoes are noted as representatives of this type. The Hawaiian Islands themselves are volcanic mountains built up on the ocean floor, a result of enormous overflows of lava. Mauna Loa (13,700 feet), a volcano on the island of Hawaii, has received widespread attention because of its activity. On the same island is the crater of Kilauea with its lake of liquid and semiliquid lava. Lava that overflows from Mauna Loa is white-hot, having a temperature in excess of 1000°F. As it flows down the mountain side, the top surface cools and becomes dark in color. Occasionally the flows reach the Pacific, resulting in a tremendous hissing of steam as the molten rock comes in contact with the water.

Igneous Extrusions. In many places there are flows of solidified lava whose extent is to be measured in square miles or scores of square miles. In a few places, and at various times in earth history, there have issued lavas so liquid and so abundant that layer after layer, at intervals, has flooded and buried the original surface for many thousands of square miles. They give rise to great expanses of igneous rocks. The Columbia Plateau in Washington, Oregon, and Idaho is an example. Here successive lava flows, over a long period, covered a total area of more than 100,000 square miles to an average depth of half a mile. In the process, valleys were filled, hills were buried, and mountains left standing like islands in a nearly level sea of lava

plains. Among the other great lava flows of the world are those of the Deccan (peninsular India), Ethiopia (Abyssinia), and southern Brazil.

Igneous Intrusions. Molten rock, or *magma*, may be thrust into openings beneath the local, or country, rock in a great variety of forms. Sometimes the magma solidifies in a vertical crevice and forms a *dike* (Figs. 131, 132). When erosion later removes the less resistant rock adjacent, the dike may stand in bold, wall-like relief in the landscape or even form a considerable range of hills. Horizontal layers of intruded magma are called *sills*.

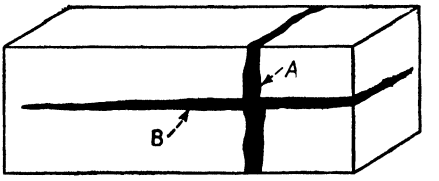


FIG. 131.—This drawing represents a block of rock with igneous intrusions. When the solidified lava forms a vertical wall as at *A*, it is called a *dike*. The horizontal layer shown at *B* is called a *sill*, or *sheet*.



FIG. 132.—An igneous dike that stands in relief because it is more resistant to erosion than the rocks on either side of it. (*Courtesy of U.S. Geological Survey.*)

At times the molten rock, coming from below, will spread out between layers of rock and slowly force the overlying layers to bend upward, forming a *laccolith* (Fig. 133). The upper layers of sedimentary rocks are in time eroded away, exposing the igneous dome. The Henry Mountains in southern Utah exhibit several stages in laccolith erosion. Many *buttes* are eroded laccoliths, an example being Bear Butte in the vicinity of the Black Hills, South Dakota (Figs. 134, 135). The igneous cores

of many mountain systems are the result of upheavals of molten rock. These great masses of magma, in a variety of forms,

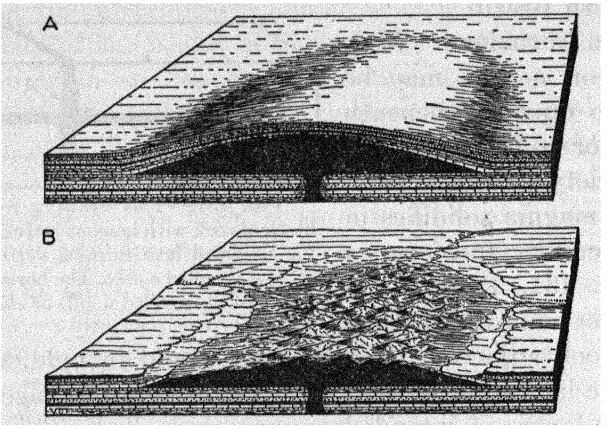


FIG. 133.—This diagram illustrates: *A*, the effects of the intrusion of a giant laccolithic mass into sedimentary rocks; *B*, features resulting from later erosion by streams.

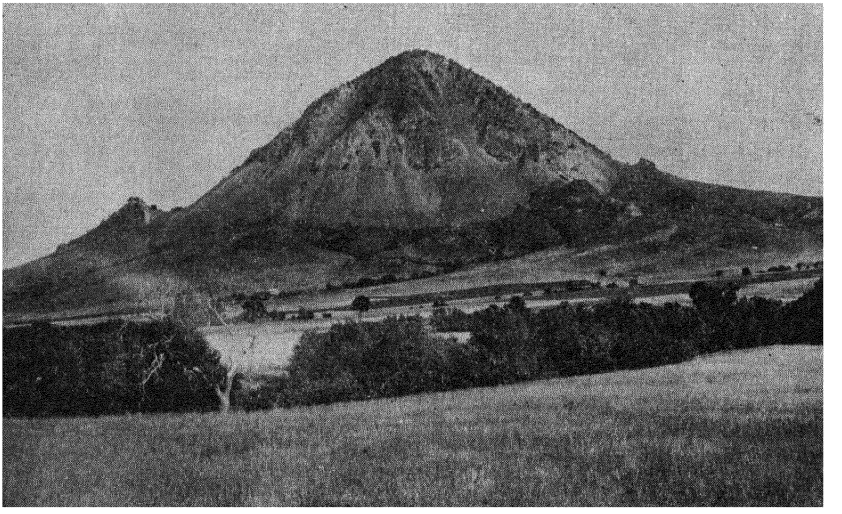


FIG. 134.—Bear Butte, east of the Black Hills in western South Dakota, rises about 1,400 feet above the surrounding plains. The center core is igneous rock. Accumulations of rock waste can be seen on the lower slopes. Such slopes as these are called *talus slopes*. Upturned edges of sedimentary rocks surround the base. (*Courtesy of U.S. Geological Survey.*)

dissolve, displace, or uplift the previously existing sedimentary or other rocks and metamorphose those which they touch. Water, seeping through the earth's crust, is heated when it comes

in contact with the magma and later may come to the surface as a hot spring. The chemical action (solution and deposition)

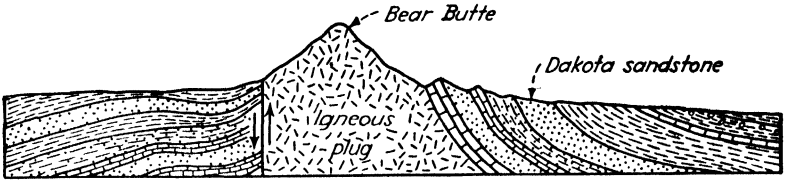


FIG. 135.—Bear Butte is a plug of igneous rock forced up through the sedimentary layers. Note the fault on the left side. The Dakota sandstone is an important formation. It is one of the layers that provides water for the numerous artesian wells in eastern South Dakota. (*After diagram by U.S. Geological Survey.*)

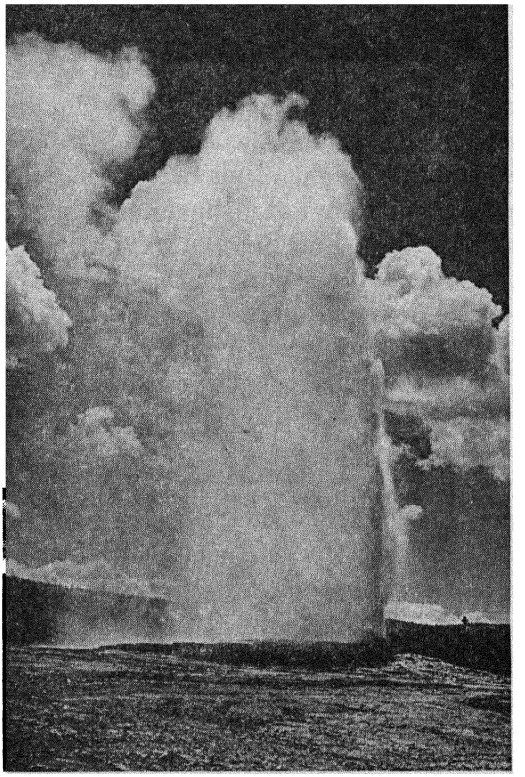


FIG. 136.—Old Faithful geyser in eruption, Yellowstone National Park. What cloud type appears in the background? (*Courtesy of Northern Pacific Railway.*)

of hot underground water sometimes results in the formation of valuable veins of ore. Igneous intrusions often are noted for their ore deposits.

Hot Springs and Geysers. In some regions underlain by hot volcanic rock, certain surface features are of interest. Such a region is illustrated by Yellowstone National Park. From several hundred openings in the surface rock, steam and other gases are given off into the air. Such are called *fumaroles*. There are many hot springs, some of which are continually boiling. These hot waters bring to the surface considerable quantities of mineral matter in solution. As the water cools or evaporates, the mineral matter accumulates on the earth's surface near the spring.

Hot springs that erupt from time to time at more or less regular intervals are called *geysers* (Fig. 136). The geyser tube extends deep into the earth, reaching hot rock. It fills with water from underground seepage. The boiling point of water under ordinary atmospheric pressure at sea level is 212°F. As pressure on the surface of the water is increased, the boiling point rises. Thus deep in the geyser tube the boiling point is considerably higher, because of the weight of all the water above. This deep water, in contact with the hot rock, finally reaches its boiling point, bursts into steam, and drives the upper water out of the tube, causing the geyser eruption. In the case of the famous Old Faithful geyser in Yellowstone National Park, the time between eruptions is about 65 minutes. In many springs, however, this time interval varies considerably. Other regions noted for geysers are found in New Zealand and Iceland.

Earthquakes

Nature of Earthquakes. Earthquakes are relatively small wavelike movements of the earth's crust. The surface of the earth is in constant vibration, but the movements usually are too small to be felt. Occasionally, tremors of such violence are set up that they spread over large areas and may even travel around and through the earth. These are recorded by instruments called *seismographs*.

The two principal causes of earthquakes are (1) faulting (see page 210) and (2) volcanic activity. In certain volcanic regions, earth tremors occur frequently. Hundreds of minor earthquakes are recorded on the island of Hawaii every year. These vibrations, as a rule, are not serious. Faulting has been largely responsible for the disastrous earthquakes in human

history. The displacement of great masses of rock along a fault plane creates a wavelike motion in the surface rocks. This wave travels in all directions. It is more marked and does greater damage near the point of origin. Rocks may slip along a fault at intervals of a few months or years. A region in which many faults have been mapped is likely to be one of more or less frequent earthquakes. Such is the case with southern California. One of the better known faults in California is the San Andreas Rift which extends from near San Francisco southwest for a distance of over 500 miles. The disastrous earthquake in San Francisco in 1906 was due to horizontal shifting of rocks along this fault, in places as much as 20 feet.

Destructiveness. "On September 1, 1923, the gates of Hell swung open in central Japan." So begins a vivid description of perhaps the most destructive earthquake the world has ever known. Two of Japan's great cities, Tokyo and Yokohama, were severely crippled. Nearly 150,000 people were killed, and the property loss was estimated at over 2 billion dollars.

Severe earthquakes may occur in remote parts of the world and cause little destruction; but when they strike in densely populated areas, the damage is tremendous. It is not the amount of the earth's movement that matters so much as the suddenness and sharpness of the shock. This may be illustrated by standing a piece of chalk on a table and striking the latter a quick, sharp blow underneath. The vibration of the table top may be too small to be seen, but the chalk may be thrown some distance upward and toppled over. A writer who was in Tokyo at the time of the 1923 earthquake says that to appreciate the sharpness of the shock one should imagine oneself standing on a board and to have it struck from beneath by a huge hammer in the hands of a giant. When such quick movements of the earth's surface occur, persons are thrown to the ground; buildings collapse; people are killed by falling debris rather than by the earthquake itself; water mains below ground are destroyed; and fire, once started, cannot be controlled.

In January, 1939, a disastrous earthquake caused great damage and the loss of nearly 50,000 lives in southern Chile. Especially in the cities of Chillán and Concepción the destruction of life and property was extremely severe. In December of the

same year, several highly destructive earthquakes visited Turkey, especially its northern and eastern districts, causing great loss of life and property in this old and densely settled region.

When an earthquake occurs on the bottom of the sea, huge water waves are created which become larger as they reach shallow coastal waters. These are commonly, and erroneously, called *tidal waves*. They have no relation to the true tide. These large waves may reach such proportions that they travel much farther inland along level coasts than do ordinary waves. In densely populated portions of the coast of southeastern Asia,

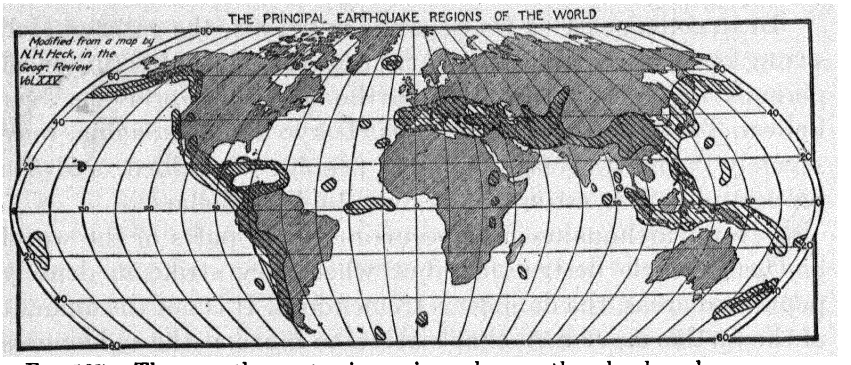


FIG. 137.—There are three extensive regions where earthquakes have been more or less frequent. They are (1) the west coasts of North and South America; (2) a belt across southern Eurasia; and (3) a belt that includes the Japanese islands, the Philippines, and the East Indies. (*Denoyer's Semielliptical Projection.*)

tidal waves have, upon occasions, destroyed thousands of human lives.

Regions of Frequent Earthquake Occurrence (Fig. 137). Since earthquakes are due largely to tectonic forces, the regions of frequent occurrence correspond closely with those zones of volcanic activity and faulting previously described. Parts of those zones, however, are more subject to earth tremors than are others. The great difference in elevation between the mountains of Japan and the great ocean deeps offshore contributes to the frequency of earthquakes in that region. The same applies to the eastern side of the Pacific. Small earthquakes are frequent on the coasts of the American continents from Cape Horn to Alaska. Several severe shocks have occurred in Chile, Mexico,

California, and Alaska since the beginning of the present century. It is said that in Tokyo a sensible shock occurs on the average once every three days.

Summary

The earth may be subdivided into

1. The atmosphere, mainly nitrogen and oxygen.
2. The hydrosphere, or oceans, seas, lakes, etc.
3. The lithosphere, composed of
    a. Solid rock.
    b. Mantle rock or regolith.

The composition of the lithosphere includes

1. Minerals, such as quartz, calcite, feldspar, and mica.
2. Rocks, which are classified as
    a. Igneous, such as granite and basalt.
    b. Sedimentary, such as limestone, sandstone, and shale.
    c. Metamorphic, such as gneiss, marble, and slate.

The forces that mold the earth's surface are of two types: tectonic and gradational. The tectonic forces operate through three processes, *viz.*,

1. Diastrophism.
2. Volcanism.
3. Earthquakes.

The gradational forces will be considered in the following chapter.

Questions

1. Define lithosphere. Rock.
2. What are the principal chemical elements found in the lithosphere?
3. Define mineral. What is limonite?
4. Name the three classes of rocks.
5. What are igneous rocks? Extrusive? Intrusive?
6. In general, how do extrusive and intrusive igneous rocks differ in mineral crystallization?
7. What is obsidian?
8. In what two ways does water transport its mineral load?
9. Why are sedimentary rocks called stratified?
10. Sedimentary rocks are usually found in what position?

11. Describe sandstone. Why is it sometimes banded in appearance?

12. Define porous and impervious rock. Name examples of each.

13. What is shale? What type of soil does it produce? What are some tests by which you can identify shale?

14. How is limestone formed? What is chert? Chalk?

15. By what process were Carlsbad Caverns formed?

16. By what tests can you identify limestone?

17. What are the principal uses of limestone? Mention two noted regions that produce building limestone.

18. Explain the formation of coal. Bog iron ore. Beds of rock salt.

19. What are metamorphic rocks? How are rocks metamorphosed?

20. Name five metamorphic rocks and the original rock from which each was formed.

21. Where are slate and marble quarried? Name the uses of each.

22. What is graphite? What are some of its uses?

23. Define mantle rock. Outcrop.

24. Define tectonic and gradational forces.

25. Define diastrophism. Volcanism.

26. Define degradation. Aggradation.

27. What are joints in rocks? What is the zone of fracture?

28. Define fault. Fault scarp.

29. How were the Basin Ranges and Sierra Nevada Mountains formed?

30. Diagram and explain the formation of a rift valley. Name and locate several such formations.

31. Define folding. Anticline. Syncline.

32. Explain warping of the earth's crust. What are some of the results? Give examples.

33. What is meant by the rock structure of a region?

34. Where are the principal zones of diastrophism?

35. Name the products of volcanic eruption.

36. What are the two general types of volcanic eruptions? How do they differ?

37. Locate Krakatao. Describe its eruption of 1883.

38. Name and locate other explosive volcanoes.

39. What is Mt. Rainier? The Devil's Tower? Locate each.

40. Describe the Hawaiian volcanoes.

41. Locate the Columbia Plateau. How formed?

42. What is magma? Diagram and explain dike. Sill. Laccolith.

43. Explain the cause of fumaroles. Hot springs. Geysers.

44. Name and locate three regions noted for geysers.

45. What is an earthquake? What instrument records earthquakes?

46. What are the two principal causes of earthquakes? Which is responsible for most destructive shocks?

47. What causes a tidal wave? Where have tidal waves done considerable damage?

Suggested Activities

1. Make a list of building stones and earth materials used in the construction of some familiar building.

2. Make inquiry concerning the source of building stones used in your own community.

3. Secure specimens of various rocks.

4. In three boxes, or trays, arrange the rocks according to the classification igneous, sedimentary, and metamorphic.

5. Secure specimens of lime, cement, and concrete.

6. Weigh a piece of thoroughly dried sandstone. Put it in water for several hours, and weigh it again. Explain results. Repeat, using other rocks.

7. On a large wall outline map of the United States, roughly outline and color the areas of igneous, sedimentary, and metamorphic rocks. (Maps of the U.S. Geological Survey are useful for this purpose.)

8. Using a band saw, cut wooden specimens to show folding and faulting. Cut one curve to show an anticline; another, a syncline. Cut a third block along a fault plane. Paint the rock layers different colors.

9. Select a talented fellow student to paint a large map of the island of Hawaii to show volcanoes and lava flows.

10. Make a list of a dozen or more active volcanoes, and print the names at the correct locations on a map of the world.

11. On the same map print the names and dates of disastrous earthquakes in the correct places.

12. Using molding clay or plaster of Paris, mold a relief model of a typical volcanic cone. Make a model of the island of Hawaii.

13. Draw a large map of Washington, Oregon, and Idaho. Outline and color the Columbia Lava Plateau.

NOTE: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. The Nature of Bedrock in Our Community
2. The Uses of Local Bedrock
3. The Characteristics of Local Mantle Rock
4. The Uses of Limestone
5. Manufacture of Portland Cement

6. Types of Faults
7. The Dead Sea Depression, a Rift Valley
8. The Island of Hawaii
9. Vesuvius
10. Yellowstone National Park
11. The San Francisco Earthquake of 1906
12. The Japan Earthquake of 1923
13. The Seismograph
14. Tidal Waves

References

BONNEY, T. G.: *Volcanoes: Their Structure and Significance*, G. P. Putnam's Sons, New York, 1913.

DALY, R. A.: *Our Mobile Earth*, Charles Scribner's Sons, New York, 1926.

ENGLISH, GEORGE L.: *Getting Acquainted with Minerals*, McGraw-Hill Book Company, Inc., New York, 1934.

FORD, W. E.: *Dana's Manual of Mineralogy*, John Wiley & Sons, Inc., New York, 1929. Revised, 1941, by C. S. Hurlbut.

PIRSSON, L. V.: *Rocks and Rock Minerals* (2d ed. by Alfred Knopf), John Wiley & Sons, Inc., New York, 1926.

Chapter IX. Wearing away and Building up of the Land

Among the various agents that reduce the surface features of the land to lower levels, the most important are water, ice, and wind. They derive their energy mainly from the sun and the force of gravity. Year after year these forces operate slowly but surely to wear away the land surface in some places and to build it up in others. They are aided by certain organic agents, such as plants, animals, and man, all of which may be called the *agents of gradation.*

The agents of gradation work in many ways to accomplish their objective. Some are completely without motion, their products remaining essentially where they were formed. These may be called the *static processes.* Others involve motion in which materials are picked up, transported, and put down. These are called *mobile processes.* The static processes prepare rock for removal; the mobile processes bring about its removal and cause its redeposition. The mobile processes include both *degradation,* or wearing away, and *aggradation,* or building up, of the land.

Landforms mark various stages in the process of gradation. Many kinds of landforms originate from steps and incidents in the gradational process. Some of them are forms carved in the solid rocks by the agents of degradation. Others are due to the temporary (in the geological sense) deposition and peculiar arrangement of material on its way to the sea. Climatic conditions greatly influence all the processes of gradation.

Static Processes

Weathering. This term is applied to all those processes which cause rocks to crumble and decay. These processes are

divided into two groups: (1) chemical and (2) mechanical. They are, however, usually operating at the same time.

Chemical weathering includes the processes that cause rock to *decompose*, or rot. Some of the minerals in the rock undergo chemical change (Fig. 138). The principal chemical changes are as follows:

1. *Oxidation.* This is the uniting of oxygen with another element. Thus, iron combines with oxygen to form iron oxide.

2. *Carbonation.* This is the action of carbon dioxide (CO_2). It is illustrated by the solution of limestone, or calcite (calcium

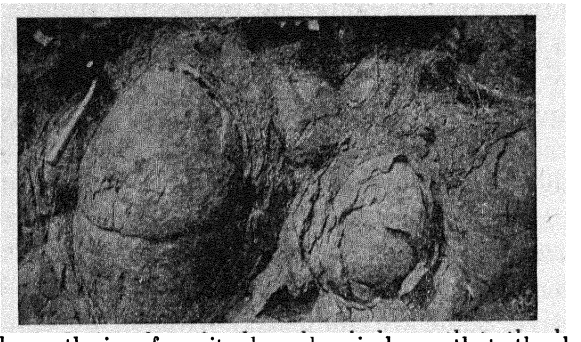


FIG. 138.—The weathering of granite shown here is due partly to the chemical decomposition of the minerals that make up the rock. (*Courtesy of Wisconsin Geological Survey.*)

carbonate, $CaCO_3$), by weak carbonic acid (H_2CO_3) which is formed by a combination of water and carbon dioxide. Here, indeed, is a most important process of chemical weathering. Limestone is *not* dissolved to any extent by rain water and therefore can be used as a building stone. Ground water, on the other hand, because of its contact with other substances, is in reality a very weak acid, containing not only carbonic but other acids. The carbonic acid changes the limestone to a soluble form which is dissolved and carried away.

3. *Hydration.* This is the chemical union of water with other elements. Thus limonite is a combination of iron oxide and water; gypsum, of calcium sulphate and water.

4. *Solution.* This is the dissolving of various substances by water. Rock salt, for example, is easily dissolved and carried away by rain water. Vastly more important results of solution are (*a*) the leaching of soils, *i.e.*, the removal of the lime content,

which lowers the fertility of the soil; and (*b*) the formation of caves by the solution of underground layers of limestone.

All the processes of chemical weathering are promoted by high temperatures and abundant moisture. Such weathering, therefore, is more rapid in warm than cold climates and in humid

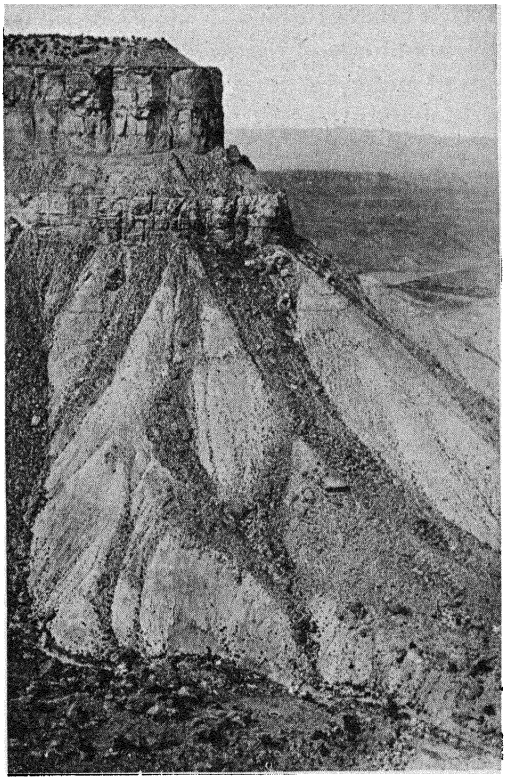


FIG. 139.—This cliff, 1,000 feet high, in the Grand River Valley, near Palisade, Colo., is an example of differential weathering. The vertical walls are resistant sandstone; the steep slopes, largely shale. (*Courtesy of U.S. Geological Survey.*)

than dry climates. Different rocks and even different parts of the same rock weather at different rates even under the same general conditions. Therefore, after prolonged weathering, some parts of a rock may be greatly changed, but others are so little changed that they stand out in bold relief after the weathered material is removed. Such features are said to be the result of *differential weathering* (Fig. 139).

Mechanical weathering includes all those processes by which solid rock is broken into fragments but is left chemically unchanged. The following are the more effective of such processes:

1. The formation of *joint planes* by diastrophism. Water, oxygen, and carbon dioxide are able to penetrate solid rock along these openings and to carry on the work of chemical weathering deep in the earth's crust.

2. The expansive force of *freezing water* in rock crevices pries apart the adjacent minerals or even large blocks of rock. When water freezes, it expands about one-tenth its volume. It is a

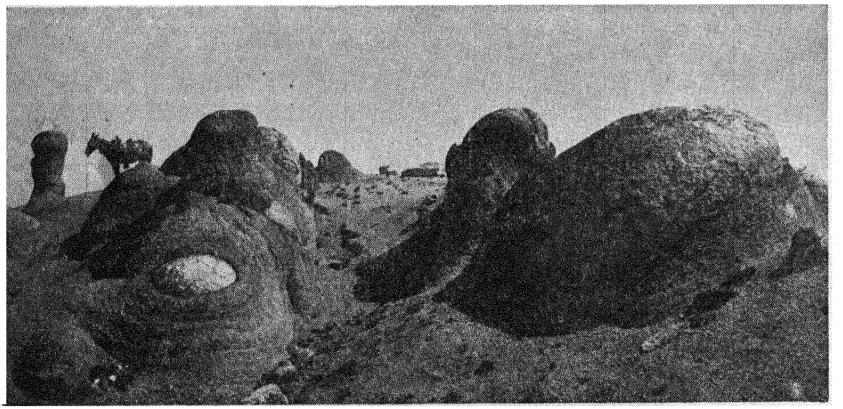


FIG. 140.—Exfoliating granite on a summit of the Sierra Nevada Mountains, Alpine County, California. (*Courtesy of U.S. Geological Survey.*)

familiar fact that iron water pipes in basements often are broken when the water is allowed to freeze. Under ideal conditions the pressure exerted by ice may even be greater than that inside a steam-engine boiler.

3. The growth of *tree roots* in crevices exerts a wedgelike force that aids in prying apart masses of rock. The amount of force exerted is illustrated by some sidewalks where blocks of concrete have been broken loose and lifted up by growing tree roots beneath.

4. Sometimes several processes of weathering operate together. In some places, especially in mountains and deserts, one may observe the shelling off of the outer layers of rocks. This is probably due to a combination of chemical weathering of the outer layers, the wedge work of ice, and expansion and contraction of the rock caused by daily heating and cooling. This shelling-off process is known as *exfoliation* (Fig. 140).

Results of Weathering. Without question the most important result of weathering is the formation of soil, which is the upper part of the mantle rock. The nature of underlying bedrock often determines to a considerable extent the type of soil that is formed. A second important result is the solution and later concentration of valuable minerals. A third is the slow disintegration and crumbling of great mountains, furnishing the loose material carried by thousands of streams on their way to the sea (Fig. 141).

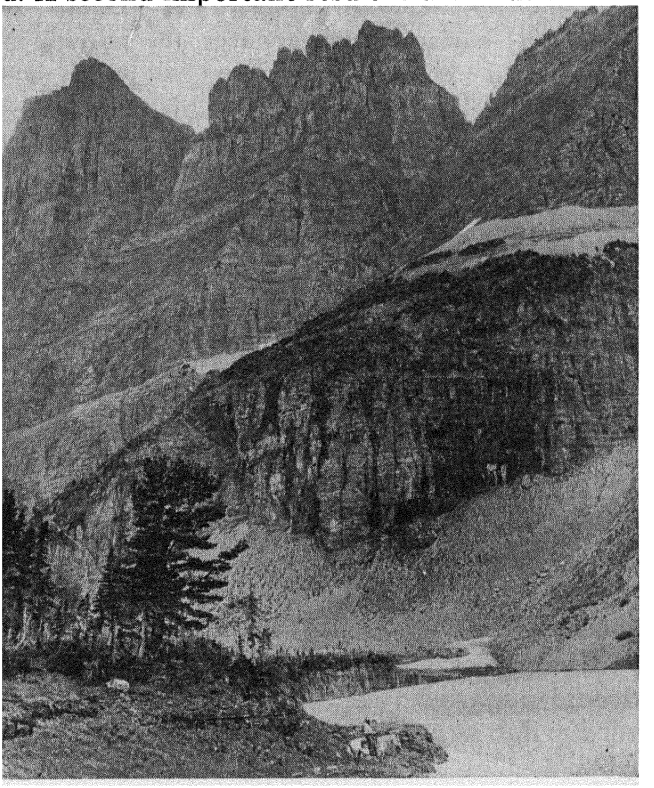


FIG. 141.—Weathering of rock is more rapid in mountains than in plains. This is due partly to greater changes in temperature and to steeper slopes. In this photograph, taken in Glacier National Park, Montana, the accumulation of rock waste, or "talus slope," can be seen just beyond the lake. (*Courtesy of U.S. Department of the Interior.*)

Mobile Processes

Erosion. The weathering processes commonly are followed, but not always immediately, by degradational processes which remove the weathered rock fragments from the places of their

origin. As these rock particles are moved from place to place, they rub against and wear away the surface of the earth. *Erosion* is the term applied to the grinding of rock on rock and the removal of rock waste. It should be emphasized that transportation is the essential factor in erosion. This transportation is furnished mainly by the following agents of erosion: (1) underground water, (2) surface running water, (3) moving snow and ice, (4) waves, and (5) wind.

The rate at which weathered material is transported by the agents of erosion depends to a considerable degree on the slope of the land. On steep cliffs, gravity itself removes weathered rock fragments about as fast as they are loosened. This leaves the rock of the cliff bare. On flat surfaces, even in rainy regions, the products of weathering tend to accumulate to greater depths. Transportation on flat surfaces must, in most cases, necessarily be slow.

Deposition. The agents of erosion pick up, transport, and deposit rock particles. It is, of course, during the period of transportation that erosion of bedrock takes place. Ultimately, however, the transported material is laid down, perhaps temporarily or for thousands of years. This deposition of sediment is aggradation. An example of such deposition is the familiar sand bar in a stream or the delta at the mouth of a river. Aggradation functions to fill slowly the depressions and basins of the earth's surface with loose rock waste. By this process certain landforms, such as floodplains, are developed. In many instances, such landforms are of vital importance in the environment of a given locality.

How Ground Water Changes the Land

Location of Ground Water. Ground water exists in the pore spaces of mantle rock, in porous rocks, and in the joint cracks and other crevices of all rocks as far down as crevices and pore space extend. The greater part of the pore space, and therefore of the water, is within a few hundred feet of the earth's surface. Many impervious or tightly capped rocks at great depths are essentially dry. The ground-water supply is maintained principally by that part of precipitation which penetrates the mantle rock. At depths that vary greatly, all pore space is filled with

water, and the ground is said to be *saturated.* The *water table* is defined as the *top surface* of the zone of the earth's crust that is saturated with water (Fig. 142). It is sometimes called the "ground-water level," but its surface is by no means level. Its depth varies with (1) water supply, (2) elevation, and (3) slope of the land. In humid regions it is nearer the earth's surface than in dry lands. It is usually deeper in hills than in lowlands and often comes to the surface as a spring.

Gradational Work of Ground Water. The gradational work of ground water is mainly *chemical,* because in most rocks it moves too slowly to accomplish much mechanical erosion. Landslides and soil-creep on slopes are a result largely of the "lubricating" effect of ground water; *i.e.,* the presence of underground

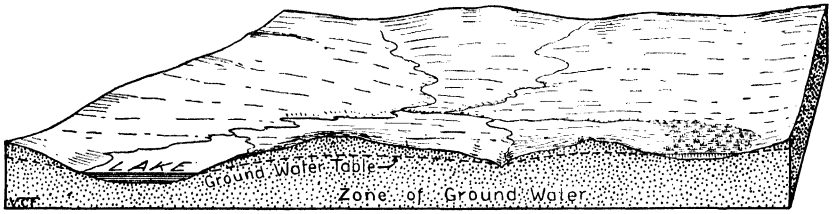


FIG. 142.—This diagram illustrates the undulating surface of a ground-water table and its relation to the land relief and drainage features.

water increases the tendency of soils to slip down slopes. However, the principal work of ground water as it influences landforms has to do with (1) solution and (2) the redepositing of dissolved minerals.

Solution, a phase of chemical weathering, is widespread. It is a process capable of giving rise to certain landforms. The solution of limestone by ground water containing weak carbonic acid may honeycomb the underlying bedrock of a region. Caverns and other cavities may be so close to the earth's surface that their roofs collapse. The land surface in such a region is likely to be dotted with numerous depressions and is said to have *karst topography.* Rain that falls on such a region tends to disappear into underground channels instead of forming the usual network of surface streams.

Under favorable conditions ground water may become overcharged with dissolved mineral matter and be forced to deposit some of it. The main causes of such deposition are (1) evapora-

tion of some of the water and (2) a decrease in temperature. There are other causes of a chemical nature. The deposited minerals are chemical precipitates. A familiar example is the lime

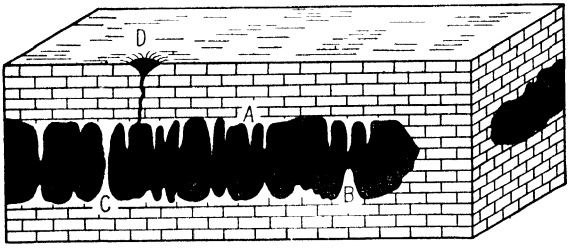


FIG. 143.—A cave caused by the solution of limestone. Note the following: *A*, stalactite; *B*, stalagmite; *C*, column; *D*, sink hole. Much of the rainfall in such a region seeps into the ground through sink holes and other crevices that lead to the cave.

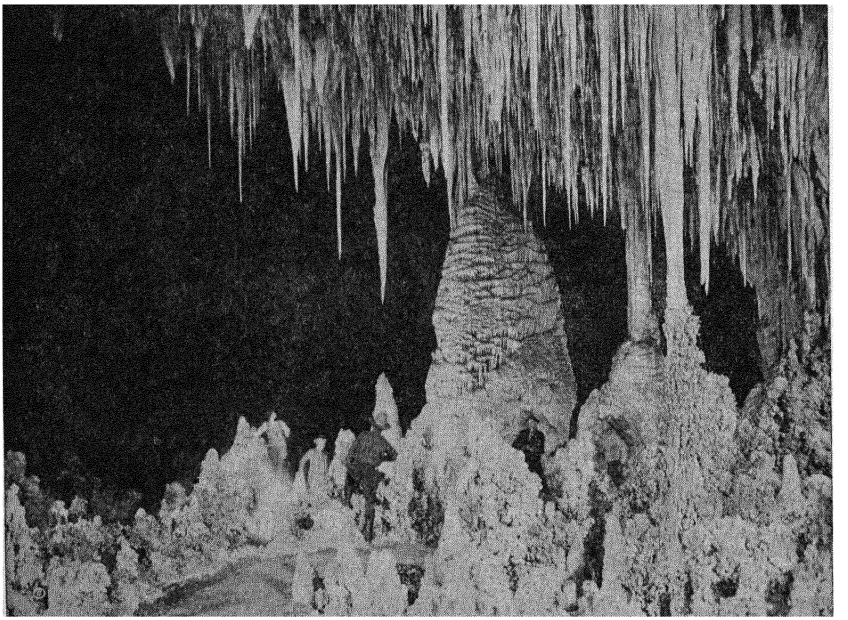


FIG. 144.—Carlsbad Caverns, New Mexico, showing stalactites, stalagmites, and columns. (*Courtesy of Atchison, Topeka, and Santa Fe Railway.*)

in a teakettle or the salt that remains when salt water evaporates. In most limestone caves, water drips from the roof in many places. As it clings to the roof, some evaporation takes place, and over a long period of time a *stalactite* is formed of the mineral matter, mainly calcite, carried in solution. When the

water drops to the floor, further evaporation causes the formation of a *stalagmite* (Fig. 143). In some cases the two deposits combine to form a column (Fig. 144). In Carlsbad Caverns these formations reach considerable size. One stalagmite is over 15 feet in diameter at the base and about 50 feet in height.

Of greater importance are certain less spectacular types of deposition. For example, ground water charged with lime may enter a bed of sand, cementing the sand grains to form a limy sandstone. Silica or lime may be deposited in crevices to form veins. Wood, bones, and shells are petrified by the action of ground water carrying silica or lime. A buried tree trunk, for example, is removed, molecule by molecule, and replaced with silica or quartz of various colors, often keeping even the microscopic details of internal structure.

The removal and replacement of minerals by ground water is an important factor in the formation of certain earth resources. The valuable deposits of *mineral ores* are largely a result of this process. The deposit may be in the form of a large *vein of ore*, such as lead sulphide, or galena; or tiny quantities of a pure metal, such as gold, may be deposited in small cavities scattered throughout a vein of quartz. Thus an important function of ground water, from the economic standpoint, is the collecting of valuable minerals from great masses of rock and redepositing them in a more concentrated form.

How Running Water, by Degradation, Changes the Land

Erosional Work of Streams. The most widespread erosion done by running water is that accomplished by the immediate runoff, that part of the precipitation which does not soak into the ground or evaporate into the air. The runoff may start its work as a sheet of water; but ordinarily, within a short distance, it collects into a stream. As streams grow larger, they are maintained by springs and seepage of underground water. Streams flow in valleys, and most valleys start as gullies. It is the work of running water to make them longer, deeper, and wider. A normal gully begins at the base of a slope and grows in length by erosion at the point where surface water pours in at its upper end. This is called *headwater erosion* (Fig. 145). New gullies branch from

the sides of the first one and lengthen in the same manner. Where mantle rock is somewhat uniform, the gullies normally have a branching, or treelike, relation to each other. Gullies of this kind may grow on unprotected slopes in such numbers as to create a serious problem in the control of soil erosion. This pattern of drainage increases in size until it may cover a large area. The major stream with all its tributaries is called a *river system.* The depression, or channel, that each stream has cut for itself is a *valley.* The entire area of land drained by a river system is called a *drainage basin.* An irregular line along an upland separating two adjacent drainage basins is called a *divide.*

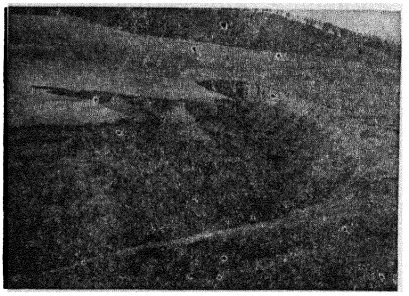


FIG. 145.—A gully head that is almost visibly gnawing its way up a slope that directs the flow of rain water into it. (*Courtesy of C., B. and Q. Railroad, photograph by F. W. Lehmann.*)

Valleys are deepened by their streams which, using sand or gravel as tools, erode the bedrock and remove the loose material. The rate of valley deepening depends upon (1) the velocity of the stream, (2) its volume, (3) the kind and amount of tools available, and (4) the resistance of the bedrock. The velocity of a stream is determined mainly by its gradient, or degree of slope from source to mouth. Streams with steep gradients are swift and are able, given tools, to deepen their valleys more rapidly than other streams of similar volume but with lower gradients. In a river system the newer tributaries and headwater streams usually have steeper gradients than the waters of the middle and lower courses where erosion has been longer in progress. For that reason the tributary streams may be eroding rapidly; and the main stream, in its lower course, may have a gradient so low that it is no longer able to cut downward, and more material collects in its channel than it is able to transport. Streams of high velocity are able to transport much more sediment than those of similar volume but low velocity.

Given time, a stream may deepen its channel to a gradient so low that it flows sluggishly. Then it is barely able to transport the material supplied to it by its tributaries, and it will deposit

sediment temporarily in its valley bottom. Such is said to be a *graded stream*, or a *stream at grade*. If time is permitted, a stream will ultimately reach the lowest gradient at which it can flow. Then it will be unable to transport any material and therefore unable to degrade its valley further. Such a stream is said to have reached its *base level*.

Characteristics of Young Streams and Their Valleys. Young streams, because of steeper gradients, usually have high velocities. They are cutting downward more vigorously than they are sidewise. Their valleys are widened at the top as the rock waste, loosened by weathering and rain, falls to the bottom. To an observer looking upstream or downstream, such valleys appear typically V-shaped (Fig. 146). In loose material which washes easily, the V is likely to be broad and open; in hard rock it tends to be narrow and gorgelike. In plateaus and mountains young valleys are often canyons or gorges. In lowlands they are only a few feet deep but maintain the V shape. Both are young in terms of stage of development, although there may be a vast difference in their ages measured in terms of years.

Young streams, rapidly eroding, often find their courses through rocks of unequal resistance which erode at different rates. The abrupt changes in gradient, which

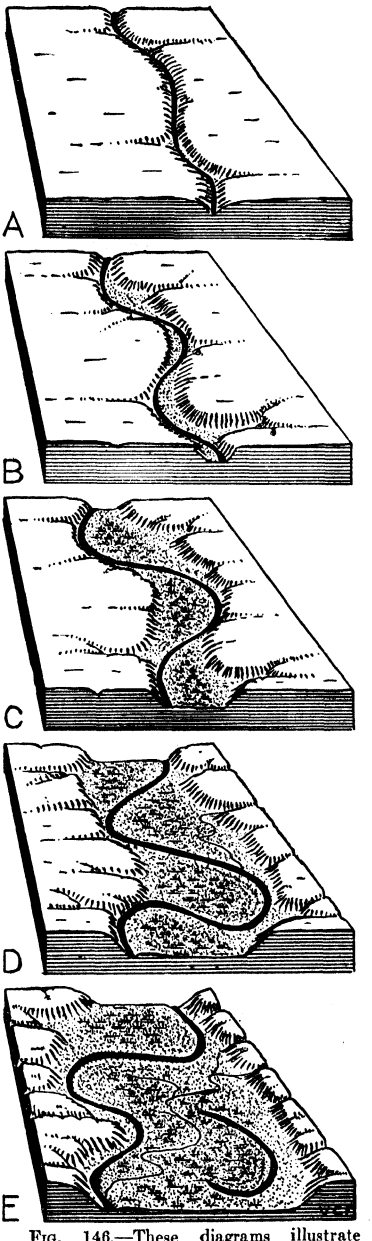


FIG. 146.—These diagrams illustrate changes in the profile of a valley: *A*, V-shaped profile of a young valley; *B*, start of meandering; *C*, retreat of valley bluffs; *D*, meander belt and long meander; *E*, meander cut off and floodplain widened by trimming of bluffs.

result from unequal erosion, cause the courses of many young streams to be interrupted by waterfalls and rapids (Fig. 147).

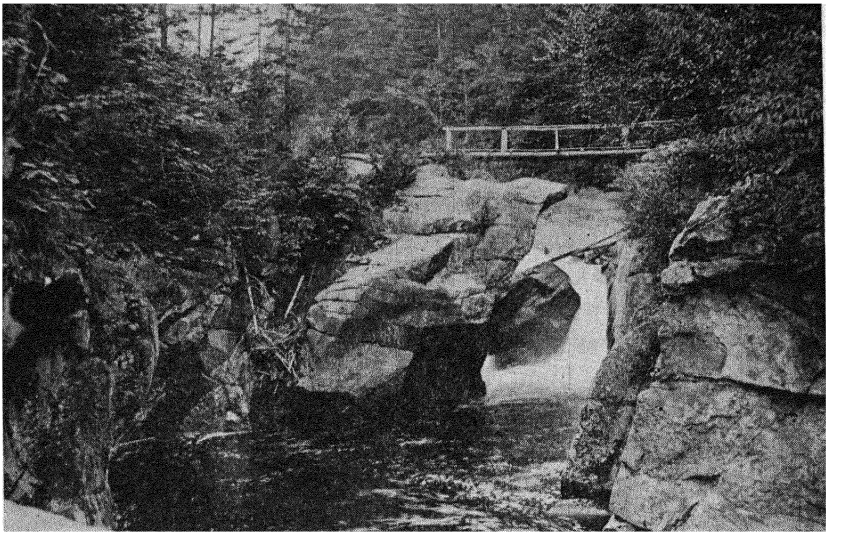


FIG. 147.—A young stream and valley. (*Courtesy of New England Council.*)

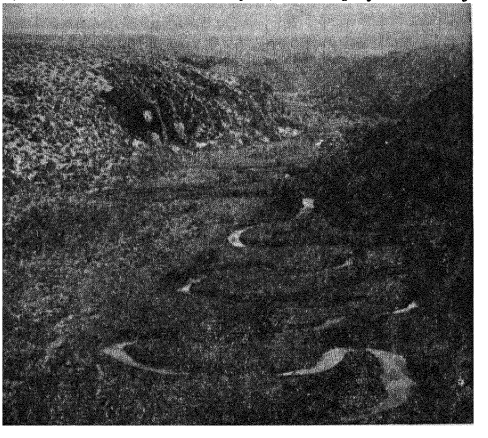


FIG. 148.—A stream meandering in an alluvial floodplain between rock walls. (*Courtesy of U.S. Geological Survey.*)

In older streams, which are nearing grade, time has permitted erosion to carve away even the hardest rocks, and falls and rapids tend to disappear.

Characteristics of Mature Streams and Their Valleys. As a stream approaches base level, both stream and valley take on

new characteristics. The stream becomes less swift and is readily turned aside. It begins to swing against its valley walls, cutting at their bases and pushing them apart by undercutting. Widening becomes more rapid than deepening. The stream swings from side to side on a widening valley floor in broad loops called *meanders* (Fig. 148).

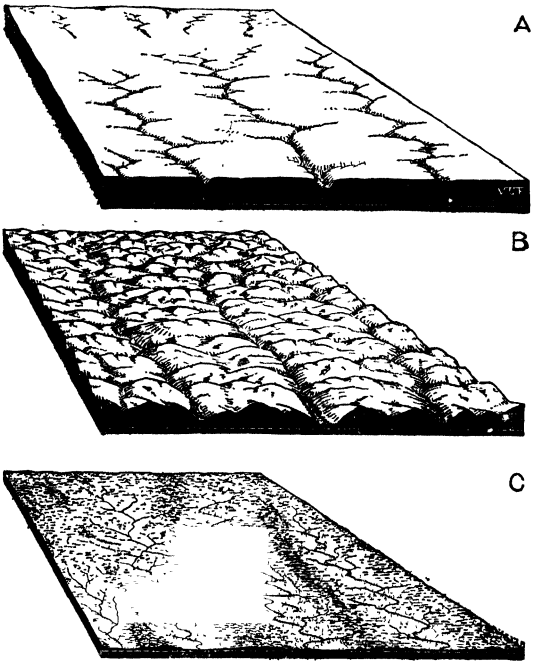


FIG. 149.—This diagram shows the development of a land surface by stream erosion from youth *A*, through maturity *B*, to old age *C*. The dotted white line indicates the base level toward which the streams are working.

Observe the Surface Relief of the Land. As you travel from place to place, observe the nature of the land surface. Are most of the valleys young, mature, or old? Note how the agents of erosion have influenced the slope of the land.

The degree to which erosion has changed the land surface makes it possible for us to identify three types of landscape. They are called (1) youth, (2) maturity, and (3) old age. Let us consider briefly the characteristics of each.

As stream valleys develop, so do the relief features of the regions through which they flow. In some areas, streams generally are young, and valleys are narrow. The tributaries are

undeveloped and few. The uplands between the streams are broad and relatively flat. The streams have only begun the task of reducing the land toward base level. Such a region is said to be in the stage of *youth* (Fig. 149*A*).

As erosion continues, many new tributary streams and a large number of gullies are formed. These cut into the former broad uplands. Valleys grow deeper and wider. The whole area becomes one of rolling hills. Divides between drainage basins are easily traced. Such a region is said to have a *mature* surface (Fig. 149*B*).

Progress of erosion beyond maturity enables the streams, first the larger ones and then the tributaries, to reach their respective grades. Beyond this point there is still a slow reduction of the land surface by weathering and slope wash. The region ultimately acquires broadly open and level-floored valleys or floodplains, which are separated by low rolling divides. This stage in surface development is referred to as *old age* (Fig. 149*C*)

How Running Water, by Aggradation, Changes the Land

How Streams Deposit Material. A stream that is overloaded with rock material is forced to deposit some of its sediment at various places. The term *alluvium* is applied to such stream deposits. The action of running water tends to sort the transported material roughly according to the weight of the particles. This sorting action results in the formation of layers of gravel, sand, silt, and clay. Water-deposited sediments, therefore, tend to be *stratified.*

Streams become overloaded with sediment for the following reasons: (1) A decrease in velocity decreases carrying power. It is a well-known fact that the faster a stream flows the more sediment it can carry. (2) Tributaries may bring more sediment than the main stream can carry. It is possible for a number of streams to transport so much sediment to a main river that the channel of the river may become choked. (3) A decrease in volume of the stream may result from a decrease in rainfall, from seepage of water into the ground, or from evaporation. A stream, for example, that originates in mountains where rainfall is abundant and then flows across a desert is almost certain to

have its volume reduced and consequently its capacity to carry sediment.

The slowing-up of a stream is perhaps the most common cause of deposition. This is especially marked at the base of mountains where the stream gradient is suddenly lessened and at places where streams flow into lakes or seas. Also, on the insides of the bends of rivers there are spots of quiet water where sediment is deposited.

Where Streams Deposit. *On the Inside of the Curve.* As a stream swings around a bend in its channel, the water on the

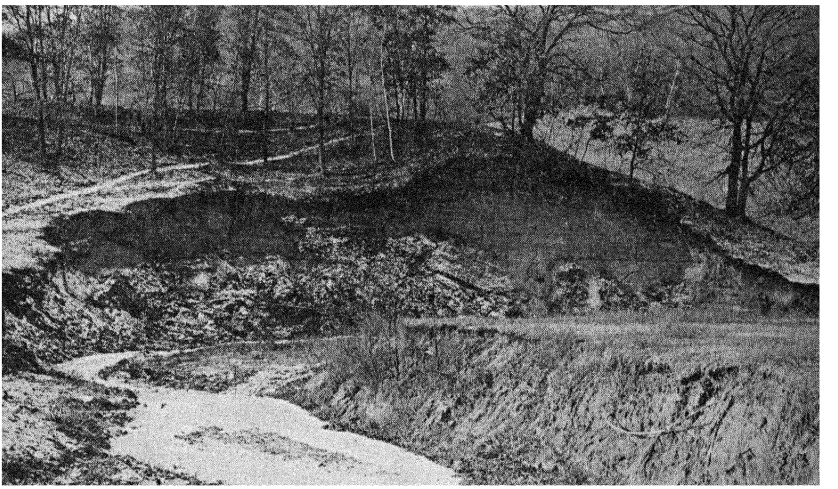


FIG. 150.—The small stream shown here is widening its valley bottom by undercutting on the outside and depositing on the inside of a bend. (*Courtesy of C., B. and Q. Railroad, photograph by F. W. Lehmann.*)

inside of the curve will have the lower velocity (Fig. 150). It is here that sand bars are formed. Such bars and similar mud flats choke the stream channel and increase the danger of floods at the time of high water. Gradually, by swinging out against the valley wall on one side and depositing on the other, the stream produces the broad, flat valley of old age. During floods, this valley is covered with alluvium. Such level land next to a river is called a *floodplain.*

Along the Stream Banks. Sometimes a stream, loaded with sediment, rises in time of flood and overflows its channel. It spreads out upon the floodplain. Much material is deposited

immediately along the stream banks where the water first goes out of its proper channel and loses its velocity. On the banks, therefore, the alluvial accumulation is thickest. It generally forms low, broad ridges bordering the stream. These low ridges, which are slightly higher than the rest of the floodplain, are called *natural levees.*

At the Stream Mouth. Nearly all streams are able to carry some sediment down their entire courses and out at their mouths.

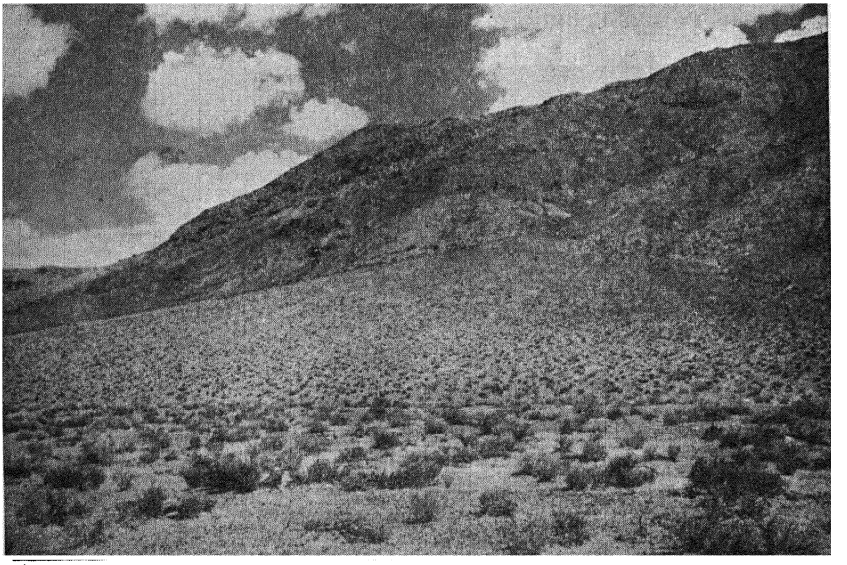


FIG. 151.—The conformation of a small, fairly steep alluvial fan in Nevada. The apex of the fan lies at the mouth of the gully from which the material was eroded. (*Photograph by John C. Weaver.*)

Where the velocity of the stream is checked as it enters a lake or sea, deposition results. The extensive accumulations of sediment at such locations are called *deltas.* Deltas fail to develop in some cases because (1) the sea water may be too deep and (2) strong waves and currents remove the sediment. As the delta becomes larger, the main stream overflows into several outlets across the muddy surface. These additional outlets are called *distributaries.*

At Sharp Decreases in Valley Gradient. The velocities of mountain streams are checked suddenly where their courses extend out upon adjacent plains. It is here that broad, fan-shaped

or conical accumulations of sediments are deposited. Such are called *alluvial fans* (Fig. 151). In humid regions many mountain streams have sufficient volume to carry their sediment farther down their courses and therefore do not form such deposits. It is in dry regions that alluvial fans reach their greatest development. There the mountain streams are sometimes dry, sometimes flooded. Such conditions favor the development of alluvial fans, and they may grow until they reach a radius of several miles. Along the bases of some mountain ranges, every stream has its alluvial fan, large or small, and the fans are so crowded that adjacent fans spread and join, making one continuous *piedmont alluvial plain.* (Piedmont means "at the foot of the mountain.")

Glaciers

Nature of Glaciers. A glacier is a body of ice that moves slowly over the earth's surface (Fig. 152). In cold climates, either in high latitudes or in high mountains, accumulations of snow form snow fields. Alternate melting and freezing ultimately changes the snow to ice, which, partly as a result of the force of gravity, slowly moves downhill. The perennial snows of high mountains give rise to valley glaciers. As the snow accumulates, the mass of ice becomes larger, expands, and pushes its lower portions down the valley. As long as the supply of snow is renewed from above, the glacier will continue to move.

The protruding ice tongue which creeps slowly forward conforms to the shape of the valley in which it lies. Its rate of motion depends largely upon (1) the thickness of the ice and (2) the steepness of the valley gradient. It is usually a few feet per day. However, some glaciers in Alaska and Greenland have been known to flow 40 to 50 feet per day. The advancing end of the ice tongue, extending down a mountain valley, ultimately reaches lower elevations where higher average temperatures prevail, and the ice wastes by melting. As long as the average forward movement of the ice is greater than the amount lost by melting, the front of the ice tongue will continue to advance. When the rates of advance and melting are equal, the ice front will remain stationary. If melting predominates, the front edge will retreat up the valley, although the ice is still moving downward.

Some valley glaciers in high latitudes, for example in Alaska and Greenland, are able to push so far down their valleys that they reach the sea. They are called *tidal glaciers*. Instead of melting away in the sea, the ends of the glaciers are continually broken off by the buoyance of the sea water, and great chunks float away in the form of icebergs. Two or more valley glaciers may combine at the base of a mountain. Such is the great Malaspina Glacier in southern Alaska. It is about 25 miles in width and extends back into the mountains for 60 to 70 miles.

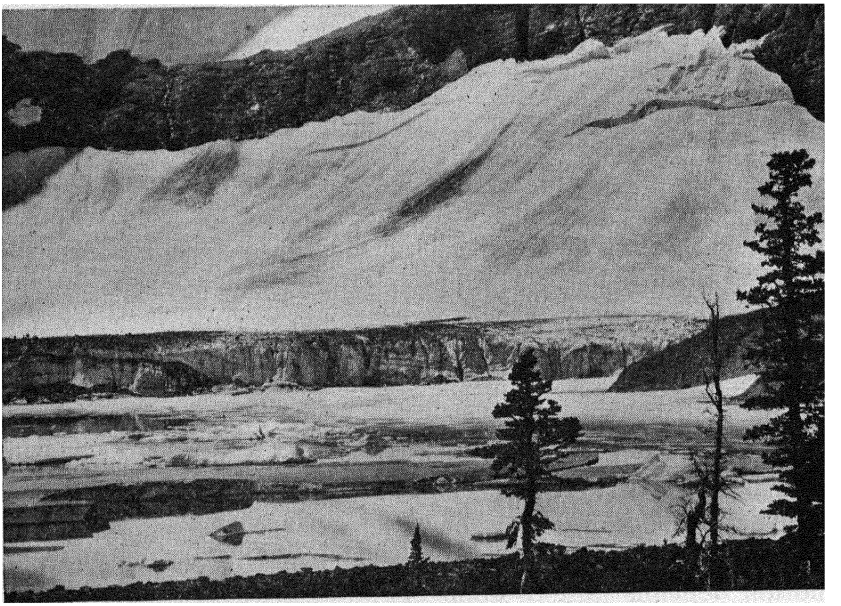


FIG. 152.—Iceberg Glacier and Iceberg Lake in Glacier National Park. (*Courtesy of Great Northern Railroad, photograph by Hileman.*)

The surface of a glacier is by no means smooth. Pressure may cause great masses of ice to be pushed above the general level. Huge cracks in the ice, known as *crevasses*, are often of unknown depth and constitute a dangerous hazard to travel over the glacier surface. On top of stagnant parts of the Malaspina Glacier, broken rocks and earth have collected to a depth sufficient to support the growth of trees.

Continental Glaciers. Great continental ice sheets now cover most of Greenland and Antarctica. In Greenland, the great mass of ice is over a mile thick near the center and covers

over 700,000 square miles. This is an area greater than that of the tier of states from Texas to North Dakota, inclusive. The ice sheet pushes outward in all directions, forming many coastal

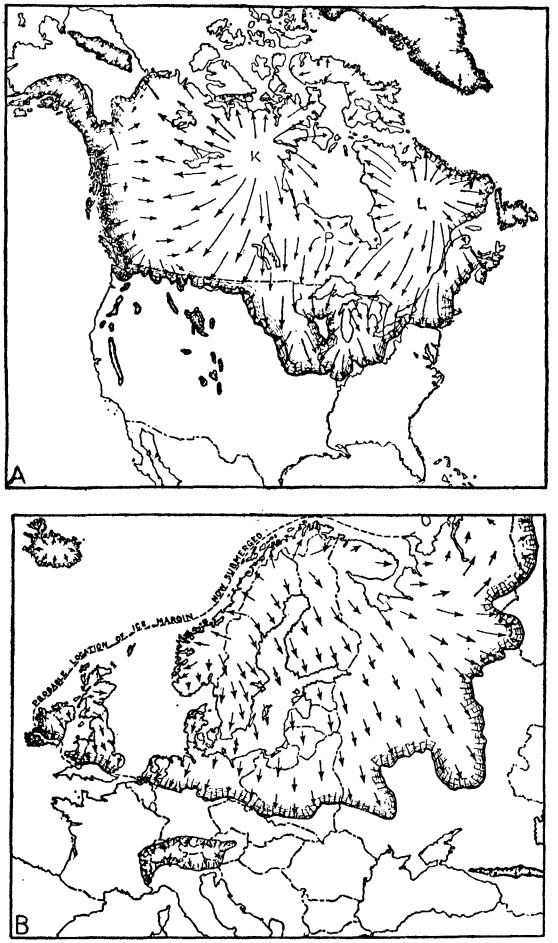


FIG. 153.—The maximum extent of the continental glaciers of North America and Europe. *A*. The letters indicate the Keewatin, Patrician, and Labradorean centers of glacial movement. *B*. The principal center of European glaciation was in Sweden or the present site of the Gulf of Bothnia.

valley glaciers. Some of these which reach the sea on the west side break off as icebergs which are carried south by the Labrador ocean current into the path of ocean liners plying between New York and Europe. The antarctic ice sheet is considerably larger than the United States.

Extensive continental glaciers formerly covered the northern half of North America and much of northwestern Europe (Fig. 153). They had their origin as huge snow fields which changed to ice and by expansion moved outward and especially toward the south. It is a mistake to assume that these great ice sheets were produced by extreme changes in climate. The only requirement for continental glaciation is that the snowfall be somewhat more, or the temperature somewhat lower, than at present. If the temperature is low enough, then the snow of one year is not quite all melted when that of the next year begins to fall. If that condition prevails, the accumulation spreads inch by inch and century by century. The ice margin moves until it reaches a position where loss by melting equals the rate of advance. The disappearance of such a glacier, conversely, results from a decrease in snowfall or an increase in temperature. The time required for either growth or disappearance probably runs into tens of thousands of years.

Areas of Former Continental Glaciation. The European ice sheet radiated from centers located in the Baltic Sea region and Scotland and extended southward into England, the Netherlands, Germany, Poland, and Russia. The centers of North American glaciation were on either side of Hudson Bay. From the American centers the ice spread outward but more extensively southward. It reached a line that trends from New York City westward across southern New York state to northeastern Ohio and from there along nearly the present courses of the Ohio and Missouri rivers to the Rocky Mountains. Within this boundary the only district to escape burial beneath the ice sheets was a large area located in southwestern Wisconsin and adjacent parts of Illinois, Iowa, and Minnesota. It is known as the *driftless area*. At the time of the continental ice sheets, there were much larger glaciers than now exist in the mountains of both North America and Europe.

How Glaciers Erode. Clean glacial ice is able to erode rock mainly by pushing and by "plucking." Rock pinnacles or other unstable or detached rocks are readily toppled over by the great weight of the advancing glacier, and loose earth is plowed up by it or frozen into the ice and carried forward. Using as tools the rocks thus obtained, the moving ice is able to accomplish a tre-

mendous amount of erosion. The tools, in their slow motion, gouge, groove, scratch, and polish the rock surfaces over which they pass. In the process the tools themselves are scoured, scraped, and reduced in size. They lose their sharp angularity and become partially rounded. The parallel scratches that may be observed on such rocks and on glaciated bedrock are called *glacial striae* (Fig. 154).



FIG. 154.—Glacial striae and polish on granite, upper valley of Ireland Creek, Sierra Nevada Mountains, California. Such striae, or grooves, on bedrock indicate the direction in which the glacier moved. (*Courtesy of U.S. Geological Survey.*)

How Glaciers Deposit. The load of a glacier is comprised of rocks and earth intermingled without regard to size or weight. It is carried in part upon the ice surface or frozen into the ice mass, but even more largely in its bottom, because that is where most of it is obtained. The lower layers of ice in some glaciers are so crowded with clay, sand, and boulders that the earthy material is more abundant than the ice. When the glacier melts, this rock waste remains as *boulder clay*, or *till*. Mixed with the soil and gravel are large glacial boulders called *erratics*. They are often entirely different from local bedrock. Granite boulders, for example, are found in regions of sandstone. The layer of boulder clay in some places is very thin; in others it reaches a thickness of scores of feet. Where roads are cut through

glacial deposits, it can be observed that the earth materials usually are not stratified, which is in contrast with water-laid sediments. The glacial drift that forms the till sheet over extensive areas is called *ground moraine.*

Other types of moraine are formed by moving ice. As the front end of the glacier advances, it pushes rock waste ahead of it forming *end moraines.* These are often observed as long, continuous ridges of glacial drift, in places more than 100 feet high. Rock waste accumulates along the sides of a valley glacier and on top of the ice, at times becoming thick enough to support the growth of trees.

Much of the glacial load, however, does not stop under the ice or upon the moraines about its margin. This material is carried beyond the glacier margin by the streams of water that result from the melting of the ice. Like all stream-transported earth, it is sorted somewhat according to weight, the fine muds being carried farthest and the coarser, heavier materials being put down close in front of the ice. Broad deposits of such sediment are known as *outwash plains.* Much of Long Island, New York, is an outwash plain.

Glacial erosion and deposition disturb the normal processes of stream development. In some ice-scoured valleys several *rock basins* may be eroded, and these become the sites of small lakes. Unequal resistance of bedrock produces many waterfalls. Regions covered with recent glacial drift have little order or pattern in their drainage systems. Differences in the age of glacial drift in various localities indicate that North America was invaded by continental glaciers at least three times, all within a comparatively recent period in earth history.

Waves and Currents

Where Land and Sea Meet. The oceans, seas, and lakes of the earth cover more than 71 per cent of its surface and are important agents in the making and changing of landforms. The work of such water bodies is accomplished chiefly by waves and currents which are caused mainly by the wind (Fig. 155). Most of the erosion and deposition done by waves and currents takes place along the margins where land and sea meet and shallow water prevails.

How Waves and Currents Wear Away Land. The greater part of marine erosion is accomplished by waves. In shallow water, waves stir up and agitate the materials of the ocean floor. With the help of currents this material is shifted to lower places. This process results in a general leveling of the sea floor.

There is little forward motion of the water in the waves of the open sea. The wave form moves forward just as waves may be seen to run across a field of standing grain or may be sent



FIG. 155.—Wave erosion in Acadia National Park, on the coast of Maine. (*Courtesy of U.S. Department of the Interior.*)

along a shaken rope. As a wave enters shallow water, it eventually topples over, or breaks. This motion throws forward a considerable amount of water. The water thrown forward by breaking waves rushes upon the shore. There it loses its velocity and runs back, under the pull of gravity, beneath the oncoming waves. The returning water, flowing seaward along the ocean floor, is called the *undertow*. It has sufficient force to be a factor in erosion.

The erosive work of waves is accomplished (1) by the forward motion or slap of the water as the waves break and (2) by the sand and rocks that they carry and use as tools. In either case

the principal work is done where the waves break. On exposed coasts, where *deep* water lies immediately offshore, even great waves do not break until they reach the shoreline. There the force exerted by the sheer weight of the water in great waves is truly impressive. Blows of a ton or more per square foot are not uncommon. This is sufficient to dislodge and move about rock fragments of great weight. The effect of the undertow is to move the broken fragments away from the shore into deeper water where they are caught by oncoming waves and moved shoreward again. This ceaseless shifting of sand, pebbles, and even boulders grinds away at the ocean shore. The general effect is to cut back coastal projections, decreasing the area of the continent and straightening the coast. Where winds more or less parallel the shore, shore currents are set up which serve to transport sediment from one part of the coast to another.

How Waves and Currents Aggrade, or Build up, the Land. The products of wave erosion together with the sediments emptied into the sea by rivers are shifted about and deposited by waves and currents. Because wave activity does not extend to great depths, the sediment does not spread far from shore. The coarser rock fragments are deposited first, and the finest carried farthest out. This process results in a general assortment of shore deposits according to their sizes. Silt and clay are carried to greater depths or are deposited in bays of quiet water. Sand covers extensive areas of the ocean bottom near shore. In some places calcium carbonate accumulates, together with the limy shells of small marine organisms. Thus are originated the muds, sands, and limes that form shale, sandstone, and limestone. These sedimentary rocks in many regions have been uplifted from shallow sea margins and have become parts of the continents.

Where Waves and Currents Aggrade. The deposition of sediment alongshore modifies the coast in several ways and influences its adaptability for human use. Deposition for the most part takes place in shallow waters, in protected bays or lagoons, and on the leeward side of the projecting coastal features. The more important shore features thus developed will be considered later.

How the Wind Changes the Land Surface

How the Wind Degrades, or Wears Away, the Land. The wind is an important transporting agent. The air is never without dust in suspension. Winds of high velocity are capable of moving sand for some distances. Some of the materials carried by the wind are thrown into the air by volcanic explo-

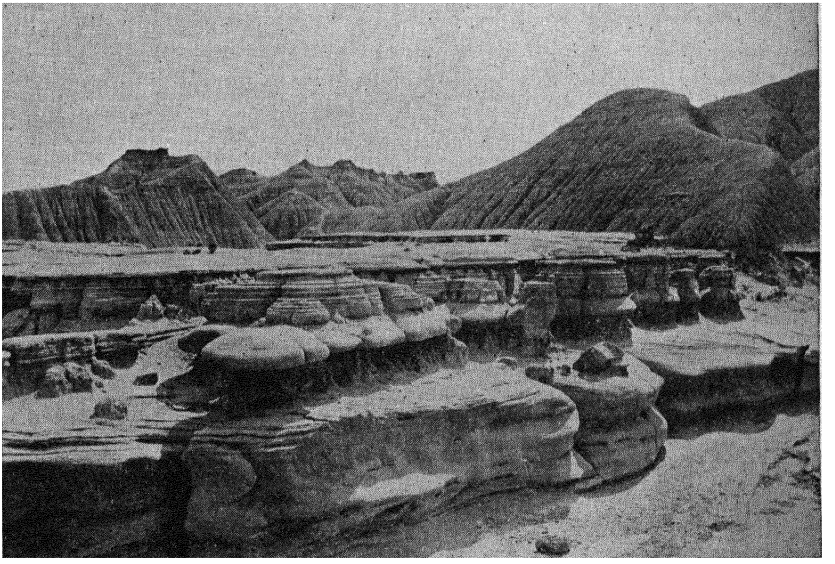


Fig. 156.—"Toadstool Park," near Adelia, Sioux County, Nebraska. The erosion has been caused mainly by wind-blown sand. Between the protruding thin layers of resistant sandstone are softer layers of clay. (*Courtesy of U.S. Geological Survey.*)

sions, but the greater part is obtained by the wind directly from the earth. This process of surface degradation, during which earth is whipped up by the wind and is transported from one place to another, is called *deflation*. Deflation is least effective in humid regions where vegetation protects the soil from wind action. It is most effective in semiarid lands and deserts, along sandy coasts, and over freshly plowed fields. From large areas of the desert surface most of the fine material has been removed by the wind. This leaves a desert pavement of the heavier gravels and boulders (Fig. 91).

The process of deflation is to some extent aided by wind erosion, or abrasion. The wind-carried sand particles scratch,

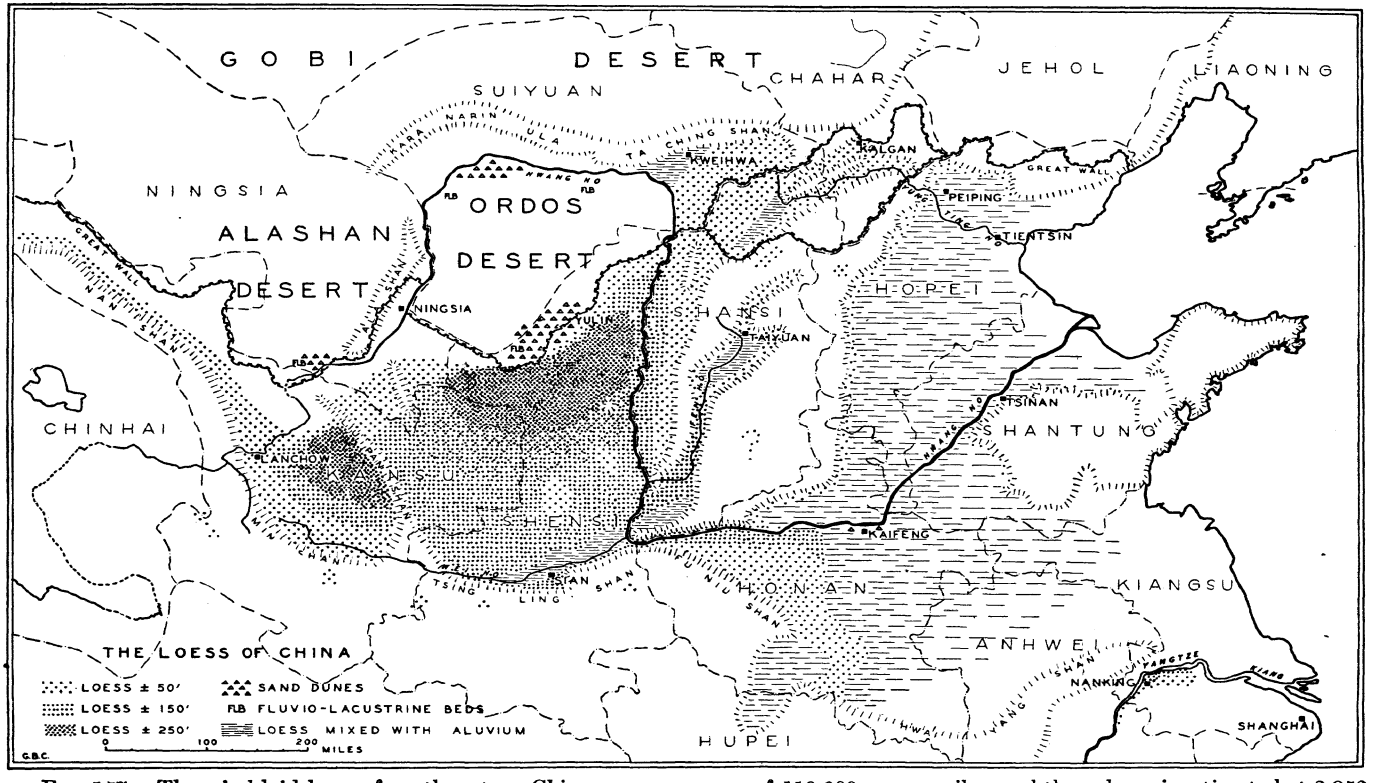


FIG. 157.—The wind-laid loess of northwestern China covers an area of 119,900 square miles, and the volume is estimated at 2,852 cubic miles. This does not include the alluvial plains which are built in part of loess. (*Courtesy of G. B. Cressey, from China's Geographical Foundations.*)

polish, and reduce each other and to some extent the solid rock (Fig. 156). As the rock particles become finer, they may be moved long distances.

How Wind Aggrades. Wind, like streams and waves, deposits its load of coarse material promptly. However, it is able to carry fine particles farther and distribute them more widely. Loose sands are supplied in abundance by the weathering of desert rocks or by wave deposition on the shorelines. Where the sands are not anchored by vegetation or moisture, they are whipped up by the wind and drifted into the shelter of some obstruction. Thus is begun the growth of a sand dune, or sand

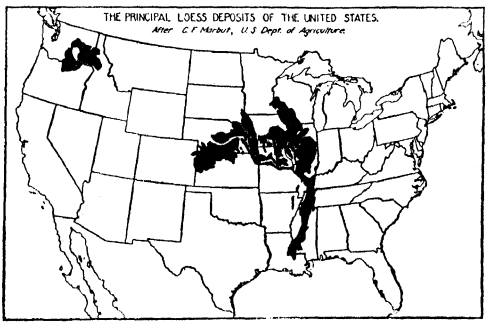


FIG. 158.

hill, which, by its own height, provides its own shelter and promotes its own growth. Some sand dunes move slowly, because the wind drives the sand up the windward side and down the leeward.

The dust supplied by rock weathering and abrasion in dry regions is drifted by prevailing winds over wide expanses. There probably is a considerable quantity of wind-blown dust in most soils. However, such dust is particularly abundant and may attain great thickness in those regions visited by dry, dusty winds that come from arid lands. Considerable accumulations of wind-deposited dust are called *loess*. In northern China the northwest winter winds from the Gobi Desert have formed loess deposits that in places are over 100 feet thick (Fig. 157). Other extensive deposits are found in central United States and central Europe (Fig. 158).

Summary

This chapter deals with the processes by which the features of the land are made.

The gradation processes are divided into static and mobile. The static processes, or weathering, are subdivided into

1. Chemical, such as oxidation, carbonation, hydration, and solution.
2. Mechanical, such as jointing, expansion of freezing water, and exfoliation.

The mobile processes are subdivided into degradation and aggradation.

Degradation means the wearing away of the land surface by underground water, rivers, glaciers, waves, and wind-blown sand. Aggradation means the building up of certain land features by these same agencies.

The next several chapters will consider mainly the results of these processes which operate to change the surface of the land.

Questions

1. What is the difference between static and mobile processes of gradation?
2. Define weathering.
3. Define chemical weathering. List the principal chemical changes involved in weathering.
4. Explain carbonation.
5. Give an example of hydration. Solution. State two important results of solution.
6. What is differential weathering?
7. Explain the more important processes of mechanical weathering.
8. Mention three important results of weathering.
9. Define erosion. Name the agents of erosion.
10. Define aggradation.
11. What is ground water? How is it supplied?
12. Define water table.
13. What are the results of solution by ground water?
14. What causes ground water to precipitate its mineral load?
15. Explain the formation of caves. Of stalactites and stalagmites.
16. Explain the formation of petrified wood. Of veins of ore.

17. What is meant by immediate runoff of rain water. By headwater erosion?

18. Define river system. Drainage basin. Divide.

19. What factors determine the rate of valley deepening?

20. Define gradient of a stream. What effect does gradient have on stream velocity?

21. How does the velocity of a stream affect its ability to carry sediment?

22. What is meant by a graded stream? By base level?

23. Describe young streams and their valleys.

24. Why are waterfalls and rapids characteristic of young valleys?

25. Describe mature streams and their valleys. What is a meander?

26. Describe the three stages in the development of the general surface relief of the land.

27. What is alluvium? Why usually stratified?

28. Why do some streams become overloaded with sediment?

29. Where are sandbars usually formed? Why?

30. What is a flood plain? A natural levee? How is each formed?

31. What is a delta? A distributary? Why do deltas fail to develop at the mouths of some rivers?

32. Explain how and where alluvial fans are formed. What is a piedmont alluvial plain?

33. What are valley glaciers? How fast do they move?

34. Explain the following: tidal glacier. Iceberg. Crevasse.

35. Discuss the Greenland ice cap.

36. What climatic changes would be necessary to start another ice age?

37. Locate areas of former continental glaciation in Europe and North America.

38. Where is the driftless area?

39. How do glaciers erode? What are striae?

40. Define or explain erratics. Ground moraine. How to differentiate between moraine and water-deposited sediments.

41. Name and describe the two principal types of moraines.

42. Explain how an outwash plain is formed.

43. How is the erosive work of waves accomplished?

44. What ocean sediment forms shale? Sandstone? Limestone?

45. Where do waves and shore currents deposit sediment?

46. What is meant by deflation? Desert pavement? Wind abrasion?

47. What is a sand dune? Why do some slowly move?

48. Explain how loess deposits are formed. Why are they so deep and widespread in northern China?

Suggested Activities

1. If possible, make local field trips to selected places to study the work of weathering, erosion, and deposition.
2. Sketch a map to show the general drainage and relief features of your community.
3. Try to find examples of differential weathering or erosion in your community.
4. Make cross section or profile drawings of valleys in different stages of development. Use various topographic maps for this purpose.
5. Using molding material, make relief models of different types of valleys.
6. Observe soil ("sheet") erosion in your locality. Find out the methods of combating such erosion.
7. Make a relief model of an imaginary region partly covered by a glacier. Use different colors to show the ice sheet, moraines, outwash plains, and other glacial features.
8. Make a small relief model to show stalactites, stalagmites, and columns.
9. Weigh a rock in air. Then tie a string around it, submerge it in water, and weigh it. How do the two weights compare? How is this of importance in river and shoreline erosion?
10. Observe streams or rivers in your locality to determine whether they are aggrading or degrading.
11. Put some fine gravel, coarse sand, fine sand, and clay in a quart jar. Fill with water and shake well. Observe resulting sedimentation.
12. Perhaps you can obtain motion pictures or slides that will show some results of weathering, erosion, and deposition of rock material.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Examples of Weathering in Our Community
2. Weathering and Erosion of Local Bedrock
3. Study of Local Valleys
4. The Nature of Local Relief Features
5. The Garden of the Gods, Colorado (An Illustration of Weathering and Erosion)
6. Famous Caves
7. Common Minerals That Are Oxides and Carbonates
8. Weathering in Deserts versus Humid Regions

9. Soil Erosion
10. Deforestation and Soil Erosion

References

BRANSON, E. B., and W. A. TARR: *Introduction to Geology*, Chaps. 3–8 and 11–14, McGraw-Hill Book Company, Inc., New York, 1935.

LOBECK, A. K.: *Geomorphology, An Introduction to the Study of Landscapes*, McGraw-Hill Book Company, Inc., New York, 1939.

LONGWELL, C. R., A. KNOPF, and R. F. FLINT: *Physical Geology*, John Wiley & Sons, Inc., New York, 1932.

SALISBURY, R. D.: *Physiography*, Chaps. 1–8, Henry Holt & Company, Inc., New York, 1913.

TARR, R. S., and O. D. VON ENGELN: *New Physical Geography*, The Macmillan Company, New York, 1926.

WORCESTER, P. G.: *Textbook of Geomorphology*, D. Van Nostrand Company, Inc., New York, 1939.

Chapter X. River-made Plains

Lying east of the Rocky Mountains and stretching from the Rio Grande northward into western Canada is a vast area of gently rolling land. These are the great high plains, covered for the most part by short grass. Climatically, we know them as middle-latitude steppes. Eastward from the high plains to the Appalachian highlands extend the interior lowlands, wherein are found some of the finest agricultural lands in the world.

Of the four great classes of landforms—plains, plateaus, hill country, and mountains—plains rank first in area and as the home of man. Vast portions of the world's plains, however, are sparsely populated. This is due largely to (1) insufficient rainfall or (2) a poor distribution of precipitation during the year. On the other hand, favorable soil, drainage, and climate enable some large areas to support moderate to dense populations. Small areas of very dense populations in many instances are supported by manufacturing and commerce.

Plains constitute the great agricultural lands of the world, many of which are well supplied with a network of railroads and highways. In some parts of the American corn belt, an area that extends from central Kansas to eastern Ohio, as much as 70 to 80 per cent of the total land area is plowed and planted to crops. That leaves but 20 to 30 per cent to be devoted to permanent pasture, wood lots, farm buildings, roads, towns, and all other uses. This could not possibly be true of plateaus, hill regions, or mountains.

Plains are characterized by gentle slopes. The local relief, *i.e.*, the difference in elevation between the highest and lowest

points within a limited area, is usually less than 500 feet. In high mountains the local relief may be several thousand feet.

A study of the location and distribution of the world's great plains reveals the fact that considerable areas are tributary, both physically and commercially, to the Atlantic Ocean. This situation accounts somewhat for the tremendous amount of world trade that moves along the routes of that particular ocean. The Pacific Ocean, on the other hand, is bordered largely by young and growing mountains.

With regard to location, plains are divided into two great groups:

1. *Coastal plains* are those which border the sea. Atlantic and Gulf coastal plains of the United States belong to this group.

2. *Interior plains* are those located in the interiors of continents. The great high plains and interior lowlands of the United States and the extensive plains of central Russia belong to this group.

Rivers are responsible for the formation of some plains and account for many of the surface features of plains. We have learned that rivers accomplish mainly two types of work: (1) the erosion, or wearing away, of the land and (2) aggradation, or the building up, of the land by deposition of sediment. In our study of plains, therefore, we shall first consider those which are influenced largely by stream erosion and later those influenced by stream aggradation.

Stream-eroded Plains

Coastal Plains May Be Formed when the Sea Floor Is Uplifted. Flat to gently rolling coastal plains are found along many continental margins. Offshore is the submerged edge of the continent, called the *continental shelf* (Fig. 159). Shallow seas cover the continental shelves. A slight elevation of the land in such localities would add to the area of the coastal plain. A slight submergence would decrease the area (Fig. 160). Because of the work of waves and currents in evenly distributing ocean sediments, the surfaces of continental shelves are smooth and essentially flat.

When a portion of a continental shelf is slowly uplifted, a low and almost featureless plain is added to the continental margin. As the land emerges, inch by inch, it is attacked by

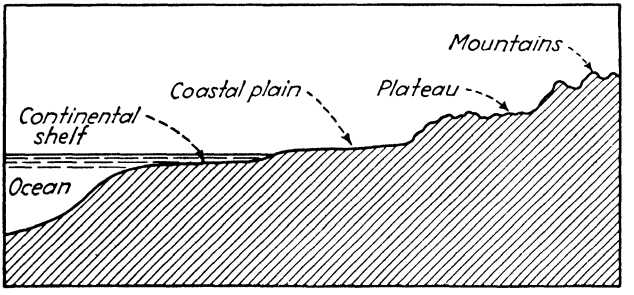


FIG. 159.—This diagram shows the relative elevation of coastal plain, plateau, and mountains. The continental shelf is a submerged portion of the continental margin. A slight uplift of the shore region would bring a part of the continental shelf above sea level.

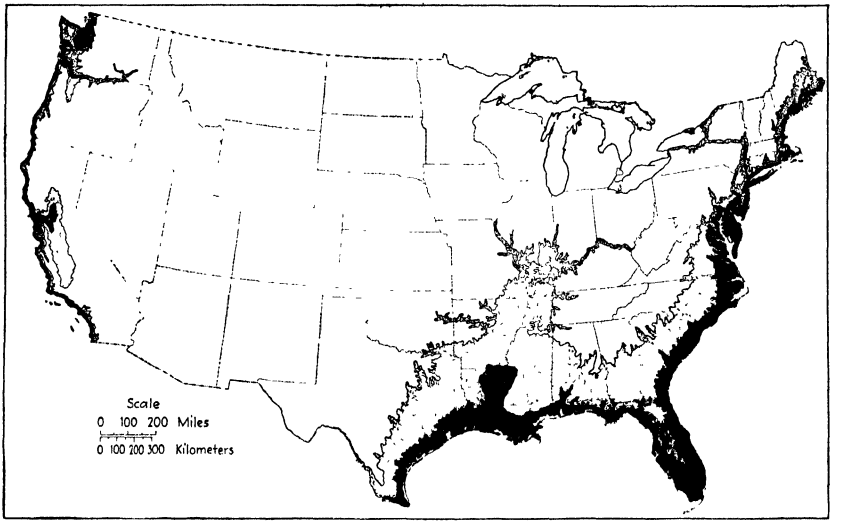


FIG. 160.—The black areas show the coastal margins that would be submerged if the land were to sink 100 feet. The dotted areas would be submerged if the land sank 500 feet. (*Courtesy of E. B. Branson and W. A. Tarr, from Introduction to Geology.*)

the agents of degradation. Streams, originating far inland, continue their courses across the new land of the coastal margin. Rainwash develops tributary gullies in it. Thus is produced a land surface modified by stream erosion. The valleys of low coastal plains, however, cannot be deep, because base level is

not far below the plain surface. Many shallow depressions that develop on such a flat coastal plain become swamps.

There are several plains of the world whose characteristic landforms indicate that they belong to the newly emerged class. Among them is that portion of the United States included in the coastal margins of the states of Virginia, the Carolinas, Georgia, and parts of the Gulf Coast from Florida to Texas. Most of this plain is flat, the local relief being less than 50 feet. There are large areas of swamps. Examples of unusually large swamps are shown by the Everglades of Florida (Fig. 161) and the Dismal Swamp of North Carolina and Virginia. The swamps of this

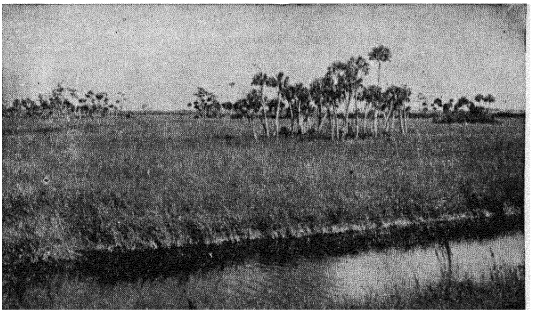


FIG. 161.—The flat, swampy surface of the Florida Everglades, part of a newly emerged plain.

coastal plain comprise nearly two-thirds of all the ill-drained lands of the United States.

Fall Line. The Atlantic Coastal Plain is bordered on the west by the Piedmont region, a higher area underlain by hard, crystalline rocks. As the streams pass from the more resistant rocks of the Piedmont on to the weaker rocks of the coastal plain, they tend to develop waterfalls and rapids. These have been harnessed in many places to provide hydroelectric power. As a result, a number of important cities, such as Augusta, Columbia, Raleigh, and Richmond, are located near these sources of power. A line trending from northeast to southwest and passing through a number of these power sites is often referred to as the *fall line* (Fig. 162). The available electrical energy, together with other factors, has stimulated manufacturing and industry in the Southeastern states. Especially is this true with respect to cotton manufacturing.

Stream-eroded Interior Plains. Extensive interior plains are located in Russia, United States, Canada, Brazil, Argentina, and Australia. For the most part these plains are underlain by more or less horizontal layers of sedimentary rocks. In North America, from the Appalachians to the Rocky Mountains, stretches the vast plains area. Near the Rockies these plains are about 5,000 feet above sea level and slope gently downward

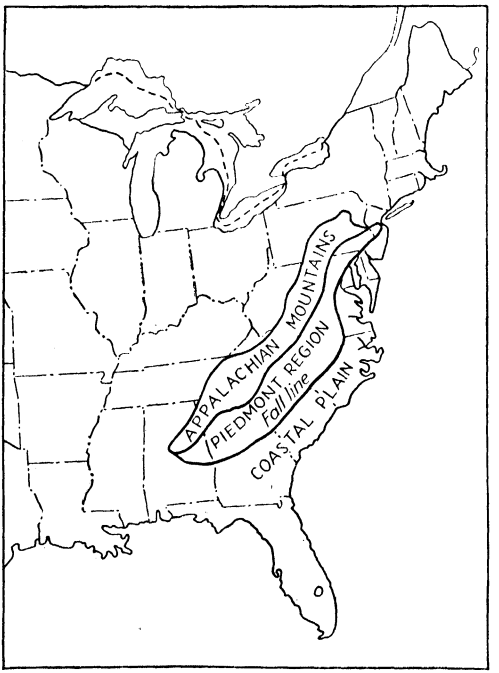


FIG. 162.—The so-called *fall line* lies along the western margin of the Atlantic Coastal Plain. The Piedmont region is higher and rougher than the coastal plain and is underlain by much harder rock.

to the Mississippi River, then upward toward the Appalachian hill region. Most of this great interior plain is drained by the Mississippi River and its thousands of tributaries.

In the *great high plains* area of the United States, broad, smooth, treeless uplands stretch for miles (Fig. 163). Because of the level surface, strong winds blow much of the time, both day and night. At intervals, narrow, steep-walled valleys traverse the plain, trending in general from west to east. Along these valleys are to be found the narrow strips of trees so typical of the Great Plains. The flat uplands between the valleys are the

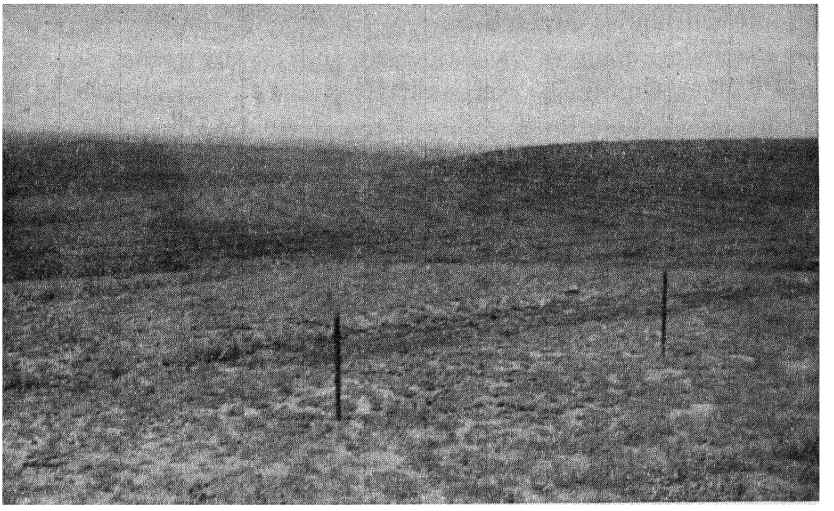


FIG. 163.—The great high plains of eastern Colorado are covered with the short grass typical of middle-latitude steppes. The parallel markings on the hill are plowed furrows made along contour lines to check soil erosion.

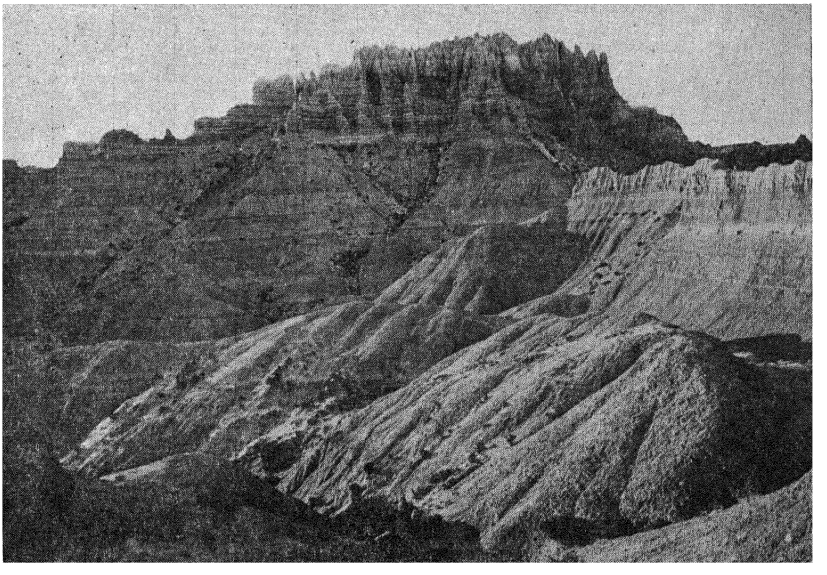


FIG. 164.—The rock formations of the Bad Lands in western South Dakota are composed of almost horizontal layers of sedimentary rocks, mainly shale. Vegetation is scarce, and erosion by hundreds of temporary streams takes place following a heavy rain. (*Courtesy of U.S. Geological Survey.*)

agricultural lands, devoted largely to grazing and dry farming. Some streams, such as the Arkansas and Platte rivers, develop wide valleys containing rich soil. Highways and railroads take advantage of these level valley floors. Irrigation projects, such as that near North Platte, Nebr., supply the much needed water that greatly increases the agricultural production of these valleys.

The *Bad Lands* of western South Dakota represent a peculiar interruption in the otherwise level to rolling Great Plains area

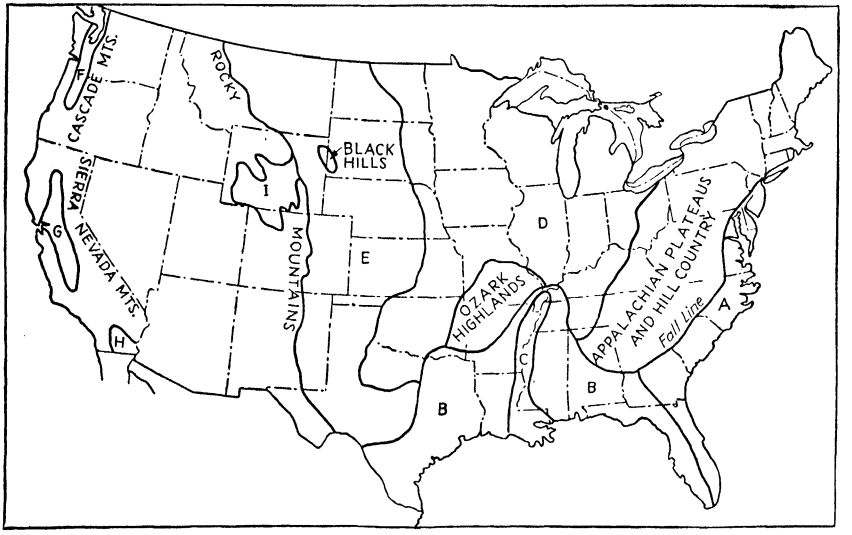


FIG. 165.—Major plains and lowlands of the United States: *A*, Coastal Plain; *B*, Gulf Coastal Plain; *C*, Mississippi floodplain; *D*, interior lowlands; *E*, Great High Plains; *F*, Puget Sound lowlands; *G*, Great California Valley; *H*, Imperial Valley; *I*, Wyoming Basin.

(Fig. 164). Here, in a semiarid climate, is found a nonresistant bedrock that is mainly shale. Occasional downpours of rain result in effective rain erosion, creating steep-sided gullies and deep valleys. Sharp-pointed hills may rise several hundred feet above adjacent valley floors. Many fossils of prehistoric animals have been discovered in the Bad Lands. An excellent automobile highway through the region makes it possible for tourists to view the peculiar erosional landforms from several vantage points.

In the *interior lowlands* (Fig. 165), where annual rainfall is greater than in the Great Plains, thousands of streams are at

work wearing away the surface of the land. A major stream with its hundreds of tributaries presents a treelike appearance on a map. Such is called a *dendritic* drainage pattern. Some streams in their downward cutting encounter rocks of unequal hardness and develop falls and rapids. Many of these waterfalls are not high. However, if they occur in the courses of large streams of uniform flow, they may have great capacity for producing water power. Examples of notable rapids or low waterfalls are (1) Muscle Shoals, Alabama, on the Tennessee River, (2) the rapids of the Mississippi at Keokuk, Iowa, and (3) the Ohio Falls at Louisville, where the Ohio River falls 26 feet in a short distance.

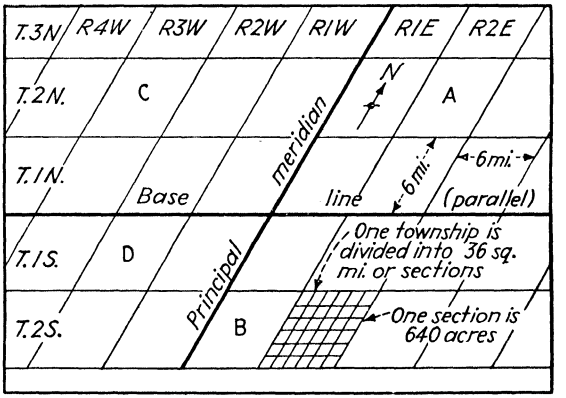


FIG. 166.—Over most of the United States, land is divided into townships and sections. Roads often follow township and section lines. Township *A* is described as Township 2 North, Range 2 East. Give the descriptions for *B*, *C*, and *D*.

Huge hydroelectric plants have been constructed at both Muscle Shoals and Keokuk. The falls at Louisville were sufficient to cause an important interruption to river navigation until they were made passable by a canal with locks.

Throughout much of the interior lowlands the land surface is gently rolling in nature. This is due largely to the fact that most of the valleys have reached various stages of maturity. Some of the larger rivers have developed valleys of old age. The sloping nature of the land for the most part provides good soil drainage. These rolling plains, under the influence of humid continental climate, comprise the extensive agricultural lands of middle America. The farm lands are divided into units by means of a system of townships and sections. A township is 6 by 6 miles, or

36 square miles (Fig. 166). One square mile is called *one section* and is divided into 640 acres. The average farm consists of 160 acres.

In the northern portions of the interior lowlands the plains were modified considerably by ancient continental glaciers. These glaciated plains will be discussed in the next chapter.

Karst Plains

Where Underground Water Dissolves and Removes Limestone. In various parts of the world are small plains, and some of considerable size, whose distinctive surface features result from the solution of rocks by underground water. They may be called *karst plains*. Regions of this kind are underlain by sedimentary rocks that include layers of pure limestone. In some karst plains the soluble limestones make up the surface rock

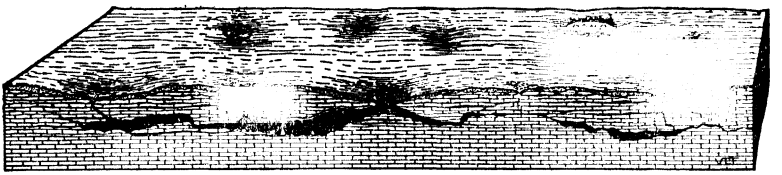


FIG. 167.—A diagram illustrating karst plain features. Sinks of various types are shown in relation to features of limestone solution underground.

formations and are covered only by a layer of soil. In other regions they lie beneath some thickness of other rocks. In either case, however, the surface features show evidence of the removal of material beneath the surface. As we have learned in a previous chapter, this is accomplished mainly by ground water containing weak carbonic acid. This acid aids in the dissolving and removal of limestone.

In contrast with stream-eroded plains, karst plains are distinguished by a general absence of valleys. There are exceptions in the case of large streams that originate outside and then flow across the karst area. Another striking characteristic of karst plains is the presence of many depressions without visible outlets. Some of these depressions are produced by surface solution, the water finding its outlet through the bottom into underground caverns. Some, on the other hand, appear to be the result of the collapse of roofs of caves. Such are called *sinks*. Some are many

feet deep, steep-sided, and have obvious openings through which the surface drainage runs underground. Others are so shallow as almost to escape notice. Occasionally the bottom outlet becomes clogged with clay or other materials, and the basin becomes a swamp or lake.

Associated with the underground drainage of karst plains is the formation of numerous caverns. In some regions these caverns thoroughly honeycomb the soluble limestones beneath (Fig. 167). Fed by surface drainage, the waters of many solution cavities pass along joint planes or dissolved channels and sometimes join to form underground streams of considerable size. They may come to the surface of the earth as springs of remarkable volume.



FIG. 168.—Numerous sinks, lakes, and swamps dot this Florida karst plain, but there are almost no surface streams.

Notable Karst Regions. Areas where surface features are due largely to solution of underlying rock take their name from the *Karst*. This is a rough limestone upland that lies back of the Adriatic shore of Yugoslavia. The same limestone structure produces similar features in the "heel" of Italy. In North America the most extensive karst areas are found in Florida, Cuba, and the peninsula of Yucatan. In the rolling upland plain of central Florida, sink holes of all sizes are separated by sandy ridges (Fig. 168). Small caverns are numerous. Underground drainage issues in springs, one of which has the largest flow of water of any spring in the United States. The entire region is characterized by the presence of lakes, ponds, and pools of which there are thousands. Another karst region is in south-central Kentucky. Considerable parts of this area are so dominated by solution features that sinks and ridges are the principal relief

features. Mammoth Cave in this region is widely known for its giant cavities and great underground extent.

Plains Formed of Stream Deposits or by Stream Aggradation

Alluvial Plains. The term *alluvium* is applied to weathered and eroded material that is carried and deposited by streams. For the most part this alluvium is deposited in the form of plains and usually in flat plains. Here it is spread out where it awaits future removal to lower elevations. In terms of geologic time, alluvial plains are temporary structures. Some indeed are of very recent origin, their accumulation still in progress. Others of much greater age are characterized by features that mark stages in the progress of their destruction. Such are called *plains of older alluvium.*

There are four principal classes of alluvial plains that we may consider. These are (1) delta plains, (2) floodplains, (3) piedmont alluvial plains, and (4) plains of older alluvium.

Delta Plains

Great Delta Plains. A delta plain is the surface of accumulations of river sediment deposited at the mouth of a stream where the stream enters a body of quiet water. Not all great streams have deltas, but all great deltas are the deposits of large streams. Among the more extensive delta plains is that of the Nile River in the Mediterranean Sea. It is characterized by a triangular shape resembling the Greek letter Δ, from which all similar alluvial deposits derive their name. Other deltas of note are situated at the mouths of the Po, Rhine, Indus, Ganges, Irrawaddy, Hwang Ho, and Mississippi. There are other large deltas, less well known, and thousands of smaller ones.

Delta Surface. The delta surface usually has a local relief of less than 50 feet. The seaward margin is the lowest portion, and slightly higher land is situated upstream. Occasional floods add to the elevation of the delta and push its boundaries seaward. The river current, except at time of flood, is very sluggish. The difference in surface elevation is not great even on large deltas. The highest portions of the upper delta of the Mississippi, which lie nearly 200 miles from the river mouth, are only about 40 feet higher than the delta margin (Fig. 169).

The features of greatest relief upon the delta surface are the *natural levees* (Fig. 170). These are low, broad ridges of alluvium that border the stream channels on either side. Such are found along the main stream and the distributaries. They are highest near the banks of the stream that builds them but, at least on the Mississippi delta, rise no more than 15 or 20 feet above the

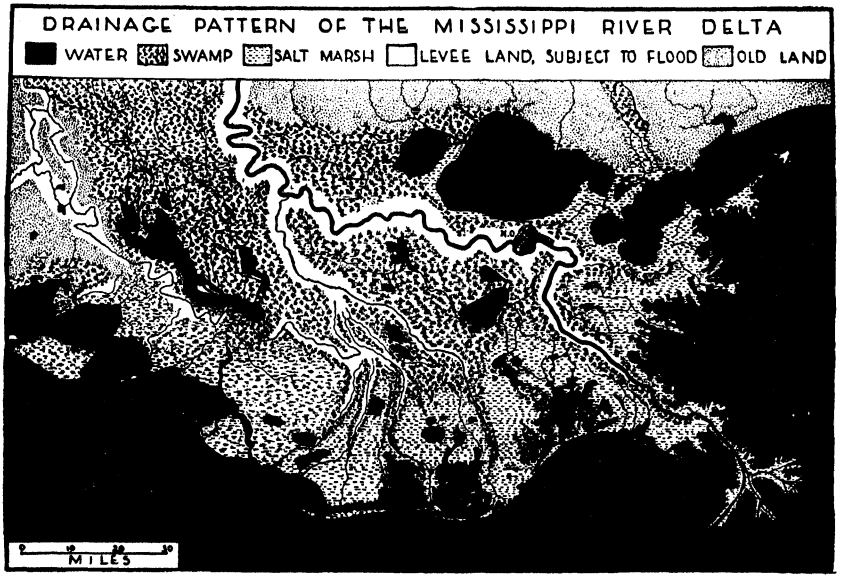


FIG. 169.—The Mississippi River delta has fringing areas of salt-marsh grass, belts of wooded swamp, and strips of tilled levee lands. Note that the levee lands grow narrow downstream and disappear.



FIG. 170.—This diagram shows the profiles of natural and artificial levees. The vertical scale is considerably exaggerated.

adjacent delta surface. New Orleans, La., is built on such a natural levee. Although the surface of the levee appears flat, there is a gentle slope from the river toward the adjoining marshes. It is this slope which makes possible a degree of drainage of these alluvial deposits. The levees and fresh-water swamps of the upper Mississippi delta formerly supported a growth of gumwood and cypress trees. The seaward margin of the delta, however, is covered mainly by vast expanses of tall, coarse grasses, the habitat of numberless muskrats.

Because the levees are the highest and best drained portions of the delta surface, they are the principal sites of human settlement. Farms, houses, and towns are found upon them, and roads and railways tend to follow them and to parallel the streams. For protection against river overflow, narrow artificial levees are built in some places near the stream upon the top of the natural levees. In times of high water on the Mississippi delta, the river surface may rise nearly to the top of the artificial

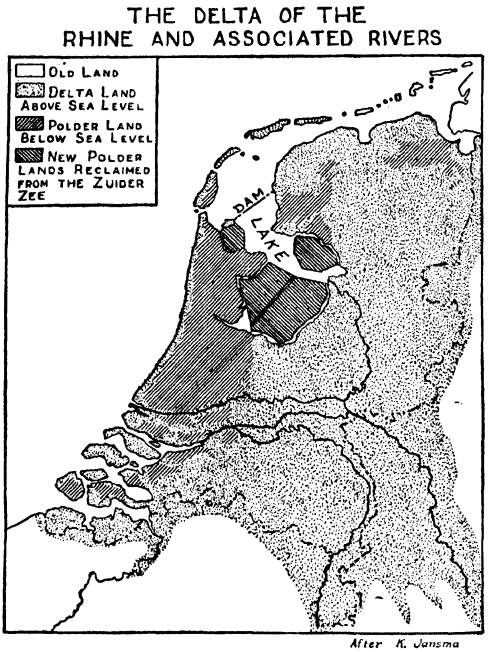


FIG. 171.—The extent of reclaimed land in the Netherlands in relation to the area of the Rhine delta.

levees or even overflow them. At such times the river stands several feet higher than the roads and farms on the natural levees and many feet above the swamps beyond. A break in the artificial levees at that time permits the flooding of a large part of the delta surface, and water may completely submerge the smaller levees of the lesser streams or even the great levees themselves.

Populous Delta Plains. Some deltas have very large human populations. The alluvial soil is rich because its silts and clays were derived from a great variety of rocks and soils found in the

headwaters of numerous tributaries. The natural food-producing capacity of such soil is great. In populous deltas, the need for additional acreage of the fertile soil has caused man to change the natural surface drainage in many places. These are illustrated by the deltas of the Rhine and the Nile.

The Netherlands coast includes the merged deltas of the Rhine, Meuse, and Scheldt rivers (Fig. 171). Originally the region had the features common to delta surfaces. Through several centuries a growing need for land has encouraged the

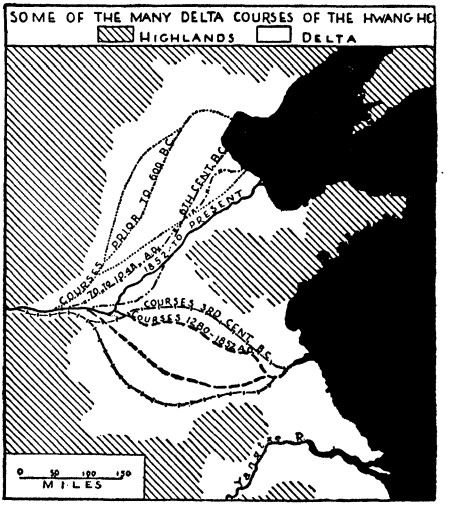


FIG. 172.—The great delta of North China, its relation to the Shantung Peninsula, and some of the many channels the river has occupied within historic times. (*After maps by G. B. Cressey and D. W. Mead.*)

inhabitants of this region to reclaim the marshlands. Actually, they have crowded the sea off the delta margin. Small areas of lower levee and swampland have been made secure from floods by the construction of dikes, or artificial levees. Each enclosed area, called a *polder*, is kept sufficiently drained for agriculture by a network of drainage ditches leading to a pump at the lowest corner. This pump lifts the water from the polder into a bordering stream or canal which lies between the dikes or really on top of them. Today large areas of drained lands lie between 5 and 10 feet, and some as much as 15 feet, below sea level. The older polders were pumped by picturesque windmills. The newer ones, designed with modern engineering skill, are pumped by engines. The newest and greatest project has been designed

to cut off and drain the Zuyder Zee. This was a great and shallow coastal bay, much like Lake Pontchartrain near New Orleans.

The great delta of North China is comprised largely of yellow loess soil derived from the highlands of northern China and deposited by the Hwang Ho and some other streams. The color of the sediment accounts for the names *Yellow River* and *Yellow Sea.* So abundant are the deposits that they have filled a considerable portion of the Yellow Sea. They half surround a large, mountainous island that formerly stood in it. What was once that island is now the Shantung Peninsula (Fig. 172). The Hwang Ho flows across the northern part of the delta on a broad levee ridge which in places is as much as 20 feet high. Owing to deposition of sediment in its channel, the river is of little use for navigation. At times of low water the inhabitants remove large quantities of soil from the stream bed. This is done partly to keep the channel open and partly because of the value of the mud as fertilizer. During severe floods the river has shifted its course to the *opposite side* of the Shantung Peninsula. Such a change, on a densely populated plain, is a major disaster. Thus the Hwang Ho is known as "China's Sorrow."

Great Delta Plains of Arid Lands. A few of the great delta plains of the world are on desert coasts. They are built by large streams which are fed by the abundant precipitation of mountain regions. Such streams have sufficient volume to flow completely across the desert areas where few tributaries exist. Finally they discharge their loads of sediment into the bordering sea. Such are called *exotic* streams. Outstanding among them are the Nile, the Tigris-Euphrates, the Indus, and the Colorado.

The delta of the Nile has a density of population comparable with that of the plain of North China. The people are supported by agriculture that depends almost wholly upon the practice of irrigation. Unlike the Netherlands, the main problem in these arid-land deltas is to distribute the water over the delta surface. Dams are constructed, and gravity carries irrigation water through ditches. The deltas and floodplains of the major exotic streams, therefore, constitute one class of desert oasis. They are the largest and most productive oases in the world.

The Nile has two important tributaries. The White Nile has its headwaters in Lake Victoria on the equator; the Blue Nile

originates as the overflow of Lake Tana in Ethiopia (Fig. 173). Periodic rains in Ethiopia cause the Blue Nile to flood. These floodwaters are impounded by dams, such as the huge one at Aswan, and are responsible for the perennial irrigation of the floodplain. In its lower course the Nile traverses 1,000 miles of desert where it loses volume (1) by the removal of water for irrigation, (2) by evaporation, and (3) by seepage. On the delta so much more water is required for irrigation that only a little

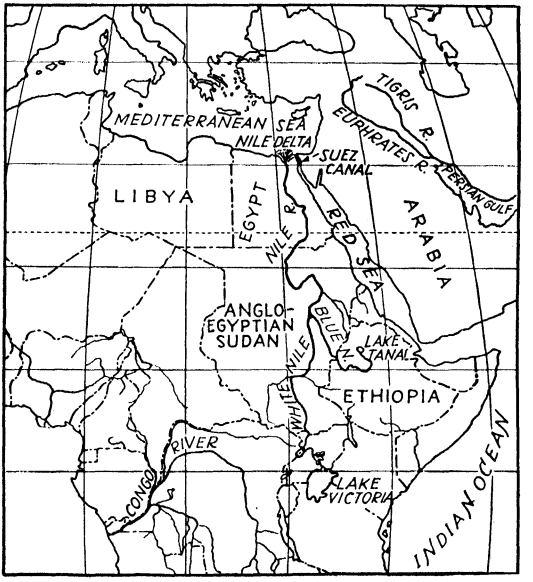


FIG. 173.—The Nile delta is built into the Mediterranean Sea. The delta of the Tigris and Euphrates rivers is built into the northern end of the Persian Gulf. Heavy rains in the mountains of Ethiopia are responsible for the floods of the Blue Nile.

is discharged through the distributary mouths into the Mediterranean. So much sediment is deposited on the delta head and so little about the margins that the surface has a fair slope. This prevents floods and makes soil drainage easier. Nearly the whole surface is cultivated, and lakes and swamps are found only about the delta margins. This is in striking contrast to conditions on the Mississippi delta.

The Colorado River delta has been built into and across the northern portion of the long tectonic depression occupied by the Gulf of California (Fig. 174). It was started on the east side, and by pushing across to the west wall of the depression it blocked

off about 150 miles of the upper end of the Gulf. The water in the depression north of the delta evaporated, forming Salton Sink, a part of whose floor lies 275 feet below sea level. Irrigation canals carry the water from the Colorado River near Yuma to the surface of the delta. In 1904 and 1905 the river flooded, broke through the canals, and poured into Salton Sink forming Salton Sea, an inland lake some 50 miles long and far below sea level. The area just south of Salton Sea is called the *Imperial Valley*. Some of it is below sea level. Under irrigation and with an all-year warm climate, it is a highly productive agricultural region. Irrigation facilities have been improved by the construction of the All-American Canal.

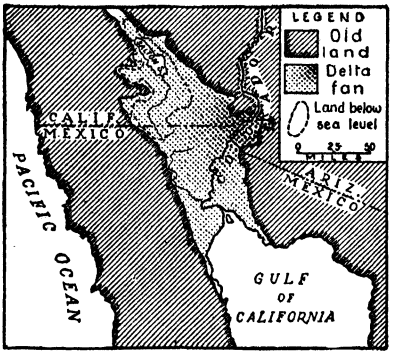


FIG. 174.—The apex of the delta fan of the Colorado River is at the east side of the long embayment into which it is built. The location and extent of Salton Sink are indicated by the broken line. Salton Sea lies in its lowest portion; its bottom is 274 feet below sea level.

FLOODPLAINS

Floodplains are the alluvial deposits spread by aggrading streams upon the floors of their valleys during the process of valley widening and stream overflow (Fig. 175). The floodplain begins to form in the lower course of the stream where it first reaches grade. Near the river mouth, delta and floodplain blend together, and it is difficult to say just where one begins and the other ends. Floodplains are confined between the bluffs cut by the lateral erosion of a meandering stream (Figs. 176, 177). The bluffs usually are much gullied. The width of the floodplain is the distance from one valley wall to the other (Fig. 178). This width varies from a few yards in the case of small, aggrading creeks to several miles in large river valleys. Width usually increases downstream. The Mississippi floodplain, where the stream flows between Iowa and Wisconsin, is from 1 to 3 miles wide; in the latitude of southern Illinois it is about 6 miles, but below Cairo it broadens rapidly and, including the plains of minor streams that join it, ranges between 25 and 75 miles in width. At Kansas City the floodplain of the Missouri River is

several miles wide. The level land provides ample space for numerous industries and for two large airports (Fig. 179).

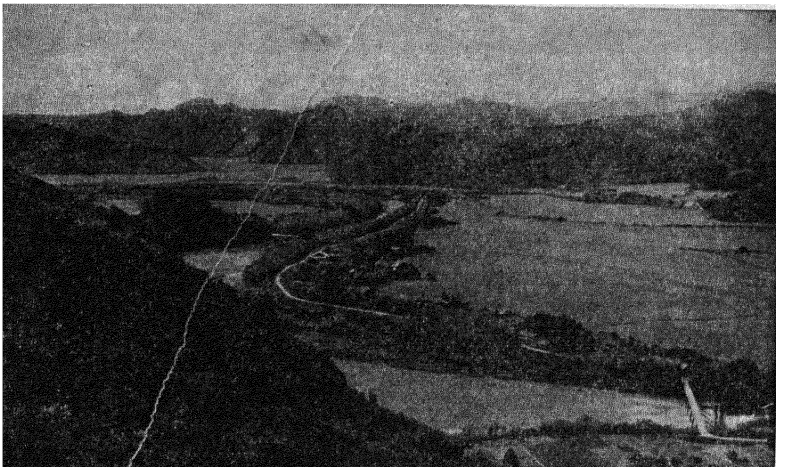


FIG. 175.—The floodplain and levees of a small stream among the hills of Japan. The stream may be located by noting the footbridges that cross it. The path follows one levee, and rice fields lie on the lower levee and floodplain surfaces.

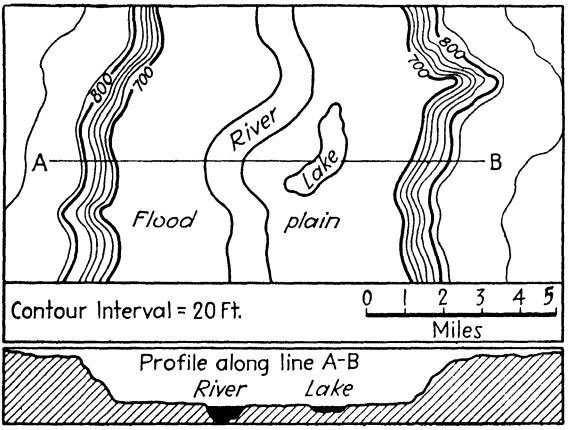


FIG. 176.—Contour map and profile drawing of a large river and its floodplain. A contour line is one that passes through points that are the same elevation above sea level. What is the elevation of the floodplain? How high are the bluffs above the floodplain? How was the lake probably formed? What is the width of the river? Of the floodplain?

Floodplain Surface. Floodplains are somewhat similar to the upper part of a delta. They comprise principally a monotonously flat surface upon which areas of levee land alternate with areas of swamps. The valley floor is at times a place of

rapid change. Its features are reshaped and modified by erosion and deposition which take place at the same time. Meanders swing back and forth from one valley wall to the other. Erosion

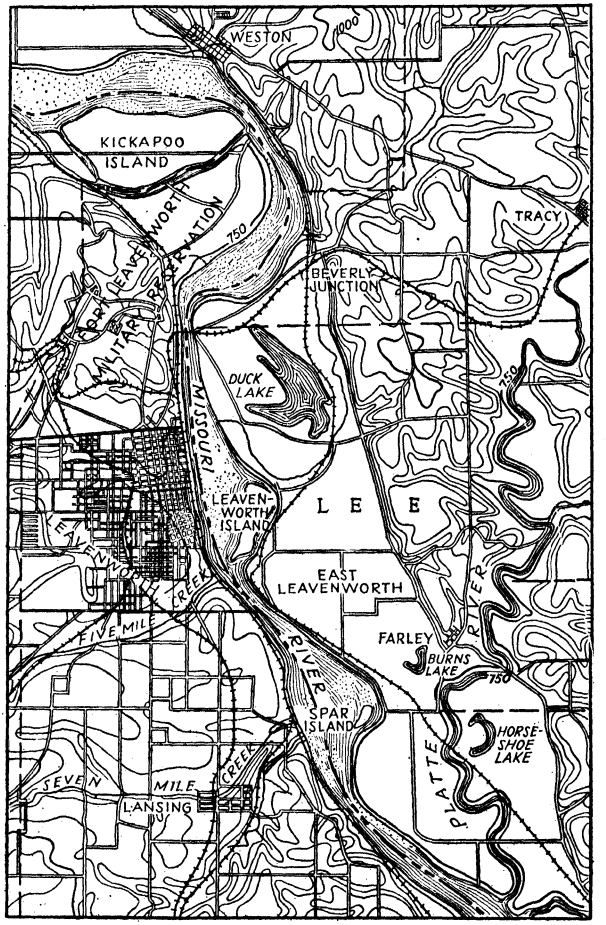


FIG. 177.—Contour map showing Missouri River floodplain at Leavenworth, Kans. The river forms the Missouri-Kansas boundary line. The contour interval is 50 feet. The entire area is 9 by 14 miles. How wide is the floodplain? What is its elevation? About how high are the bluffs along the edge of the floodplain? The dotted areas in the river represent sand bars. Both Missouri and Platte rivers flow toward the south. Explain how the three lakes probably were formed. (*After map by U.S. Geological Survey.*)

on the outside and deposition on the inside of a curve cause the meander to change shape. It sometimes happens that a river will curve in such a way as to form almost a complete loop. Ultimately the stream cuts through the narrow neck of land

separating the two ends of the loop; and the long, horseshoe-shaped meander is abandoned and remains on the floodplain

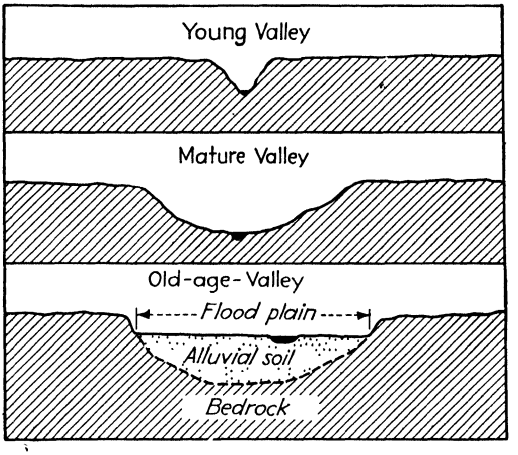


FIG. 178.—This diagram shows the profiles of various types of valleys. Broad floodplains are characteristic of old-age valleys.

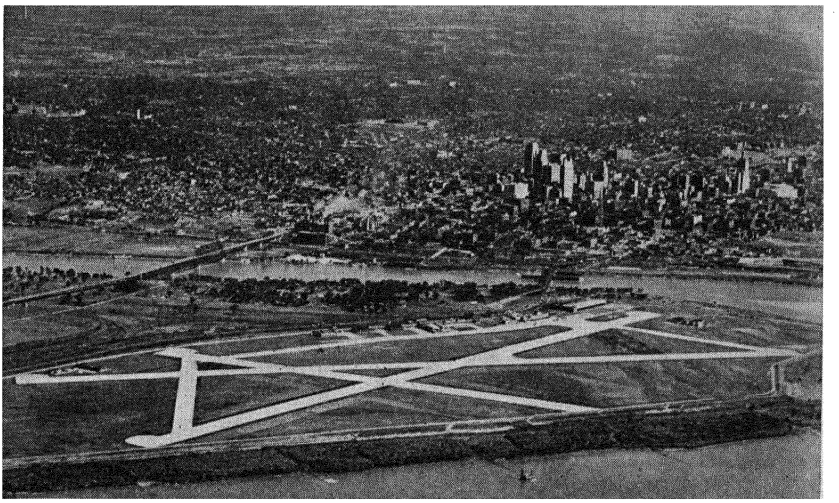


FIG. 179.—The Kansas City, Mo., Municipal Air Terminal is located on the floodplain of the Missouri River. Note the artificial levee in the foreground. The business district of the city may be seen in the background. (*Courtesy of Kansas City Chamber of Commerce.*)

as a lake. Such are called *oxbow lakes* (Fig. 180). Locally they are known as *sloughs* or, in southern United States, *bayous*. In time these oxbow lakes are filled (1) by sediment deposited during general river floods, (2) by rainwashed sediment from

the adjacent surface, and (3) by the growth and decay of vegetation.

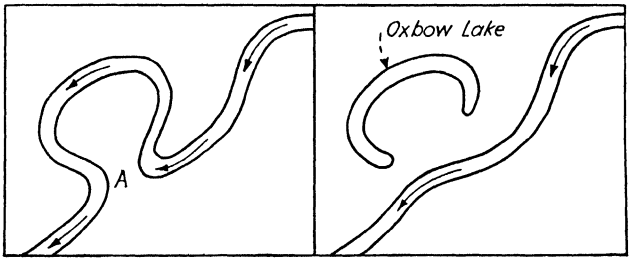


FIG. 180.—Formation of an oxbow lake. The river breaks through the narrow neck of land at *A*. The abandoned channel of the river is the basin occupied by the oxbow lake.

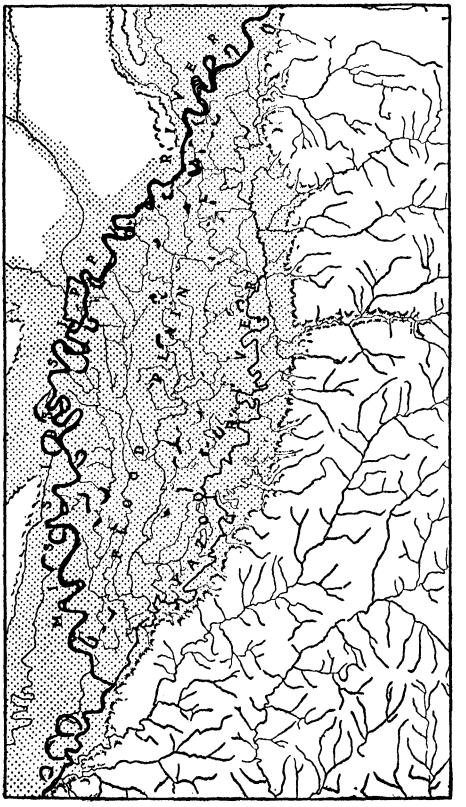


FIG. 181.—After the upper headwaters of the Yazoo River enter the broad bottom lands, the stream follows the bluffs for 175 miles before it enters the Mississippi.

Small streams entering the floodplain from the bordering uplands are sometimes prevented from joining the main stream

at once because of the upward slope of the natural levees. Instead, they turn downstream and, after paralleling the main stream some distance, find a place of entrance. The junction of the St. Francis and Yazoo rivers with the Mississippi illustrates this condition (Fig. 181).

Alluvial Terraces. Suppose that the upper end of an old valley is uplifted several feet. The stream is given renewed velocity. It cuts a new valley in the old one. Along the sides of the new valley will be observed the flat benches formed by the remnants of the old floodplain. They are called *alluvial terraces* (Fig. 182). Some valleys exhibit several such terraces. Although they seldom are high or continuous, they frequently contain many acres and sometimes many square miles of land. Because such terrace land is sufficiently above present river level to be free from floods, it generally is well drained and admirably

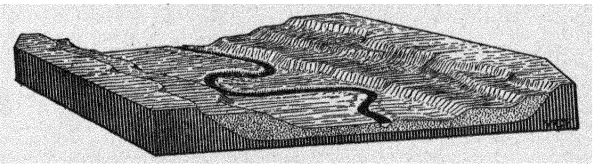


FIG. 182.—This diagram illustrates the development of alluvial terraces. Natural levees border the present stream course.

adapted to cultivation. Sites of this kind are suitable for the building of river towns and cities. Part of St. Paul, Minn., is built on alluvial terraces.

River Floods. Floods do their greatest damage in old-age valleys, because (1) the valley floor is level and easily flooded and (2) such valleys often are densely populated within limited areas (Fig. 183). Among the major causes of river floods are abnormally heavy rains and the rapid melting of deep snows in mountains. The cutting of forests increases the immediate runoff of rain water. More water is carried to the main river than it can hold within its levee banks.

Means of flood control are being established in many American rivers. A number of dams have been built across the Mississippi River to impound floodwaters and to aid navigation. Millions of dollars have been spent on the Ohio and Missouri rivers. The Missouri River, with its great dam at Fort Peck, Mont., is being confined to a straighter channel by means of

dikes and revetments, or retaining walls. Artificial levees along the lower Mississippi have been increased in height. Floods, however, continue to do great damage. The lower Mississippi flooded disastrously in the spring of 1927; the lower Missouri, in the spring of 1935. Considerable loss resulted from the 1936 floods of the Connecticut and other eastern rivers. One of the most severe floods in the history of the United States occurred



FIG. 183.—High water on the lower Mississippi floodplain. The artificial levee is the only land remaining unsubmerged. The main channel of the river is seen in the far distance. The locations of several natural levees associated with minor channels are indicated by the belts of submerged woodlands and the town. (*Courtesy of U.S. Army Air Corps, official photograph.*)

in the Ohio Valley in February, 1937. Certainly the flood problem is by no means solved. Reforestation and the building of flood-control dams should help considerably.

Drainage of Floodplains. Where possible, floodplain soils are drained of excess water. This drainage is accomplished (1) by digging huge ditches which carry the water to the river and (2) by laying tile leading into the ditches. The rich alluvial soils, when properly drained, usually are highly productive. The higher portions of the floodplain, especially the natural levees,

are more valuable as farm land because they are more easily drained. The water table is never very far from the surface, and during droughts crops in floodplains may survive while those on adjoining uplands suffer serious injury.

Piedmont Alluvial Plains

Alluvial Fans. As previously explained, alluvial fans form at the base of mountains and are more characteristic of arid and semiarid lands than of humid regions. Piedmont alluvial plains are made up of alluvial fans so closely spaced that their margins are merged into one continuous plain.

Streams with steep gradients furnish abundant sediment, some of it coarse in texture. This sediment clogs the stream channel at the point where the mountain gradient changes to that of the bordering plain. The choked stream breaks over its banks into several distributary channels. A network of such channels produces an alluvial deposit with a nicely rounded or semicircular outline and gives the feature its fanlike shape (Fig. 184). The coarser materials are deposited at the apex or head of the fan; the finer are spread out over the margins. As the feature grows in size, the ordinary flow of the stream that produces it may be wholly absorbed by seepage into the coarse upper fan deposits. Here the stream deposits much of its sediment. Thus the upper part of the fan has steeper slopes than the lower. However, not even the upper slopes of a great fan are very steep. The outer margins are so gently sloping as to seem an almost flat and featureless plain. Because the slopes of the fan radiate from the apex, irrigation water applied at its upper end may be distributed by gravity to all parts of the fan surface.

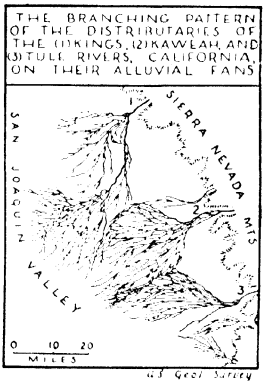


FIG. 184.

Piedmont Alluvial Plains. The size of a piedmont alluvial plain depends upon the volume and deposits of the several streams draining the mountain front. The "heads," or highest portions, of the several fans may be distinguished at the mouths of the valleys. These heads are composed largely of gravel and

sand. Their surfaces often are strewn with boulders distributed by floodwaters following torrential rains in the mountains. Here are to be found coarse soils that are unable to retain irrigation water. For these reasons the higher parts of the fans are somewhat avoided for intensive agricultural use. However, they may furnish sand and gravel for constructional purposes.

Many piedmont alluvial plains are covered only with desert shrubs or sparse grasses. The finer soils, however, are rich in mineral content and under irrigation are highly productive. Irrigation water is supplied (1) by the streams that have formed the fans and (2) by wells drilled below the water table beneath the fan surface. In some cases the water is carried beyond the fan and used to irrigate floodplains that occur at lower elevations.

Noted Piedmont Alluvial Plains. Some piedmont alluvial plains that are properly irrigated are noted for their agricultural wealth. Among them are the Sacramento and San Joaquin valleys of California, the Vale of Chile, the Valencia district of Spain, the Samarkand district of Russian Turkestan, the Tarim Basin, and many others.

The valleys of the San Joaquin and Sacramento rivers constitute the Great California Valley. This valley lies between the Sierra Nevada Mountains and the Coastal Ranges. It is often called a *filled valley*, like the Vale of Chile, because of the tremendous amount of alluvium that has been deposited over the valley floor. The most numerous alluvial fans are found along the western slopes of the Sierras. One, formed by the King's River, extends outward into the valley for 50 miles from the mountain base. The melting snows of the Sierras furnish large supplies of irrigation water. The combination of rich alluvial soil, irrigation, and warm, dry climate makes this a region noted for fruit production.

Plains of Older Alluvium

Nature of Older Alluvium. Certain of the world's considerable plains are described as plains of older alluvium. The material forming them is much older than that of recently formed deltas and alluvial fans. The largest plains of this type are distributed beyond the margins of great mountain systems and were no doubt, at the time of their formation, vast piedmont alluvial

plains. At present they are traversed by the valleys of streams that originate in the near-by mountains.

Important Plains of Older Alluvium. In northern India the broad middle and upper valleys of the Ganges and Indus rivers are filled to great depth with older alluvium. Into this plain the present streams that drain the Himalaya mountain front have cut new valleys. Part of the Po plain in northern Italy consists of older alluvium derived from the southern slopes of the Alps. The Pampa of Argentina (Fig. 185) is underlain by deep accumulations of sediment thought to have been washed from the eastern slopes of the Andes.



FIG. 185.—The Argentine *pampa*, near Rosario, a low flat plain comprised largely of older alluvium. (*Photograph by H. G. Olds.*)

In the United States almost the entire eastern front of the Rocky Mountains is bordered by plains of older alluvium. This is the Great Plains region. It is being worn down very slowly by streams that originate in the Rockies and flow east. Just east of the mountains in northern Colorado, these plains are irrigated and constitute the leading sugar-beet area of the United States. This highly productive region is known as the *Colorado Piedmont.*

Summary

Landforms that are caused by

River erosion	River deposition
Valleys	Deltas and sandbars
Divides	Alluvial fans
Canyons	Alluvial terraces

Gorges
Waterfalls
Rapids
Floodplains
Piedmont alluvial plains

Vast areas of the world's plains have gently rolling surfaces due largely to river and stream erosion. Such a rolling surface makes for better soil drainage. Where slopes are too steep, however, cultivation of the land is difficult, and much rain water is lost by immediate surface runoff.

Floodplains and delta plains, composed as they are of rich alluvial soil, are highly productive agricultural lands when they can be properly drained. Irrigated alluvial fans and other alluvial deposits constitute much of the rich fruit lands of California and other western states.

Questions

1. Name the four great classes of landforms. Which is most extensive?
2. Why are some parts of plains sparsely populated? Densely populated?
3. What is meant by local relief?
4. What is a continental shelf?
5. What type of plain is produced by slow emergence of a continental shelf? Describe its surface.
6. Where are the Everglades? Where is the Dismal Swamp?
7. Where is the fall line? What use is made of waterfalls along this line?
8. Name several cities along the fall line.
9. In the United States, where are the great high plains? Interior lowlands?
10. Describe the great high plains. What use is made of these rolling plains?
11. Extensive irrigation is done along the Arkansas and Platte rivers. Locate these rivers.
12. Locate and describe the Bad Lands. What caused such an area as this?
13. What is meant by dendritic drainage?
14. Locate Keokuk. Muscle Shoals. Ohio Falls.
15. What factors combine to make the interior lowlands an important agricultural region?
16. What is a township? A section?
17. Explain how karst plains are formed. Describe such a region.

18. Locate several noted karst plains.

19. Why do some karst plains have few large surface streams?

20. Define alluvium.

21. Name the four principal classes of alluvial plains.

22. Define delta plain. What is the origin of the name "delta"?

23. Name 10 rivers having large deltas. Locate each (use atlas).

24. What is the usual local relief of a delta plain?

25. What is a natural levee? How is it formed? Why is it important?

26. Describe the natural vegetation of the Mississippi delta.

27. What is an artificial levee? Where is such a levee often built?

28. Why do they say in Louisiana, "We go up to see the river"?

29. Why are soils that are derived from a great variety of rocks likely to be rich?

30. What rivers form the Netherlands delta? What is a polder? How is it drained?

31. Where is the Shantung Peninsula? Is it densely or sparsely populated?

32. What kind of sediment does the Hwang Ho carry? What is its source? Its color?

33. How does the Hwang Ho change its course during bad floods? What is the result?

34. What is an exotic stream? Name and locate four.

35. Name the two important tributaries of the Nile. Locate the source of each.

36. Why are the periodic rains of Ethiopia of vital importance to Egypt?

37. Why does the Nile become smaller in its lower course?

38. Why does the Nile delta have a fair slope? Why is this important?

39. Explain how Salton Sink was formed. Locate.

40. Explain how Salton Sea was formed.

41. Where is Imperial Valley? Why is it highly productive?

42. Define floodplain.

43. How is the width of a floodplain measured? How does the width of the Mississippi floodplain vary?

44. Explain how oxbow lakes are formed. By what other names are they called? Are they of any value? Why do they disappear?

45. How are alluvial terraces formed?

46. Should you prefer a farm on an alluvial terrace or on a floodplain? Why?

47. Why do floods do greatest damage in old-age valleys?

48. Mention the principal causes of floods.

49. What steps are being taken to prevent floods?

50. The Missouri River channel is being straightened and made more permanent by dikes and revetments. What will be the advantage of this?

51. How are floodplains drained? Why remove excess water from soil?

52. Explain the deposition of sediment on an alluvial fan.

53. Why is irrigation of an alluvial fan not a difficult matter provided sufficient water is available?

54. Why are the higher parts of alluvial fans less valuable for agriculture than the lower margins?

55. What are the possible sources of irrigation water for alluvial fans?

56. Name and locate five noted piedmont alluvial plains.

57. What two principal rivers occupy the Great California Valley? Why is this sometimes called a "filled valley"?

58. What three conditions combine to make the California Valley noted for fruit production?

59. How does older alluvium differ from the soil of a recently formed alluvial fan?

60. Why is old alluvium in humid climates generally leached?

61. Name and locate several important plains of older alluvium.

62. Where is the Colorado Piedmont? Discuss its importance.

Suggested Activities

1. On an outline map of the world, locate and label every place mentioned in this chapter.

2. Make a chart as follows: On the left margin print the names of the continents. Under each continent list the principal rivers. Across the top of the chart print the following column headings: In what country? Flows toward what direction? Empties into what body of water? Important cities on delta or floodplain?

3. On an outline map of the world draw 25 to 50 important rivers. Number them. Test your knowledge of location by trying to name each one correctly. Name at least 25 in the United States alone.

4. On a map of the United States, color and label the principal government irrigation projects.

5. Draw a map of the Tennessee River region. Locate and label the various dams.

6. Contrast in as many ways as possible the Nile and Mississippi deltas.

7. Contrast in as many ways as possible the Amazon and Mississippi floodplains.

8. Using molding materials, make relief models of a delta, alluvial fans, alluvial terraces, Salton Sink, Great California Valley, etc. Color the water blue.

9. Make a relief model of a floodplain showing natural levees, oxbow lakes, drainage, etc.

10. Mold a surface showing typical karst surface features.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Muscle Shoals
2. The Everglades of Florida
3. The Karst Region of Florida
4. The Valley of the Rio Grande River
5. The Delta of the Ganges
6. The Mississippi Delta
7. The 1936 Flood of the Ohio River
8. Flood Control on the Mississippi
9. Bad Lands of South Dakota
10. Imperial Valley of Southern California
11. The Tigris-Euphrates Valley
12. The Colorado Piedmont

REFERENCES

BRANSON, E. B., and W. A. TARR: *Introduction to Geology*, McGraw-Hill Book Company, Inc., New York, 1935.

LOBECK, A. K.: *Airways of America*, The Geographical Press, Columbia University, New York, 1933.

SALISBURY, R. D.: *Physiography*, Henry Holt & Company, Inc., New York, 1919.

TARR, R. S., and LAWRENCE MARTIN: *College Physiography*, The Macmillan Company, New York, 1928.

Chapter XI. Glaciated Plains

Imagine that Fig. 186 represents a plain about 500 miles long. A glacier, centered at *A*, slowly pushes its way southward. The moving ice erodes and scours the upper half of the plain. Much of the loose rock and soil at *A* is carried southward and deposited over the lower part of the plain marked *B*. Then comes a slight change in climate which causes the glacier to melt slowly. Many streams issue from the front edge of the ice, and much of the area labeled *C* is covered with water-deposited sediment. This illustration shows that a large glacier may change the land surface in three ways:

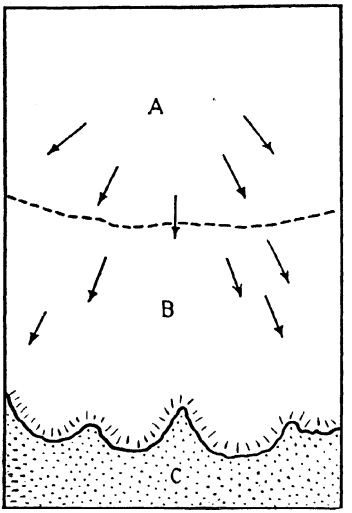


FIG. 186.

1. By glacial scour or erosion
2. By the deposition of rock waste or glacial drift
3. By deposition of sediment by streams issuing from the ice.

Now imagine that, after the glacier has disappeared, we can travel over the entire area. At *A* we can study the features of a plain resulting mainly from glacial scour. At *B* we can study a plain influenced mainly by deposition of glacial drift. Our observations show that the two types of plains differ considerably.

Thousands of years ago, huge continental glaciers moved slowly southward over northern North America and northwestern Europe. These glaciers greatly modified or changed

the features of the land. Over certain extensive areas the land surface is the result mainly of glacial erosion. Over other areas deposition of glacial drift predominates. It is possible, therefore, to distinguish two general types of glaciated plains:

1. *Ice-scoured plains*, where erosion predominated
2. *Drift plains*, where deposition predominated

The Features of Ice-scoured Plains

Ice-scoured Surface. The stream-eroded hills and valleys that previously existed on the plains over which the great con-

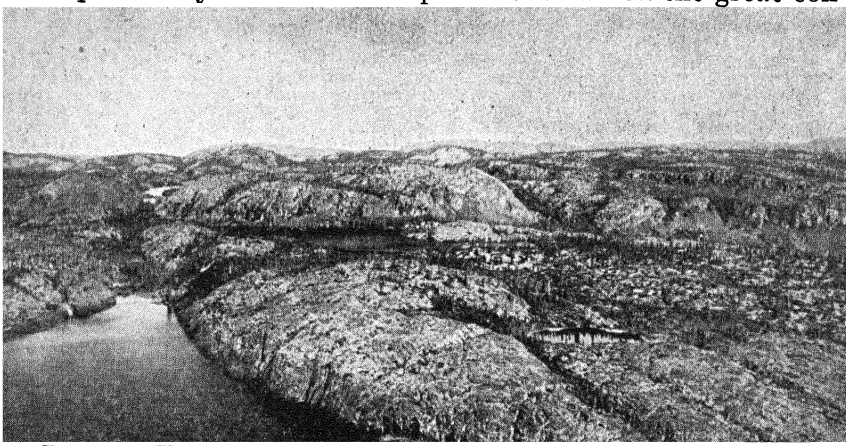


FIG. 187.—The rounded hills and rock basins of an ice-scoured surface in northern Canada where vegetation is scant. Note the different elevations of the lakes. (*Courtesy of Royal Canadian Air Force.*)

tinental glacier crept were reshaped by the overpowering weight of the moving ice. Angular rock features were changed to smooth, rounded forms. Over the valley floor was deposited a thin coating of glacial drift.

The drift of ice-scoured plains is neither continuous nor deep enough to be used for agricultural production except in patches or localities. It is strewn with boulders torn from adjacent slopes by the ice. It may, however, support a stand of trees, especially the shallow-rooted conifers, such as pines. Through the glacial drift project the smoothed and rounded tops of rock hills, many of which are entirely without soil covering (Fig. 187). Such surfaces, scoured and polished by ice erosion, often bear the grooves and striations scratched upon them by ice-pushed pebbles. Some of these marks are as fresh

as if they had been formed only recently instead of thousands of years ago. From studies of these scratches much has been learned about the nature and directions of ice motion during the time of glaciation.

Drainage of Ice-scoured Plains. Surface changes produced by ice scour were sufficient to change considerably the pre-

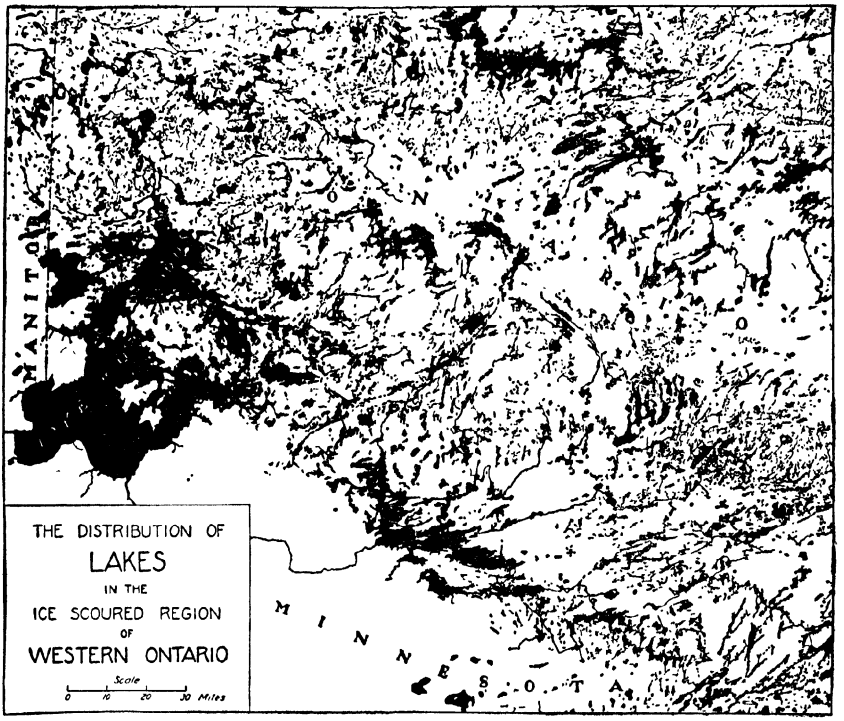


FIG. 188.—Sprawling lakes, mainly in rock basins, occupy much of the ice-scoured plain of western Ontario. They are proving a valuable resource in the development of the summer-resort industry. (*After Map 24A, Province of Ontario, Department of Surveys.*)

existing drainage. Glaciated areas do not have the complete system of stream drainage typical of many unglaciated regions. Lakes are numerous (Fig. 188). Many of these lakes lie in rock basins gouged out of the surface rock by the ice. The larger lakes often are dotted with numerous islands which are the rounded tops of more resistant rock masses. These lakes tend to be more permanent than those formed in other ways. The reasons for that are: (1) Incoming streams, flowing over hard rock, carry little sediment; (2) overflow water is clear and,

therefore, erodes the place of overflow very little; and (3) forests check immediate runoff of rain water which would collect sediment and tend to fill the lake basins.

The rock basins eroded by the ice sometimes differ considerably in elevation. Consequently, streams flowing from one basin to another often are characterized by rapids and waterfalls. Because of the hard rock and lack of sediment carried by these streams, the waterfalls are more permanent than those

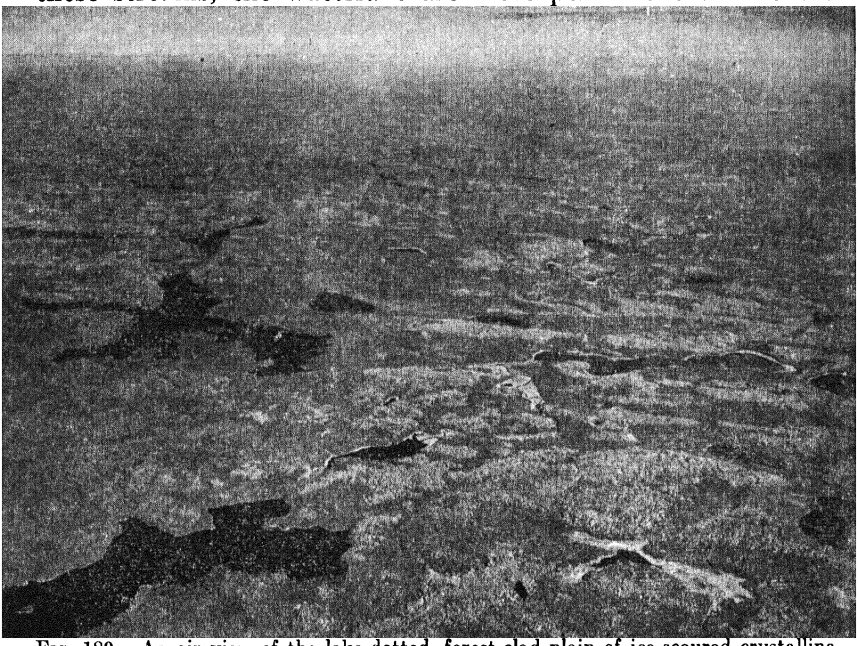


FIG. 189.—An air view of the lake-dotted, forest-clad plain of ice-scoured crystalline rocks north of Lake Superior. (*Courtesy of Royal Canadian Air Force.*)

existing under different conditions. Ice-scoured plains, therefore, rank high in available water power.

Extensive Ice-scoured Plains. The most extensive ice-scoured plains in the world are found close to the centers from which the great glaciers of Europe and North America radiated. These regions are

1. The Laurentian upland—a large part of Canada north of the Great Lakes and the St. Lawrence River
2. Finland and Sweden—in northern Europe

The landscape in either of these regions appears as an irregularly rolling plain, covered in large part by coniferous forest.

Much of the forest is thin and poor. Knobs or patches of bare rock outcrop at frequent intervals. Better forests are found in the depressions, many of which are swampy. Among the woodlands lie thousands of rock-rimmed lakes, most of them small, others large enough to contain several islands. Study of a map of Finland and of that part of Ontario north and west of Lake Superior will reveal the remarkable number of lakes (Fig. 189). It is said that there are more than 35,000 lakes in Finland.

The numerous lakes of western Ontario attract thousands of summer tourists, especially those interested in fishing. The so-called *Arrowhead Country* of Minnesota, north of Lake Superior, contains glacial lakes connected by streams. Ely is a small city where fishing parties are outfitted to travel by canoe from one lake to another, even reaching and going beyond the Canadian border. The large Lake of the Woods is dotted with hundreds of islands of solid rock upon which a thin covering of soil supports the growth of conifers. This lake annually yields great quantities of fish.

The Features of Drift Plains

Glacial Drift in General. The drift plains of the principal regions of continental glaciation are of greater area and of much greater human significance than are the ice-scoured plains. They occupy most of the broad outer margins of the areas that were covered by ice in both Europe and North America. Over them is spread a tremendous quantity of rock waste.

The drift is of variable thickness (Fig. 190). In valleys it is sometimes very deep. On the tops of near-by, rounded, ice-scoured hills it may be thin. In some localities drift completely buries the rock surface under an unbroken mantle which may be several tens of feet or even 400 to 500 feet in thickness. In general, the land surface covered by drift was made smoother and more level. This resulted from the erosion of hilltops and the filling of valleys.

Ground Moraine. The mantle of unassorted drift deposited underneath glacial ice is known as *ground moraine.* It is a widely distributed surface deposit and is the foundation upon which other features may be built. It consists of rock materials

of all degrees of size from large boulders down to the finest of clay or rock flour. These ingredients are thoroughly mixed and show no separation into strata of different size or weight classes such as are deposited by running water (Fig. 191).

Glacial drift usually is composed of materials that largely are of local origin. In regions of sandstone bedrock, the drift commonly has a large percentage of sand. In regions of shale, it has a large percentage of clay. Usually, however, foreign materials are present also. Some are fine materials such as sand, clay,

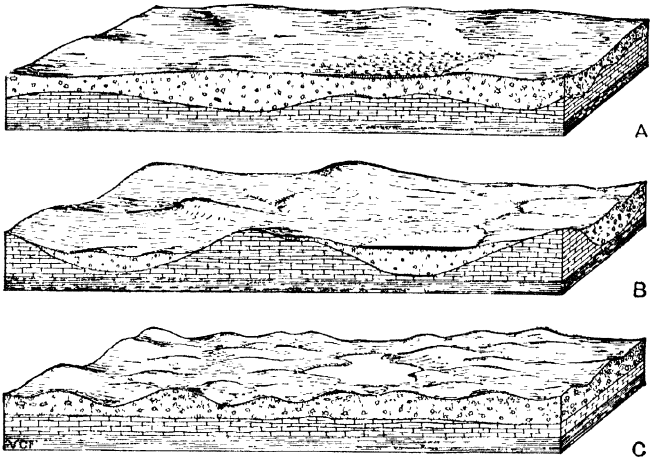


FIG. 190.—Different effects of glacial deposits upon previous rock surfaces: *A*, a hilly rock surface made more smooth by drift; *B*, a rock surface of considerable relief partly buried by drift; *C*, a smooth rock surface made irregular by the deposition of rough moraine.

and pulverized limestone brought from regions of different kinds of rocks. Others are pebbles and boulders of harder sedimentary rocks or of igneous or metamorphic rocks. These may have been transported scores or even hundreds of miles from their nearest known sources. Such rocks often are conspicuous because of their large size or their hard and unweathered condition. Because they are obviously foreign to their present situations, they are called *erratic boulders*. Many of them show scratches, or striae, caused by grinding against other boulders or against bedrock (Fig. 192).

In some regions erratic boulders are so numerous in the till sheet as to interfere seriously with the cultivation of the soil. In parts of South Dakota, Minnesota, and other northern



FIG. 191.—An exposure of glacial till, in a road-cut through a long narrow drumlin. The unassorted clay, pebbles, and boulders of which it is composed are clearly visible. (*Courtesy of U.S. Geological Survey.*)



FIG. 192.—A subangular boulder showing glacial striae. (*Courtesy of U.S. Geological Survey.*)

states, farmers collect the erratics and pile them along fences or in little-used places. Such is the case especially in New England, where the glacial drift is thin. Here the surface features are about as much the result of ice scour as of the deposition of rock waste.

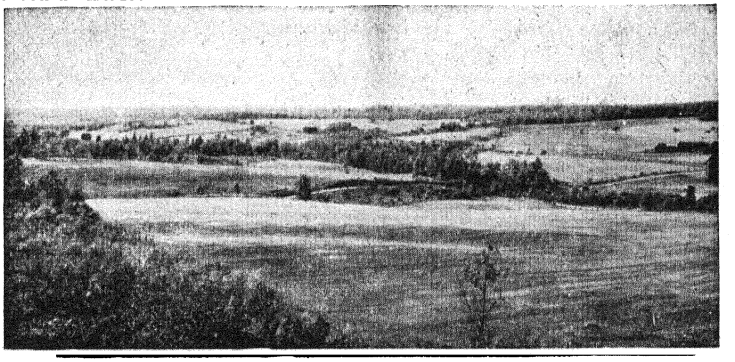


FIG. 193.—The undulating surface of a till plain. (*Courtesy of Wisconsin Geological Survey.*)

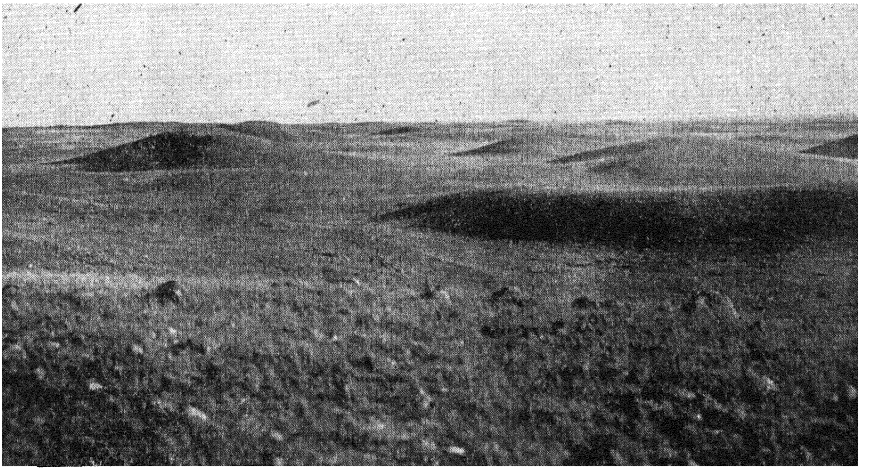


FIG. 194.—Drumlins rise somewhat abruptly from the surface of a till plain. They are frequently strewn with boulders, like those on the surface of the drumlin in the foreground. (*Courtesy of U.S. Geological Survey.*)

The features of young ground moraine may be observed in parts of the North Central states and in western New York (Fig. 193). Its surface appears mainly as a rolling plain with broad, low hills and wide, shallow depressions. These depressions, or basins, often have no outlets. They result from the unequal deposition of the ground moraine. There is no systematic

arrangements of hills and depressions. Local relief commonly is less than 100 feet, although it is more in some places.

In a few localities there are hills of considerable height that are composed entirely of glacial drift. The exact manner of formation of these peculiar hills is not known. They are commonly shaped like the half of an egg. They are called *drumlins* (Figs. 194, 195). Some of them reach heights of 100 feet or more and may be a mile long, but many are smaller. Where conditions under the ice were favorable for the formation of one drumlin, they apparently were equally favorable to the formation of others, for commonly they are found in groups that occupy many square miles. The individual drumlins of a group are separated by the undulating, or wavelike, surface of the drift plain from which they rise somewhat abruptly. Many drumlins, because of their steep slopes, remain wooded while the intervening plain is cultivated, save where pockets of marshland are included. One region noted for its drumlins lies south of Lake Ontario. There is another a few miles northeast of Madison, Wis., Bunker Hill, in Boston, Mass., is a drumlin.

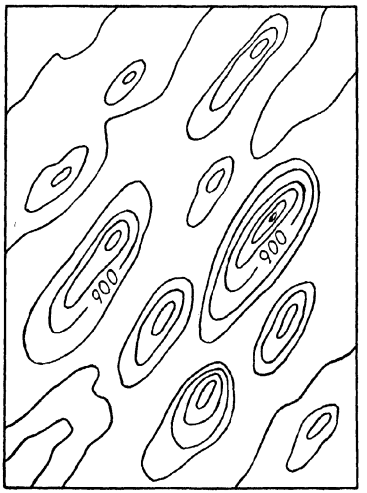


FIG. 195.—Contour map showing general appearance of drumlins east of Sun Prairie, Wis. The contour interval is 20 feet. The largest drumlins are about 1 mile in length.

The uneven and patternless dumping of ground moraine is responsible for the ill-developed arrangement of the streams in such areas. The drainage in general is poor. Streams wander aimlessly over the surface and, like those in ice-scoured plains, are youthful. Their courses are interrupted by swamps, lakes, falls, and rapids. Later erosion has caused the disappearance of many waterfalls. Some streams have cut through the drift and have encountered ledges of bedrock over which they flow to form more permanent waterfalls. Such are Niagara Falls in western New York and the St. Anthony Falls in the Mississippi River at Minneapolis. The power furnished by these

falls has promoted the development of industry in near-by localities.

Niagara Falls (Figs. 196, 197, and 301). The overflow of Lake Erie at Buffalo forms the Niagara River, which flows north to Lake Ontario. About halfway between the two lakes, the river flows over Niagara Falls, where the water drops vertically some 160 feet. The falls are separated into two parts by Goat Island. The larger, called the *Canadian*, or *Horseshoe, Falls*, lie west of Goat Island. The smaller *American Falls* lie between the island and the New York shore of the river.

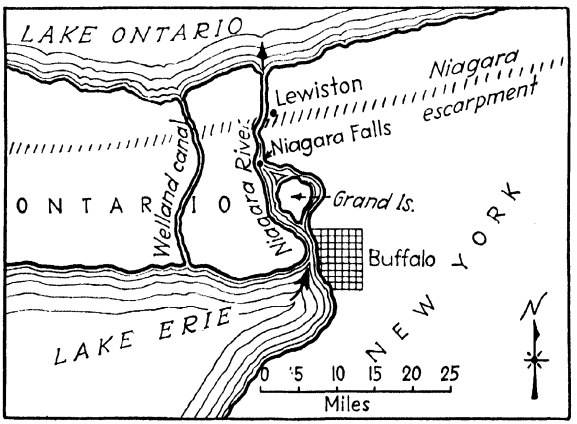


FIG. 196.—Map of Niagara Falls and vicinity. The Niagara River flows north from Lake Erie to Lake Ontario. The Niagara escarpment is shown just south of the city of Lewiston, N.Y. This escarpment is some 200 feet high.

The falls recede upstream about 4 feet per year. In so doing, they have cut a gorge from near Lewiston, N. Y., to their present location. At Lewiston is a high bluff which extends east and west for many miles. This is the *Niagara escarpment.* It is here that Niagara Falls had their beginning, probably near the end of the last ice age.

Niagara Falls recede upstream by a process of undercutting. The surface rock at the falls is limestone which is underlain mainly by a softer shale. The shale is eroded by great chunks of limestone which are churned around at the base of the falls. As the shale is worn away from beneath the limestone, the limestone in turn breaks off in great blocks. These fall to the bottom and become the "tools" used by the powerful waterfall in undermining its own brink.

The fall of the water is utilized for power by several hydroelectric plants, on both the American and the Canadian side of the Niagara River.

Great Lakes of North America. In basins that are mainly river valleys that have been modified by glaciation lie the Great Lakes. In some places, ice scour enlarged these valleys. In others, dams of glacial drift blocked them. Continental glaciation has worked to the advantage of mankind in more ways than one. The Great Lakes, for instance, constitute the greatest inland waterway in the world, even though they cannot be used during the winter months. Cheap water transportation and abundant mineral, timber, and agricultural resources in near-by areas have been responsible for the growth of large industrial cities.

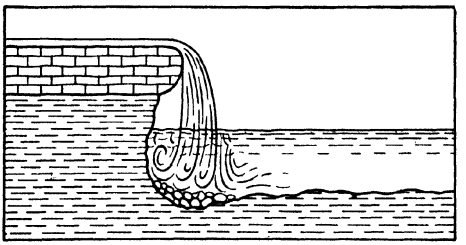


FIG. 197.—This diagram shows the principal rock formations at Niagara Falls. The blocks of limestone at the base of the falls are churned around and slowly wear away the softer shale.

Ships may pass from any one lake to all others. Two canals are necessary because of rock ledges over which the connecting streams flow, causing unnavigable rapids and falls. The Welland Canal connects Lakes Erie and Ontario and is a few miles west of Niagara Falls. The "Soo" Canals, Canadian and American, are made necessary because of rapids in the St. Marys River which flows from Lake Superior to Lake Huron. No falls or rapids exist in the vicinity of Lake St. Clair. Mainly because of a number of rapids in the St. Lawrence River, ocean-going vessels are prevented from reaching the many lake ports. The United States and Canada have considered a project whereby the entire St. Lawrence River would be made navigable. This is the so-called *Great Lakes-St. Lawrence waterway*.[1] Such a waterway, of course, would increase the commercial importance of

[1] In the spring of 1941 an agreement was negotiated by the United States and Canada which made possible the beginning of work on this project.

lake ports. Its cost, however, would be several hundred million dollars.

The New York state barge canal, or Erie Canal, follows the Mohawk lowland from the Hudson River near Albany west to Lake Erie. It was constructed for the purpose of providing water transportation from the Great Lakes to the Atlantic seaboard.

Other Glacial Lakes. The numerous lakes that occupy depressions in the ground moraine are not so permanent as those found in ice-scoured plains. There are several reasons for this: (1) The lakes for the most part are shallow; (2) inflowing drainage is abundantly supplied with sediment which tends to fill the lake basins; (3) outflowing drainage in a relatively short time is able to cut a notch in the soft morainic rim; (4) as one lake is drained, the lowering of the water table may lower the level of near-by lakes; and (5) the growth of vegetation aids in filling the lake basin. As the shallow basins are filled with sediment and vegetation, they become areas of marshland. Some are partly filled with *peat*, which is half-decayed remains of rank vegetative growths. Some lake basins are now covered with grasses and appear as marsh meadows. Others are covered by spongy mosses. In northern Minnesota, north of Red Lake, there is one considerable area known as a *floating peat bog*. In the North Central states, thousands of acres of such marsh- and lakeland have been artificially drained and put to agricultural or pastural use.

Marginal Moraines. While the great glaciers were in existence, there occurred periods of *balance* between the rate of glacial advance and the rate of melting. This sometimes permitted the position of the ice *margin* to remain stationary or to change only slightly for many years. During such a time the moving ice continued to drag forward in its bottom or to carry forward in its mass or on its surface great quantities of drift. This was deposited about the relatively stationary margin of the ice to form marginal moraines. Thus were created ridges, or belts, of drift of greater thickness than the ground moraine. In appearance, these belts differ considerably from ground moraine.

Hills of glacial drift that were left about the margin of the ice at its most advanced position are called *terminal*, or *end*, moraines.

The rate of retreat of the ice margin was most irregular. This was probably due to slight changes in atmospheric conditions which influenced the annual snowfall or degree of melting. Long pauses, during which marginal moraines were formed,



FIG. 198.—The pattern of arrangement of the glacial and glacial-lake deposits in the Great Lakes region. (*Reproduced by permission of F. T. Thwaites.*)

alternated with periods of rather steady retreat. This is indicated by successive morainic ridges separated by areas of the till plain (Fig. 198).

The rough and knobby surface peculiar to belts of marginal moraine sometimes is called *kame-and-kettle topography* (Fig. 199). Kames are rounded or irregular hills of glacial gravel. Kettles are steep-sided hollows, often quite round, in the drift.

The moraine surface commonly is dotted with lakes which lie in the kettle holes. Lakes of this kind vary from small round ponds to some of considerable size (Fig. 200). Many of them

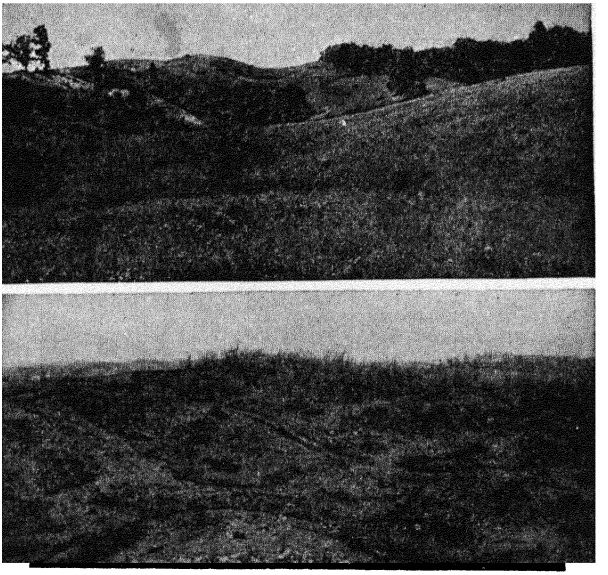


FIG. 199.—Two views showing the rough kame-and-kettle surfaces of marginal moraines. (*Photographs by John R. Randall.*)

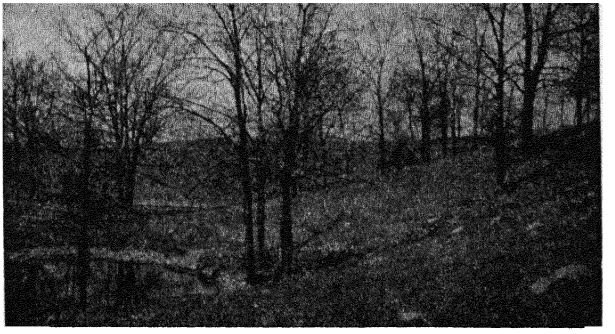


FIG. 200.—Small kettle ponds surrounded by boulder-strewn kames in a marginal moraine near Whitewater, Wis.

have neither visible inlet nor visible outlet. They are maintained by surface drainage and by springs in the glacial deposits. Pleasantly irregular surfaces, numerous lakes, and scattered woodlands cause belts of marginal moraine to be sought as summer playgrounds by the inhabitants of adjacent flatter plains.

Plains Formed by Glacial Water. Drainage from a long ice front was discharged through many small, temporary, and shifting streams. These streams flowed through crevasses or tunnels at the bottom of the ice. Often they were overloaded

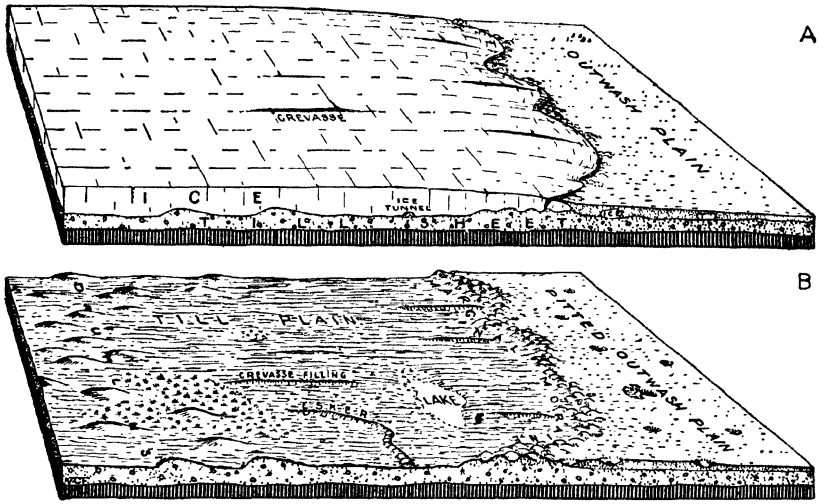


FIG. 201.—This diagram illustrates the relationship of several classes of glacial and glacial-stream deposits to the parts of the glacier by which they were formed. *A* shows a plain partly covered by the margin of a stagnant glacier; *B*, the same plain after the disappearance of the ice by melting.

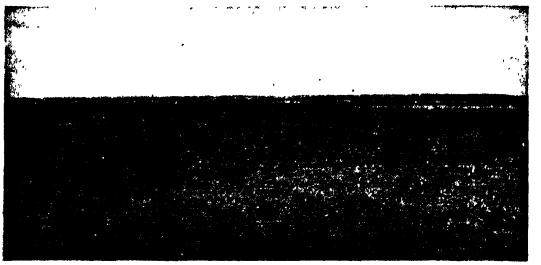


FIG. 202.—The flat or gently undulating surface of an outwash plain. (*Courtesy of Wisconsin Geological Survey.*)

with sediment. Beyond the marginal moraines this water-carried sediment was deposited to form outwash plains (Fig. 201). These plains have flat surfaces and consist largely of sand, gravels, and small boulders.

Because of the materials of which outwash plains are composed, they commonly are of rather low agricultural productivity as compared with ground moraine. Even though their surfaces

are very flat, they are in some places stony and in others sandy. Usually they are subject to drought because of the gravelly subsoil and free underdrainage (Fig. 202). They are, however, provided with naturally crushed and rudely assorted sands and gravels. These are valuable for constructional use, and the supply is abundant, since some of the outwash deposits are many feet thick. The large gravel pits of the Great Lakes region mainly

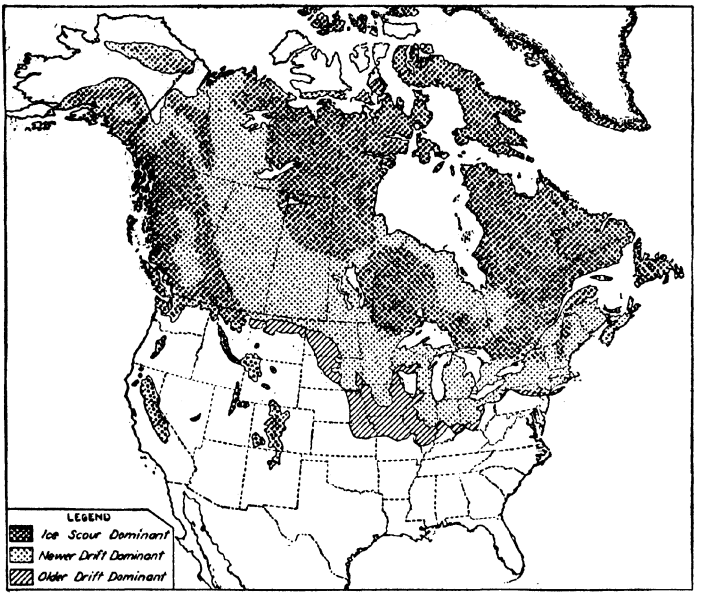


FIG. 203.—The glaciated regions of North America distinguished as to the dominance of older drift, newer drift, and ice scour.

are located in outwash plains. Roughly, the northern half of Long Island, which lies south of Connecticut, consists of marginal moraines; and the southern half, of an outwash plain. In South Dakota, Minnesota, Michigan, and other Northern states, the thousands of miles of gravel roads reflect another use to which the abundant glacial deposits have been put.

Drift Plains of America and Europe. Those parts of glaciated North America and Europe in which the features made by glacial deposition predominate over those which result from ice scour are roughly indicated in Figs. 203 and 204. The drift plains not only are extensive but include a large part of the most populous and highly developed sections of those con-

tinents. They contain localities of different appearance and utility. There are poor areas and productive areas. Each continent has its areas of lake-dotted marginal moraine and its areas of ground moraine with drumlins, marshes, and gently rolling, cultivated land.

New Drift Plains and Old. The characteristic features of drift plains, as they have been described, are mainly those of recent glacial deposits. Such drift plains have been little altered by weathering and erosion since their deposition.

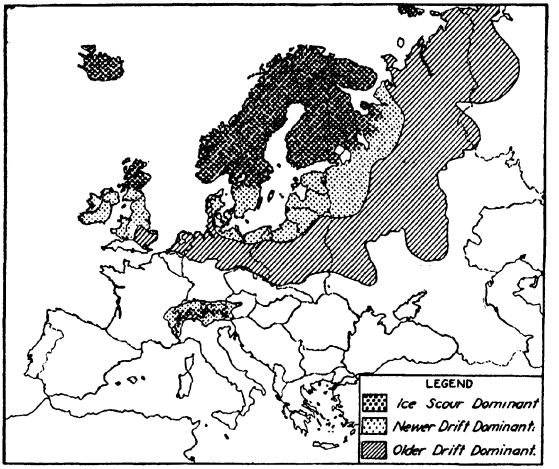


FIG. 204.—The regions of older and newer glaciation in Europe, the latter subdivided as in Fig. 203.

In both North America and Europe, however, are extensive plains that bear unmistakable evidence of being ice deposited but that clearly are much older. Gradational processes have largely erased the typical features of drift plains and have created new features. Morainic ridges have been reduced, kames worn down, kettles filled, and lakes drained or filled. Only the most resistant erratic boulders remain. Areas of old drift plains are found, for example, in parts of Iowa, western Illinois, and northern Missouri.

Differences in the older drift give evidence of the advance and retreat of several different continental glaciers separated by intervals of many thousands of years. The easily observed features of the newer drift in the northern states show that the last ice age was, in terms of geological time, relatively recent.

Glacial Lakes and Lake Plains. It has been pointed out that most glacial lakes of the present are due to some kind of glacial obstruction of present drainage. This is in some degree true even of the Great Lakes. However, in an earlier stage of their history, the drainage of the Great Lakes was obstructed by the ice of the glacier itself. This was true also of other lakes that today have partly or wholly disappeared.

Sometimes the glacial front retreated by melting down a gentle slope. When this happened, a lake was formed, because the glacier front acted as a dam. Such a lake would increase in



FIG. 205.—This diagram illustrates the formation of a temporary lake between the margin of a glacier and a low divide across which the surplus drainage escapes. Glacial-lake deposits are seen in the lake bottom.

area and elevation until it found an overflow at the lowest place in its rim (Fig. 205). Temporary former glacial lakes of that kind are known as *marginal lakes*. The final withdrawal of the ice barrier back of a marginal lake removed the dam that caused it. The drainage then found a new and lower outlet, and the lake dwindled in size or disappeared entirely.

During the periods of their existence, marginal lakes modified the land surface. The areas that they covered are now called *lake plains*. Such plains are exceedingly flat. They are composed of the wave-worked clays, silts, and sands of the glacial drift. Marginal lakes were generally shallow. Waves and currents shifted sediment over the lake floor, filling the depressions. As a result, when the lakes were completely or partially drained, plains appeared that rank among the flattest in the world. Shore features, such as beach ridges and deltas, are spread over

them at intervals. These mark successive stages in the lowering of the outlet and the decrease of the lake area.

Notable Lake Plains. Glacial lake plains are found in certain parts of Europe. Several of great extent and unusual economic significance are located in North America. Notable among these are the Lake Agassiz Plain, certain margins of the Great Lakes, the Ontario clay belt, and the plain of central Wisconsin (Fig. 206).

The Lake Agassiz Plain is situated in northwestern Minnesota, eastern North Dakota, and Manitoba. Lakes Winnipeg

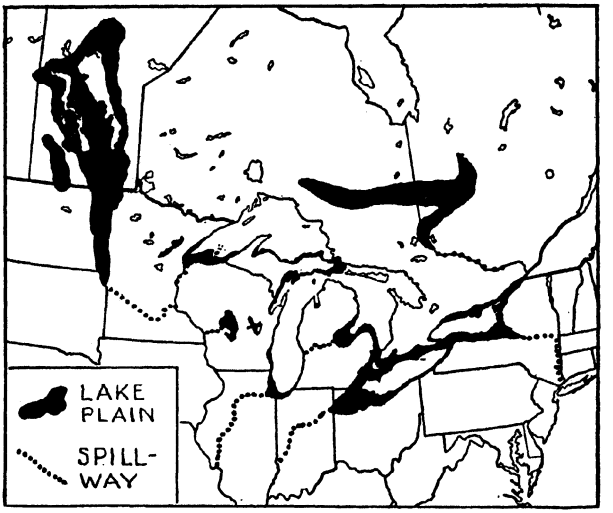


FIG. 206.—The principal glacial-lake plains and glacial spillways of North America.

and Winnipegosis in Manitoba at present occupy the lowest portions of the plain (Fig. 207). In this region the glacier front acted as a dam across a shallow and widespread depression with normal surface drainage toward Hudson Bay. For a long time the huge lake overflowed to the south through what is today the Minnesota River, which empties into the Mississippi at Minneapolis. One of the early scientists to study this region was Louis Agassiz (ăg′ȧ·sē), a noted Swiss geologist and zoologist. He traced the shorelines of the ancient lake. His discoveries led to the use of his name in connection with the area. This region is sometimes referred to as the *Red River Valley*. More correctly it should be called the *Red River Basin*, because the Red River, which slowly meanders its way northward across

the flat surface, occupies a narrow, shallow valley that is only a very small fraction of the entire lake plain. Over much of the Agassiz Plain, soils are rich. Especially is this true in the vicinity of Fargo, Moorhead, and Grand Forks. In other localities it is sandy and underlain by gravel beds, like so many soils found throughout the area of recent glacial drift. Such soils dry out by underground seepage much faster than certain other types. The Agassiz Plain is noted for its production of spring wheat,

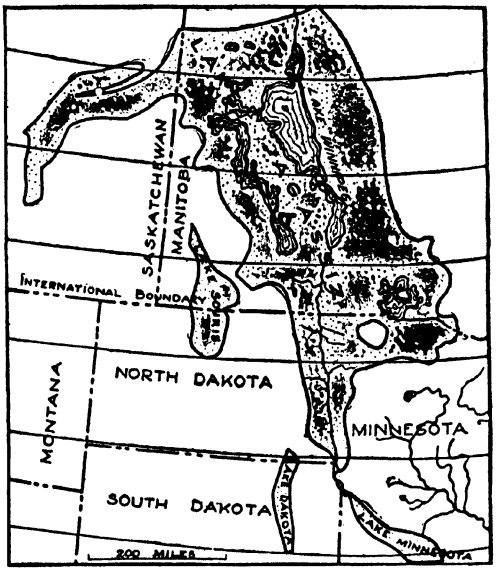


FIG. 207.—Map showing the extent of ancient glacial Lake Agassiz. (*After Upham U.S. Geological Survey. Courtesy of E. B. Branson and W. A. Tarr, from "Introduction to Geology."*)

potatoes, and flax. Barring occasional drought, it is a highly productive region.

While the continental glacier blocked the St. Lawrence Valley, the Great Lakes not only overflowed through different outlets but also covered more territory. As a result, rather extensive lake plains are found around certain margins of the present lakes, especially in western New York, eastern Michigan, and northern Ohio. The city of Chicago stands in large part upon such a plain. A very extensive lake plain, known as the *Ontario clay belt*, is located about midway between Lake Huron and James Bay. In central Wisconsin is a flat, sandy, and infertile lake plain. In such sandy plains, rain water sinks

quickly into the ground and is of little use to shallow-rooted plants.

Important Glacial Spillways. Summer melting along an extended ice margin must have produced large volumes of

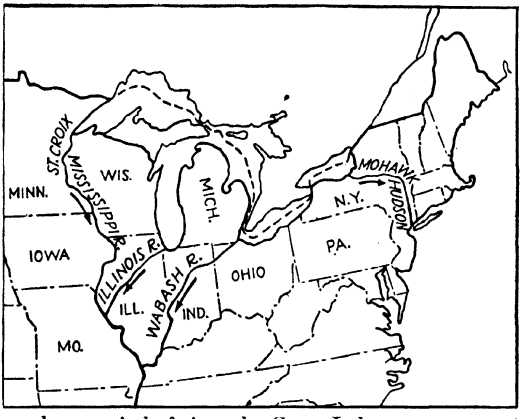


FIG. 208.—For a long period of time the Great Lakes were prevented from draining into the Atlantic through the St. Lawrence River because the continental glacier acted as a dam across the St. Lawrence. The four principal spillways at that time are shown on this map. They are (1) the St. Croix-Mississippi, (2) the Illinois, (3) the Wabash, and (4) the Mohawk-Hudson.

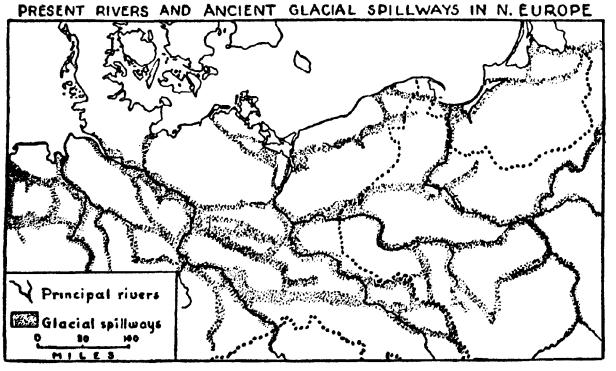


FIG. 209.—The glacial spillways that drained the long European ice front toward the west at various stages of its disappearance. (*After Paul Woldstedt, Das Eiszeitalter.*)

drainage water. It would be strange if streams of sufficient size to carry so much water had not left their marks upon the landscape. The principal marks are ancient spillways. They are recognized as broad but short valleys. Many such spillways are known, in both Europe and North America. Several of them are now occupied by streams that seem ridiculously small in valleys that appear to have been eroded by streams of the size

of the Mississippi. Figure 206 shows the location and drainage relationships of the principal American spillways. It will be recognized at once that some of them are of unusual significance as routes of present-day transportation. The Chicago outlet provided a naturally graded site that made possible the economical construction of the Illinois and Michigan Canal and later the Chicago Sanitary and Ship Canal which runs through the city of Chicago. It is traversed also by railway lines and an important highway. The Mohawk Valley outlet toward the Hudson River furnishes the lowest and best graded route across the Appalachian highlands (Fig. 208). It became a busy thoroughfare after the construction of the Erie Canal and now carries a high concentration of rail, highway, and airplane traffic.

Figure 209 shows the network of spillways that carried drainage from the retreating ice fronts of Europe. The channels made by this drainage cut across the present trend of the river valleys of the North European Plain and provide natural access from one of them to another. The German system of canals utilizes these graded courses to link together the natural waterways of the country.

Summary

The most important results of continental glaciation in North America may be listed as follows:

1. The ice-scoured Laurentian upland, with the exception of certain bare spots, is covered with a thin soil that supports the growth of forests of shallow-rooted conifers.

2. Western Ontario and northeastern Minnesota contain hundreds of lakes occupying rock basins that resulted from ice scour.

3. The ice-scoured plains have numerous waterfalls and rapids available for water power.

4. The North Central states of the United States are covered largely with recent glacial drift. Between them and the Ohio and Missouri rivers are areas of older drift.

5. The glacial drift has contributed to the formation of some of the richest soils in America.

6. Numerous lakes in the till sheet are sites for summer resorts.

7. The Great Lakes, the greatest inland waterway in the world, are a result of ice scour and glacial deposition in preglacial valleys.

8. The thousands of lakes yield abundant supplies of food fish.

9. The Agassiz Plain and other lake plains are valuable agricultural lands.

10. The glacial spillways provide important transportation thoroughfares.

11. In contrast to some glaciated regions characterized by rich soils are others where soils are made more or less infertile by the presence of abundant sand and gravel.

12. In some localities, erratic boulders interfere with the cultivation of the land.

Questions

1. What are three ways in which continental glaciers affect a land surface?

2. What are the two great types of glaciated plains? How is each formed?

3. Describe the surface of an ice-scoured plain.

4. What are striations? What do they sometimes indicate?

5. Describe the drainage of ice-scoured plains.

6. Why are rock basins and waterfalls numerous in ice-scoured plains?

7. Name and locate two extensive ice-scoured plains.

8. Of what economic value are the lakes of Ontario?

9. Where is the Arrowhead Country of Minnesota? The Lake of the Woods?

10. Where is the most northerly point of the United States?

11. Where are the drift plains with respect to the ice-scoured plains?

12. What is the thickness of the drift?

13. Define ground moraine, or till plain.

14. How can you differentiate between glacial drift and the sediments deposited by water?

15. Why is the presence of numerous erratic boulders a handicap to farming?

16. Why are numerous depressions without outlets found in ground moraine?

17. What is a drumlin? Where are drumlins found?

18. Why is the drainage of ground moraine generally poor?

19. Locate Niagara and St. Anthony waterfalls. Discuss the importance of each.

20. How did glaciation contribute to the formation of the Great Lakes?

21. Why are large industrial cities located in the Great Lakes region?

22. Why is the Welland Canal necessary? The "Soo" Canals? Locate each.

23. Mention several reasons why the St. Lawrence River should be deepened to accommodate ocean liners? What are some arguments against the project?

24. Where is the Mohawk River? The Erie Canal?

25. Why are lakes in ground moraine less permanent than those in ice-scoured plains?

26. What is peat?

27. Which state, Minnesota or Iowa, has more swampland? Why?

28. How were marginal moraines formed?

29. Why were there periods of halting in the movement of the ice front?

30. What are end, or terminal, moraines?

31. Comparing regions of ground and marginal moraines: Which would you expect to be more hilly? More swampy?

32. What is a kame? A kettle?

33. How is an outwash plain formed?

34. Why are outwash plains of rather low agricultural value?

35. What constructional materials are secured from outwash plains?

36. Where is Long Island? Of what glacial features is it composed?

37. Locate the drift plains of Europe and North America.

38. How do old drift plains differ from new drift?

39. Old drift plains may be observed in what parts of what states?

40. How were marginal lakes formed? Why did they wholly or partly disappear?

41. Why are lake plains extremely flat?

42. Locate several notable lake plains in North America.

43. What lakes occupy the lowest portions of the Agassiz Plain?

44. Why is the name "Agassiz" applied to this plain?

45. Why is it incorrect to refer to the Agassiz Plain as the Red River Valley?

46. For what agricultural crops is the Agassiz Plain noted?

47. Where are lake plains located around the Great Lakes?

48. Locate the principal glacial spillways in North America. For what are they used today?

49. State several results of continental glaciation in North America.

50. Why are some glacial soils infertile?

Suggested Activities

1. Secure a large map of Ontario, and count the lakes. Can many of them be reached by railroad? By highway?

2. Draw a large map of the Lake of the Woods. Note the railroads and highways in the region. Draw the international boundary line in this lake. Look up the history of that line.

3. Learn to sketch a map of the Great Lakes from memory. Label important cities and the four important canals.

4. Secure a good map showing the system of canals at Sault Sainte Marie. How many canals are there? For what are they used?

5. Outline the corn belt on a map of the United States. Use different colors to show the portions of this belt covered by new and old glacial drift.

6. If possible, secure some erratic boulders showing striae.

7. Secure automobile highway maps of the North Central states, New England, and New York. Note the distribution of lakes. Some counties in Minnesota have 40 or more summer resorts. Are these counties north or south of St. Paul? How were most lakes in north central Minnesota formed? How about the lakes of Maine?

8. Describe the route that you would follow in making a summer tour of the Great Lakes region.

9. Look up the area and depth of each of the Great Lakes.

10. If you live in the glaciated area, make field trips to study any local evidences of glaciation.

11. Secure molding materials, and make a relief model of Niagara Falls, using the contour map of the region to determine elevations and distances.

12. Make a relief model to show drumlins. Use the Sun Prairie, Wis., quadrangle (U.S. Geological Survey).

13. Secure several topographic maps of a certain glaciated region that you wish to study. Trim off the edges of each map, and fasten them together to provide a map of a more extensive area.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. The Laurentian Upland
2. Finland

3. The Arrowhead Country of Minnesota
4. The Lake of the Woods
5. Niagara Falls
6. The Great Lakes—St. Lawrence Waterway to the Ocean
7. The Mohawk Lowland as a Transportation Thoroughfare
8. The Surface Features of Long Island
9. Agriculture in Regions of Older Drift
10. The Lake Agassiz Plain

References

EMMONS, W. H., G. A. THIEL, C. R. STAUFFER, and I. S. ALLISON: *Geology*, McGraw-Hill Book Company, Inc., New York, 1932.

SALISBURY, R. D.: *Physiography*, Chap. 5, Henry Holt & Company, Inc., New York, 1919.

THWAITES, F. T.: *Outlines of Glacial Geology*, Edwards Bros., Inc., Ann Arbor, Mich., 1934.

Chapter XII. Plateaus and Hill Country

In our study of environment we are much concerned with landforms because they have such a great deal to do with the way in which people make a living in the various regions of the earth. Plains that have good climate and soil are used by man for agricultural pursuits. In certain small localities where transportation and commerce are favorable, manufacturing may attract thousands of people. In such relatively small areas the density of population often is very great. Enormous portions of the world's plains, however, are sparsely or thinly populated, mainly because of unfavorable climate.

In the last two chapters we learned about landforms that may be observed on plains, landforms resulting largely from erosion and deposition by rivers and glaciers. In the present chapter and the next we shall consider landforms of a more rugged nature and that are higher above sea level than plains. These are (1) plateaus, (2) hill country, and (3) mountains. In general we may say that these rougher and higher landforms are more sparsely populated than are plains. The rugged nature of the land makes transportation more difficult. Agriculture is limited largely to the grazing of cattle and sheep. Mining, however, in some localities, is of considerable importance. Climate often is severe, especially in winter.

Plateaus

What Is a Plateau? A plateau is a large area that has considerable elevation above sea level (Fig. 210). Most of the great plateaus of the earth have an average elevation of at least 2,000 feet above sea level. They have considerable local relief of 500 feet or more and usually have an abrupt escarpment, or bluff, at

least on one side. We shall study three types of plateaus. They are (1) *intermontane*, meaning between mountains, (2) *piedmont*, and (3) *continental* plateaus, or tablelands (Fig. 211).

Intermontane Plateaus. These are high land surfaces surrounded more or less by mountains. The plateau of Tibet, north of India, is an eastward-sloping highland, much of the surface of which lies at an elevation between 10,000 and 15,000 feet

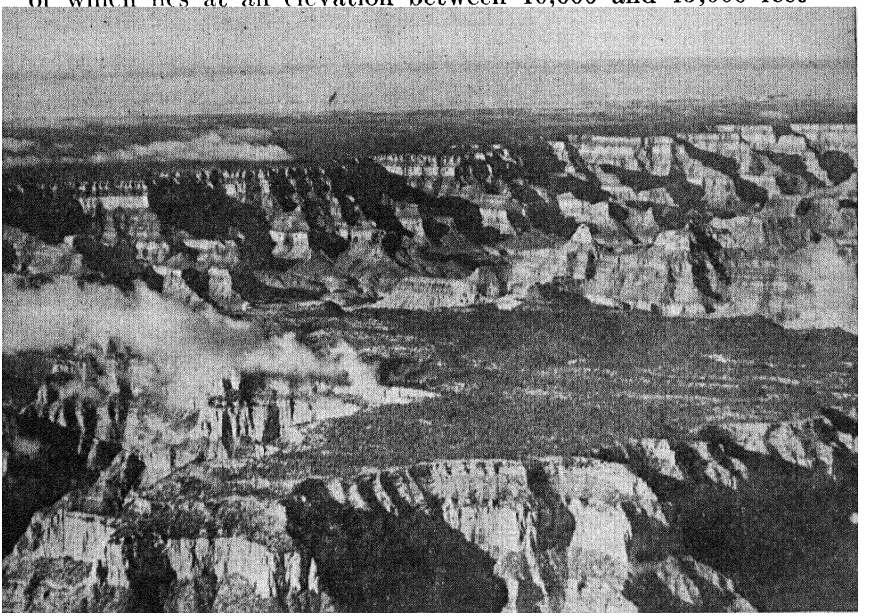


FIG. 210.—Aerial photograph showing in the background the fairly flat surface of the Colorado Plateau in northern Arizona. This plateau surface ranges from 6,000 to 9,000 feet above sea level. In the foreground are sedimentary rocks exposed in the Grand Canyon of the Colorado River. (*Courtesy of Transcontinental and Western Air, Inc.*)

above sea level. On the south of it rise the great heights of the Himalaya Mountains. On the other sides are mountains of lower elevation yet sufficient to cause much of the plateau to have interior drainage. Interior drainage means surface waters that flow into lakes or seas that have no outlet to the ocean. Surplus water escapes through deeply cut valleys and gorges that notch the mountain margins. A similar plateau in Bolivia has an elevation between 10,000 and 15,000 feet. These are the highest of the intermontane plateaus. Others of lower elevation are the dry plateaus of Mongolia, the Tarim Basin in Asia, and in the United States the Great Basin and the Columbia Plateau.

Mexico is largely a high plateau, bordered on the east and west by rugged mountains. This plateau has a decided effect on climate in that it makes night temperatures much lower than they otherwise would be. The climate of Mexico City, almost 8,000 feet above sea level, is very pleasant the year round. Days may be warm to hot, but nights are usually cool. This contrasts with the continuously hot, humid climate of Veracruz, which lies east of Mexico City on the shore of the Gulf of Mexico. The rugged plateau and mountains of Mexico have made the building of transportation lines difficult and expensive. Only within recent years has a concrete highway been completed from Texas to Mexico City. Especially does the northern portion of the Mexican plateau suffer from scanty rainfall. The southern part is more favored, and it is here that cereals, especially corn, are produced in considerable quantities. This plateau for years has been famous as the world's greatest producer of silver. Other metals, especially gold, are mined with the silver.

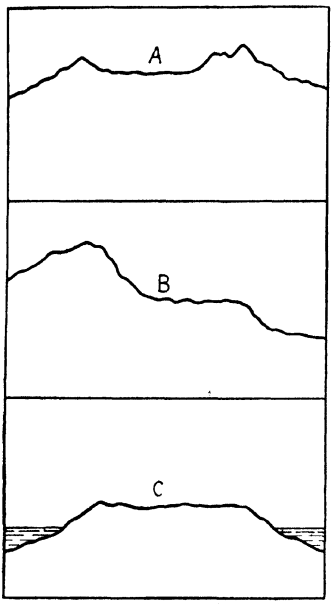


FIG. 211.—This diagram shows the three types of plateaus: *A*, intermontane; *B*, piedmont; *C*, continental plateau or tableland.

Piedmont Plateaus. There are many small piedmont plateaus; few large ones. They lie between mountains and bordering plains or the sea. The plateau of Patagonia, in southern Argentina, lies east of the Andes Mountains. Streams have cut this plateau surface into roughly parallel blocks somewhat like the Great Plains of the United States. However, instead of grading into lower plains, as do the Great Plains, the Patagonian plateau ends near the Atlantic in an abrupt escarpment 300 to 600 feet high. The Colorado plateaus in southwestern United States are, in a sense, piedmont plateaus. They are bordered on the north and east by the high ranges of the Wasatch, Uinta, Rocky, and San Juan Mountains. On the west and south they

stand above the adjacent basins in escarpments that are from a few hundreds to as much as 5,000 feet in height.

Continental Plateaus. These plateaus, or tablelands, rise with some abruptness from bordering lowlands or from the sea. In general they do not have conspicuous mountain rims. Examples of great tablelands are shown by the peninsulas of India,

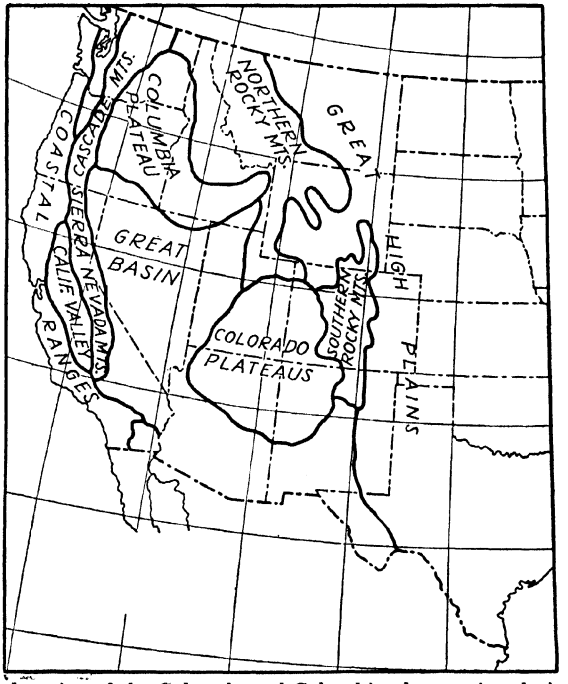


FIG. 212.—The location of the Colorado and Columbia plateaus in relation to the Great Basin and western mountains is shown on this map.

Spain, and Arabia; by southern Africa; by parts of Australia: and by ice-covered Greenland and Antarctica.

Tablelands in general are areas of relatively recent crustal uplift. Such uplift may produce a regular shoreline with very few indentations. Africa, for example, has a very regular shoreline. This causes a lack of natural harbors and is a handicap to the development of commercial ports.

The Continental Plateau, or tableland character, *of Africa* is clearly shown by the gradients of its major streams. Arising in interior uplands, each of the great African rivers, the Nile,

Zambezi, Limpopo, Orange, Congo, and Niger, has a middle course of relatively gentle gradient, after which it plunges over the plateau escarpment in falls or rapids which make it unnavigable. The fall of the Nile is distributed among its six famous *cataracts* which are separated from each other by distances of 150 to 200 miles. The Congo, near its mouth, descends nearly 1,000 feet from the plateau surface over a stretch of wild rapids. The Zambezi River leaves the plateau by means of

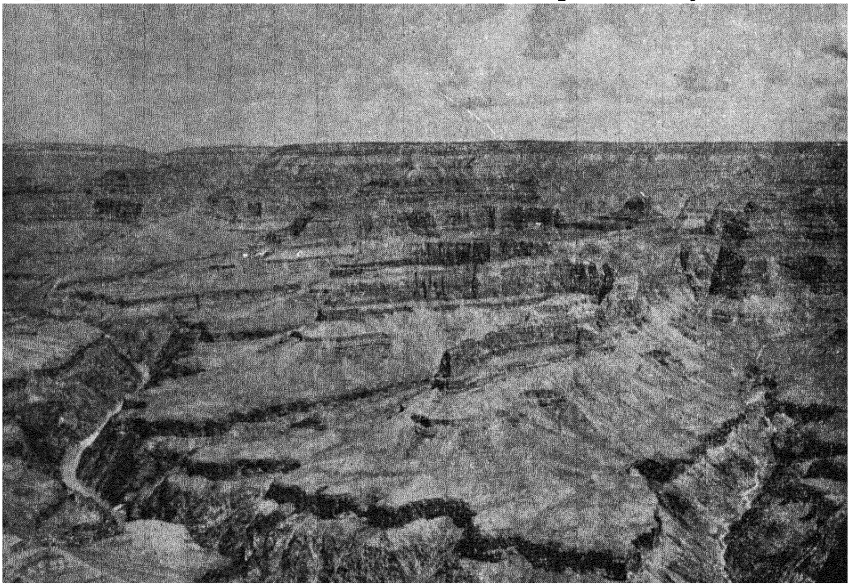


FIG. 213.—The Grand Canyon of the Colorado River. The narrow inner gorge, cut in crystalline rock, is in striking contrast to the intricately carved steps eroded in the sedimentary rocks above.

Victoria Falls. These falls are twice as high as Niagara but only half as wide. The river then descends through a 40-mile gorge and over a series of rapids before it reaches the level of the coastal plain. Even the smaller Orange River has a 300-foot waterfall in its lower course. The impossibility of reaching the interior of the continent by uninterrupted stream navigation is one of the reasons why Africa was the last of the continents to be penetrated by Europeans.

The Colorado plateaus are located in parts of Arizona, Utah, Colorado, and New Mexico (Fig. 212). This vast region is equal in area to the combined areas of Ohio, Indiana, and Illinois.

Sedimentary rocks, mainly sandstone, limestone, and shale, totaling several thousands of feet in thickness, lie in a nearly horizontal position upon a foundation of crystalline rocks (Fig. 213). Here one observes a land surface that is mainly flattish, table-like or steplike in formation. The various plateaus are separated by canyons or bold escarpments. The *Kaibab Plateau* in northern Arizona, one of the group, reaches an elevation of some 9,000 feet above sea level. The entire region is arid to semiarid.

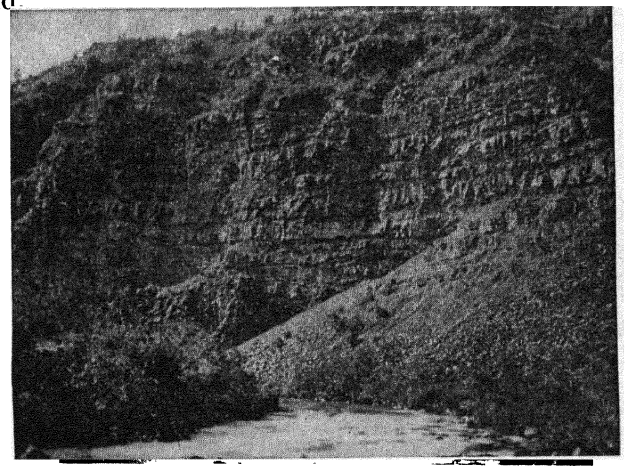


FIG. 214.—An exposure of the Columbia Plateau basalts showing beds that result from successive lava flows. (*Courtesy of U.S. Geological Survey.*)

The Columbia Plateau in Washington, Oregon, and Idaho is an outstanding example of a lava plateau. In this region, lavas have covered an area as large as that of the combined states of New York, New Jersey, and Pennsylvania. The lavas occur in nearly horizontal flows of variable thickness (Fig. 214). The successive layers bury an uneven surface of former erosion. Through this plateau, which extends to Yellowstone National Park, the Snake River, in parts of its course, has cut deep canyons. In the walls of the canyon the layers of extruded, solidified lava are exposed.

The igneous rocks of this plateau over considerable areas are covered by a fairly rich soil. Lying on the leeward side of the Cascade Mountains, this area is semiarid. Rainfall, however, is sufficient for the growth of wheat, and the region around Spokane, Wash., is noted for the production of this cereal.

Plateau Features Developed in Dry Climates

Many Plateaus Are Arid. Climatic conditions largely determine the characteristic features of the plateau surface. The greater number of the world's plateaus have arid or semiarid climates for the following reasons:

1. Some plateaus are in regions of the trade winds.
2. Intermontane plateaus are almost certain to lie on the leeward side of mountain barriers.
3. Certain plateaus have their high sides facing the prevailing winds. Moderate or abundant precipitation falls on the windward slopes, but the plateau surface is relatively dry.
4. Plateaus in regions of abundant rainfall do not long retain their plateau features. In a relatively short time, geologically speaking, such a plateau becomes much dissected or cut up. Then it changes to a hill region or mountain mass.

Arid Plateau Valleys. The valleys of arid plateaus generally have the features that are characteristic of young valleys. Streams that originate outside the plateau in regions of plentiful rain, called *exotic* streams, are likely to form canyons. The same is true of some tributary streams, even of some that flow only intermittently, *i.e.*, after occasional rains.

The development of canyons is largely the result of the following conditions:

1. Orographic rainfall in near-by mountains may provide sufficient water for a river to cross a plateau and to descend to the sea beyond.
2. A swift river carrying sand and gravel has great eroding power.
3. The plateau surface is high above its base level.
4. The solid rocks are able to stand in steep slopes.
5. The slow rate of weathering and small amount of slope wash in arid lands tend to preserve the steepness of the valley walls.

The typical canyon is not favorable to the various means of transportation. Its narrow bottom offers little space for railroad or highway. The stream itself is likely to have a high velocity and to be interrupted by great boulders, rapids, and waterfalls. Moreover, the stream is subject to rapid and large changes in

volume. The canyon floor is reached only by a steep climb down a precipitous valley wall or by the difficult route of a tributary canyon. At the plateau surface, the canyon walls are usually so far apart that bridging is out of the question. It is evident, therefore, that canyons greatly increase the inaccessibility of plateau regions.

The Grand Canyon of the Colorado River, in northern Arizona, is the most magnificent of its kind, and for that reason part of it has been included in one of the national parks. This great canyon has been carved in solid rock by the swift Colorado River, which originates in the Rocky Mountains of Colorado and flows across high, arid plateaus on its way to the Gulf of California. Few permanent tributaries join the main stream. In one part of its valley the Colorado River has cut through more than 4,000 feet of nearly horizontal sedimentary rocks and more than 1,000 feet into crystalline rocks beneath them (Figs. 210–213). The erosion of the latter has produced a narrow inner gorge, above which the walls of sedimentary rocks rise in a series of giant steps. These steps were produced by the unequal resistance to river erosion of such rocks as shale and sandstone. The exposed edges of the more resistant sedimentary strata form the almost vertical walls of the canyon; the less resistant layers appear as intervening slopes. At its top the huge valley varies from 8 to 12 miles in width, but the bottom is little more than the width of the river itself.

To attempt to describe the scenic grandeur of the Grand Canyon is indeed a difficult task. The walls of solid rock present hundreds of intricate forms. From certain points on the canyon rim, the Colorado River is seen as a tiny ribbon of water, a mile below, persistently grinding its channel deeper and deeper into the solid earth. But even more impressive than the rock formations is the display of beautiful colors shown by the various kinds of rocks. Reddish sandstones, gray-blue shales, and whitish limestones intermingle to produce a pleasing variety of colors. Especially at sundown, the blending of colors and the ceaseless change in color combinations present one of the most fascinating sights in the world.

The enormous size of the Grand Canyon compels the traveler to consider the vast amount of time required for geological

processes to produce such a feature on the earth's surface. For hundreds of millions of years the entire region was covered by the sea. Sands, muds, and limes collected on the sea floor to form successive layers of sandstone, shale, and limestone, now thousands of feet thick. Then came the slow uplift of the sedimentary



FIG. 215.—This illustration shows a large mesa in the background and Boulder Dam on the Colorado River in the foreground. (*Courtesy of U.S. Department of the Interior.*)

rocks, the disappearance of the sea, and the carving of the canyon, requiring other millions of years. As one beholds the Grand Canyon, he is deeply conscious of the earth's great age. The span of human life seems, by comparison, truly insignificant.

Mesas and Buttes. In American dry lands, a plateau upland of small to moderate size and having a flat top and steep sides is called a *mesa* (Fig. 215). Usually mesas are portions of larger plateaus that have been detached by the formation and widening of canyons or *arroyos* (a Spanish name applied to

flat-bottomed, steep-sided valleys). A resistant layer of rock, such as sandstone or some form of solidified lava, usually forms the top of a mesa. The more rapid erosion of less resistant rocks beneath is responsible for the table-like appearance of this plateau feature. Formations of similar origin but of smaller size are called *buttes*. Mesas are especially characteristic of New Mexico and Arizona; buttes, of Montana, the Dakotas, and Wyoming.

Interior Drainage. As mentioned before, interior drainage refers to that drainage in which surface waters flow into interior basins that have no outlet to the sea. Such drainage is to be found in certain dry plains, such as the plains of Turkestan and Russia which drain into the Caspian and Aral seas, and those around Lake Eyre in Australia. Likewise some arid plateaus have interior drainage. Especially is this true of intermontane plateaus. Here, along the mountain sides, may be observed numerous alluvial fans and, over the basin floor, dry stream beds and occasional sand dunes. Such features may be observed in the Great Basin of the United States, which is located mainly in Nevada.

The lakes that occupy the lowest portions of interior basins often contain salt water, because (1) streams carry salt to the lakes and (2) evaporation of the lake water causes the percentage of salt to increase. Examples of salt lakes in plateau basins are shown by Great Salt Lake, Utah; Mono Lake, California; Koko Nor in central Asia; and the lakes of Iran (Persia). Not all lakes similarly located contain salt water, because they overflow into other lakes at lower elevations. This is true of Lake Titicaca, Bolivia, the highest large body of water in the world, and of Utah Lake, which overflows through the Jordan River into Great Salt Lake. In the Great Basin, many shallow lake beds contain water only after occasional rains. At other times they appear as flat expanses of mud, which, under the heat of the sun, soon become dry and cracked. Such are called *playa* lakes.

Plateaus in Humid Climates

Plateaus that are situated in humid climates tend to be much more dissected or cut up by stream valleys than those in the dry

climates. Some are so dissected that they have lost most of their plateau characteristics. The eastern highland of Australia, the eastern front of the Brazilian plateau, and the western front of the Deccan Plateau of India receive considerable rainfall. They have been dissected into hill regions, locally called mountains. More continuous stream erosion and the greater rapidity of the weathering processes change the plateau surface into one of broad divides with rounded and irregular upland areas. Such dissected plateaus are to be found in certain parts of the Allegheny-Cumberland highland of the United States and in other parts of the world.

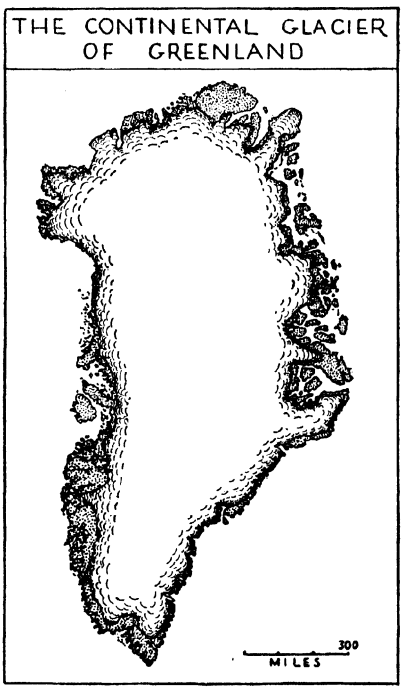


FIG. 216.

THE GREAT ICE PLATEAUS

Location and General Characteristics. Vast sheets of ice cover most of Greenland and the Antarctic Continent. They are probably much like the great ice sheets that once covered large parts of North America and Europe. Both may be regarded as ice plateaus. The Greenland ice cap (Fig. 216) is largely held within fringing mountain walls. That of Antarctica, for the most part, rises abruptly for several scores of feet. Then it slopes rapidly up to a flattish interior which has an average elevation of about 7,000 feet and a maximum of more than 9,000 feet in the region of the geographical South Pole. Its vast expanse includes an area about one and two-thirds times that of the United States, almost entirely ice covered. In general, the surface of the ice plateau is flat. In places there are cracks, or crevasses, some of great depth. Around most of its margin, the antarctic glacier extends into the sea, so that the exact position of the shoreline of the continent is not known. The glacier edge appears as a high ice cliff, many miles in length. From this cliff

huge masses of ice break off to form the largest icebergs in the world. In Greenland, tongues of ice extend down valleys to the sea (Fig. 217), producing icebergs that create a hazard to navigation when they drift southward into the North Atlantic steamship lanes in the spring.

Hill Lands

The Meaning of Hill Land. The misfortune of the word *hill* in common use is that it is applied to elevations that range



FIG. 217.—Tongues from the Greenland ice plateau protrude coastward through the fringing mountains. (*Courtesy of Geographical Review, published by American Geographical Society of New York, photograph by Rasmussen.*)

all the way from mounds to mountains. Hill lands are different from plains, even rough plains, in that they have, by definition, considerably greater local relief. They resemble mountain regions in that they include land of which a large part is in steep slopes. Some very rough hills are mountain-like in comparison with adjacent plains and locally are called mountains. However, in most hill regions the features are less massive than those of mountains, their parts are less complicated, and their detailed features are of a smaller order of size. Hill land may be thought of as a region (1) having a high percentage of fairly steep slopes (2) with uplands of small summit area and (3) having a local relief of from about 500 to 2,000 feet.

Allegheny-Cumberland Hill Region. This region also goes by the name of *Appalachian plateaus*. It extends from northern

Pennsylvania to northeastern Alabama (Fig. 218, 219). This is a region developed mainly by stream erosion in a humid climate and where bedrock consists of horizontal sedimentary strata. Local relief in general is from 500 to 2,000 feet. In places it reaches 3,000 feet or more, giving the landscape the appearance of low mountains. The stream pattern of a large part of the area is dendritic, or treelike (Fig. 220). The major streams have

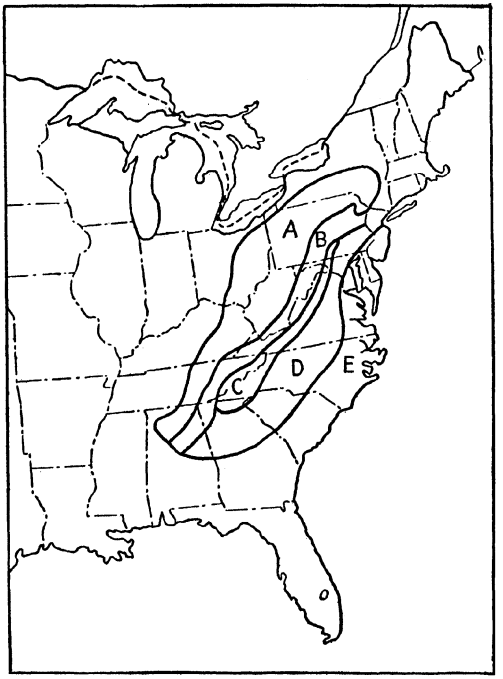


FIG. 218.—The hill regions of the Eastern states: *A*, Appalachian hill region; *B*, ridge-and-valley region; *C*, Blue Ridge region; *D*, Piedmont region; *E*, Atlantic Coastal Plain.

broadened their valleys and developed small floodplains. The secondary streams occupy V-shaped valleys which, however, may be followed by roads or railroads. The minor tributary valleys are of great number.

In the western part of this region, good roads and well-developed farms occupy the spacious valleys. The rounded hills are pastured, and only the steeper slopes remain in woodland. In the rougher areas farther east, crop land is limited in extent, since both bottom lands and flat uplands are nearly lacking.

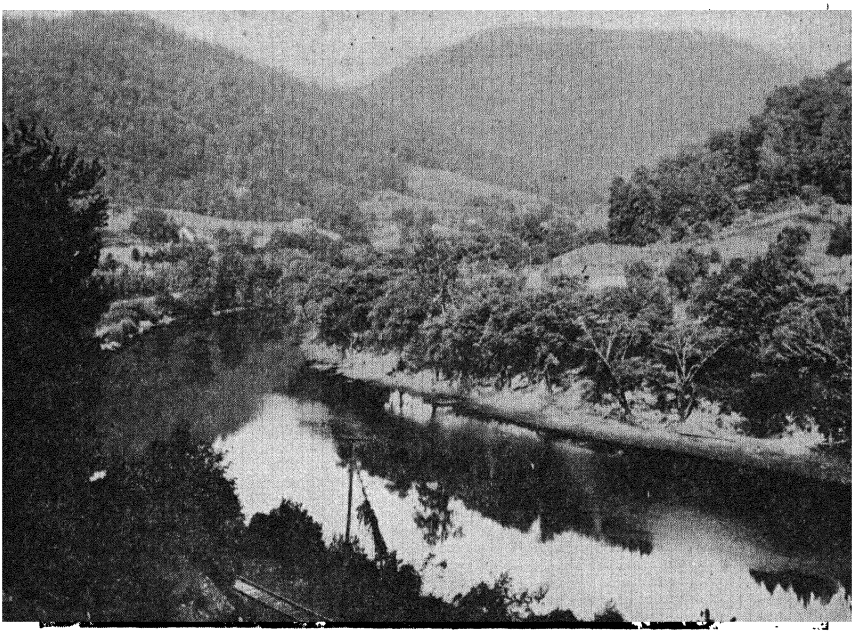


FIG. 219.—View near Swiss, W.Va., looking up the valley of the Gauley River, in the Allegheny-Cumberland hill region.

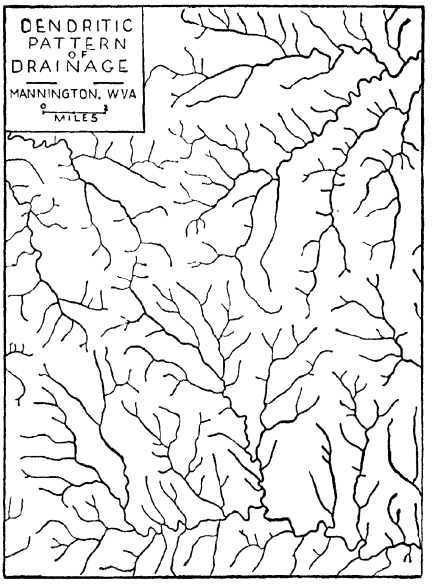


FIG. 220.—Dendritic pattern is characteristic of stream development in the maturely dissected Allegheny-Cumberland hill region.

Most of the slopes are wooded, but some of surprising steepness are cultivated. Roads, railroads, and settlements are in the narrow valleys. Many of the larger settlements, mostly coal-

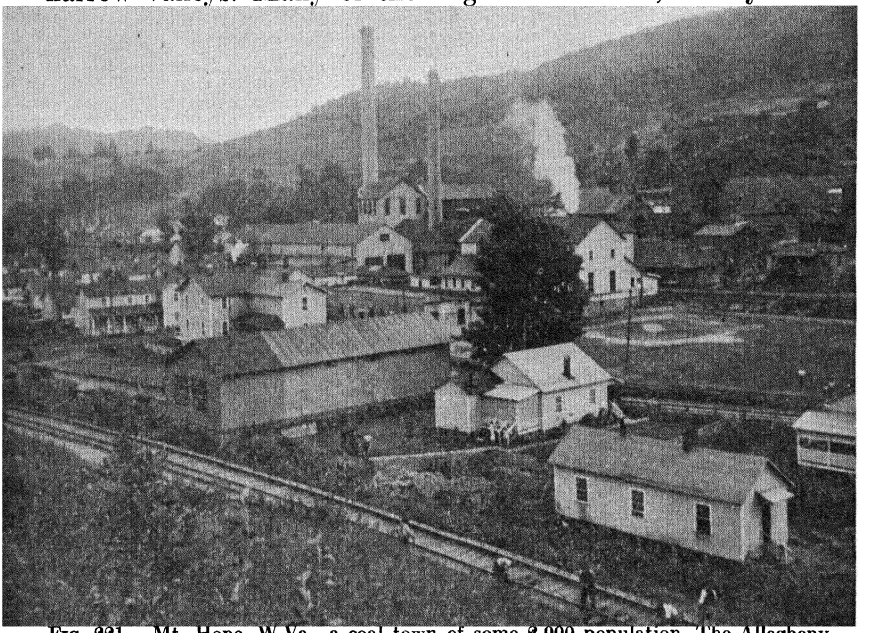


FIG. 221.—Mt. Hope, W.Va., a coal town of some 2,000 population. The Allegheny-Cumberland hill region is famous for its extensive coal deposits.

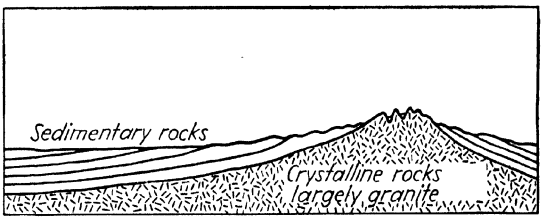


FIG. 222.—The Ozark dome in southeastern Missouri showing how the crystalline rocks outcrop to form the St. Francis "Mountains." Some sedimentary rocks that are 1,600 feet above sea level in the vicinity of the St. Francis "Mountains" are 1,000 feet below sea level in western Missouri.

mining camps, are strung along the valleys (Fig. 221). Some, especially in eastern Kentucky, have little contact with the outside world. This particular hill region is outstanding in one respect. It contains some of the most extensive coal deposits in the world.

Ozark Hill Lands. These are situated mainly in southern Missouri and northern Arkansas. Here the sedimentary strata

dip slightly downward from the uplifted granite dome that forms the St. Francis "Mountains" in southeastern Missouri (Fig. 222). Few railroads penetrate the more hilly sections. Dendritic drainage carries surface waters to the Missouri and Mississippi rivers. Because the hills are well covered with a growth of deciduous hardwoods, several national forests have been established in the region. The larger streams are of such volume that some have been dammed to create artificial lakes and to provide hydroelectric power.

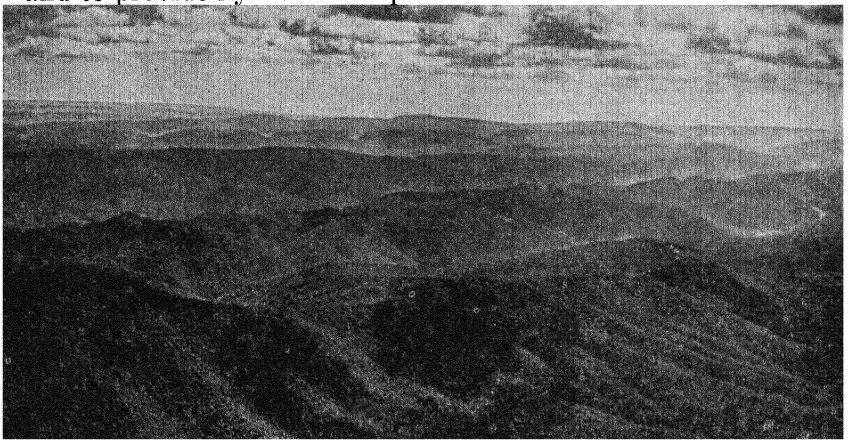


FIG. 223.—A view across the parallel ridges and valleys of one section of the folded Appalachians. Water gaps cut two of the ridges at the extreme right. In many parts of the ridge-and-valley region the valleys are much wider than those shown here and contain large areas of farm land. (*Fairchild Aerial Surveys, Inc.*)

In addition to the Allegheny and Ozark hill lands, there are others developed under similar conditions. Among them are regions located in southern Germany, in parts of peninsular India, and east of the Drakensberg Mountains in southeastern Africa.

Appalachian Ridge-and-valley Region. Certain hill regions are characterized by ridges and valleys that are roughly parallel. These contrast sharply with hills having the dendritic valley pattern. The parallel arrangement results from the erosion of crustal wrinkles in sedimentary rocks of unequal resistance. The Appalachian ridge-and-valley region is the most notable example in the world of such hill country (Fig. 223). It extends from central Pennsylvania southwestward into northeastern Alabama and lies immediately east of the Allegheny-Cumberland area

previously discussed. Folding of the sedimentary rocks was produced by compression from east and west. The synclines and anticlines that were produced have been greatly eroded and, in places, faulted. The present ridges are largely the upturned edges of more resistant rocks, such as sandstone and conglomerate. The valleys are eroded in softer rocks, mainly shale and limestone (Fig. 224). The major ridges range in height from 500 to 1,500 feet above the adjacent valleys.

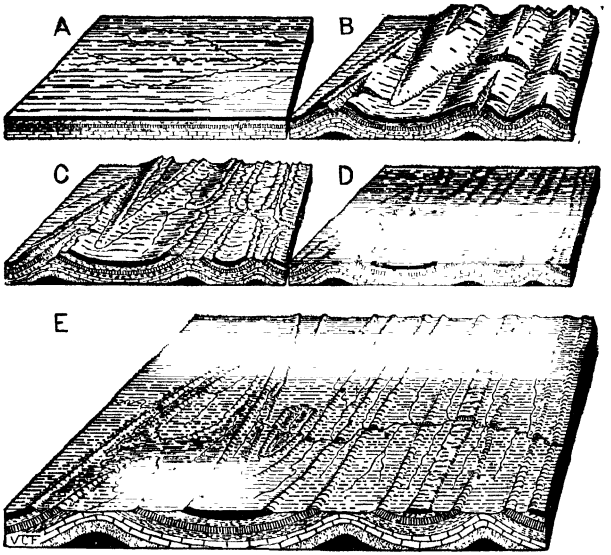


FIG. 224.—This diagram illustrates the development of linear ridges, parallel valleys, and enclosed valleys. *A*, horizontal strata; *B*, anticlinal and synclinal folding, with pitching anticlines; *C*, erosional mountains cut in the folded structures; *D*, the region baseleveled; *E*, the peneplain slightly elevated and reeroded. Linear ridges, broad valleys, enclosed or canoe-shaped valleys, and water gaps are shown. They are of the types seen in the Appalachians.

Certain large rivers cut across the folded Appalachians, some almost at right angles to the long, parallel hills. Their valleys now form notches in the ridges. These notches are known as *water gaps* and are utilized by east-west railroads and highways (Fig. 225). Among the more notable water gaps are those cut by the Lehigh, Delaware, Susquehanna, and Potomac rivers. One explanation offered for the formation of some water gaps is that the streams had enough erosive power to degrade their channels into the rock layers that were being pushed upward across their courses. Such are called *antecedent* streams, because

they antedate the time when the rocks were uplifted. Such an explanation applies to certain water gaps in the Appalachian ridges and to that formed by the Columbia River through the Cascade Mountains. In some cases the notches in uplifted rocks have been abandoned by the streams that cut them. Such

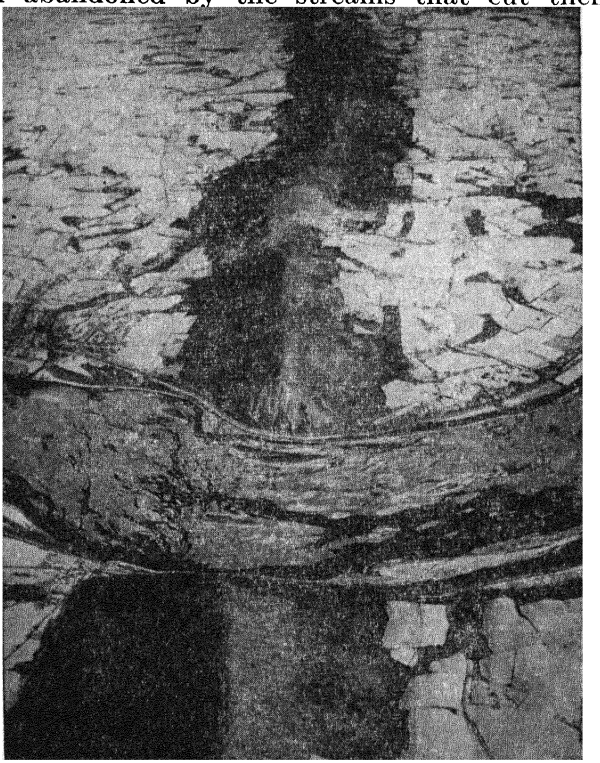


FIG. 225.—An aerial view of a ridge in the folded Appalachians, showing a water gap where the river cuts the ridge at right angles. The fields of the cultivated valleys are snow covered; the wooded ridge shows dark. The river is nearly ice covered. (*Fairchild Aerial Surveys, Inc.*)

notches are called *wind gaps*. In the Appalachian region, smaller streams flow through the parallel valleys and empty into the larger antecedent rivers. Thus is developed a somewhat rectangular pattern of drainage, called *trellis drainage* (Fig. 226).

Some of the valleys in this region are noted for their continuity, and a few for their agricultural productivity. The most famed is the Great Appalachian Valley which extends from New York to Alabama. This is not a single, continuous valley like one occupied by a river. Instead, it is composed of a number of

valleys, among which two of the best known are the Tennessee and Shenandoah. The Tennessee Valley is noted as the site of the

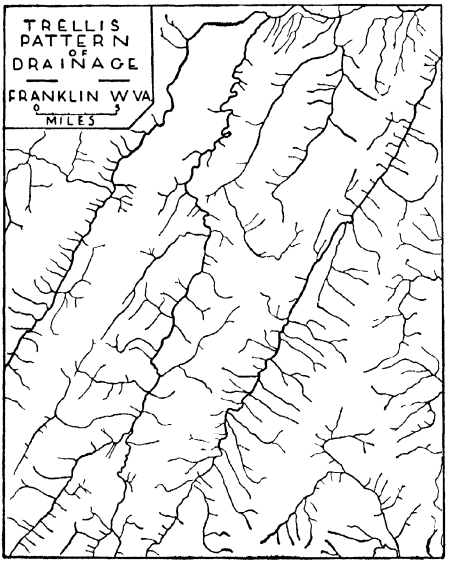


FIG. 226.—The type of drainage pattern developed in association with relief features and rock structures like those shown in Fig. 223.

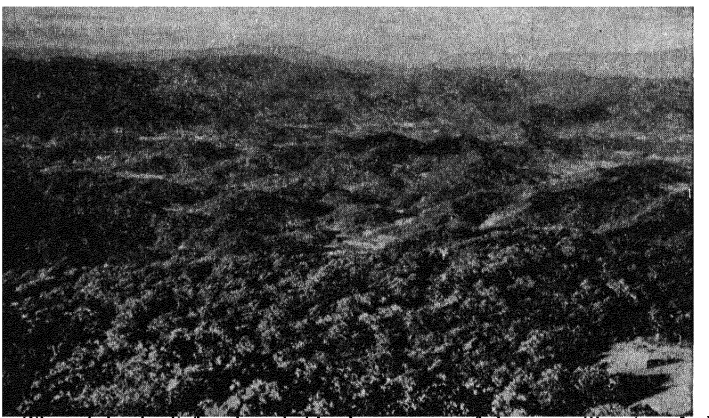


FIG. 227.—The subdued relief and eroded basins or coves of the crystalline Appalachians in western North Carolina. (*Photograph by Cline.*)

famous hydroelectric and flood-control project known as the *Tennessee Valley Authority* (TVA). Farther downstream at Muscle Shoals, in northern Alabama, is a somewhat similar project. The Shenandoah Valley is a result of the erosion of less

resistant layers of limestone. It is noted not only for beauty of landscape but also for agricultural wealth.

Crystalline Appalachian Highland of the South. This highland is located mainly in western Virginia, North Carolina, and Georgia. The region is known popularly as the *Blue Ridge Mountains.* It is comprised of igneous and metamorphic rocks of great age and structural complexity. The widest portion of the region, where local relief is over 2,000 feet, is in western North Carolina (Fig. 227). Most of the area is a hill region of great irregularity. At the western margin, some rocks of exceptional resistance form the Great Smoky Mountains.

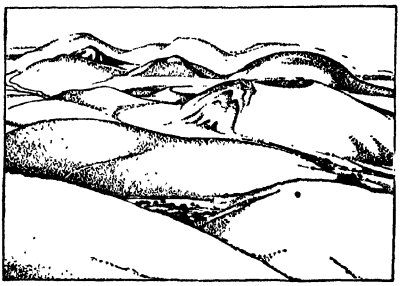


FIG. 228.—Domelike hills in central France that are the remnants of ancient volcanic cones. (*After photograph by Tempest Anderson.*)

Other Hill Regions. Some hill regions have been developed under conditions different from any of those described above.

1. *The California Coastal Ranges,* especially those south of San Francisco, are composed of sedimentary rocks of several kinds and degrees of resistance, together with some igneous and metamorphic rocks. The rocks have been severely folded and are arranged in a parallel ridge-and-valley pattern. These hills have been subject to recent faulting. The faults bear a close relation to the positions and arrangement of the parallel valleys.

2. *The Black Hills* have been carved from a dome-shaped uplift caused by a laccolithic intrusion. The igneous rock is exposed in the central area of the hills. The eroded, upturned edges of sedimentary rocks surround the central core. Local relief is about 2,000 feet.

3. In the *central highland of France* and the *Eifel of western Germany* are hill regions of a type found in modified form in other parts of the world. Upon a platform of older rocks are the remains of lava flows and volcanic cones. Erosion has long since modified these surfaces but has not entirely removed the volcanic features. Subdued volcanic cones remain and also domelike hills which are the weathered stumps of the lava cores, or plugs, that led to the former volcanic outlets (Fig. 228). A somewhat similar region is

located in northeastern New Mexico in the vicinity of Mt. Capulin, an extinct volcano. This mountain is a national monument.

4. The most extensive and least known hill region in the world is located in eastern Asia. It includes not only large mainland areas in Siberia, Manchuria, and Central and South China but also most of Chosen and Japan. Herein are rocks and structures of great diversity. There are hill regions of various patterns of arrangement and containing many kinds of features. The large human population of those regions is distributed through the limited valley and basin areas among the hills.

Ice-scoured Hill Regions. In a previous consideration of ice-scoured plains, the features resulting from ice erosion were described. Within the areas of continental glaciation are hill regions that were similarly eroded. The intricate patterns caused by previous gullying were erased. In their place are found rounded features generally devoid of pinnacled promontories or sharp contours. Mantle rock was largely swept away and replaced by thin, stony soils or bare rock. Some of the ice-shaped hills have steep slopes and considerable local relief. Associated with the hills are broad, open valleys, usually thin-soiled and boulder-strewn. Agricultural land is scant and poor, save in areas where considerable glacial drift accumulated. Some ice-scoured hills have no agricultural use but are given over wholly to timber. In others, meadows and pastures occupy the greater part of the area, and the slopes and uplands bear only poor timber or shrubby heath.

The drainage of ice-scoured hills, like that of ice-scoured plains, shows abundant evidence of glacial disturbance. Waterfalls and rapids, large and small, interrupt the courses of streams. Lakes and swamps also abound, even amid the highlands. Some are small morainic ponds or marshes of temporary nature. Others occupy ice-eroded rock basins and are beautifully set amid forested hills.

Many ice-scoured hill regions are situated in regions of ancient crystalline rocks. Such are the more rugged portions of eastern Canada, the Adirondack Mountains, parts of New England, the Highlands of Scotland, and parts of the ancient highland of Scandinavia. They have many features in common.

With some exceptions they are clothed mainly with coniferous forests, are deeply snow covered in winter, and have little agricultural development

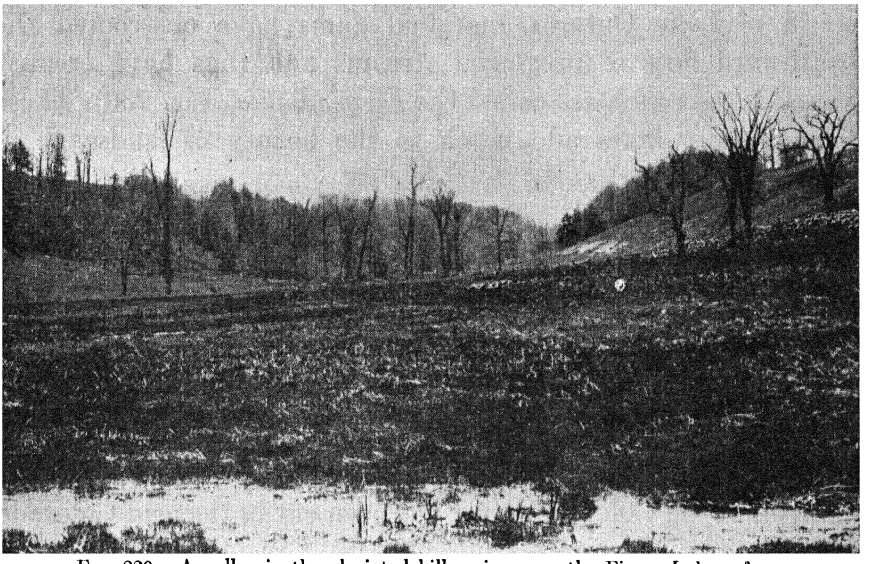


FIG. 229.—A valley in the glaciated hill region near the Finger Lakes of western New York. The hills are ice scoured, but the valley floor is underlain by drift. (*Courtesy of U.S. Geological Survey.*)

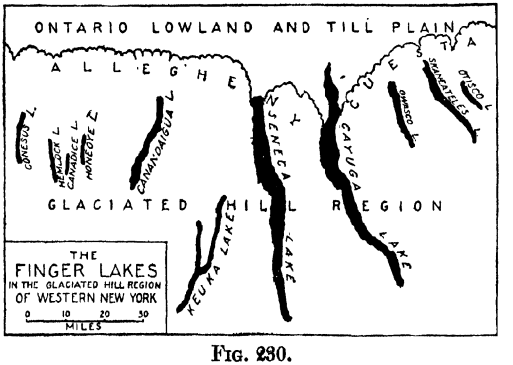


FIG. 230.

In such regions, the principal occupations are (1) pasturing of cattle and sheep, (2) the utilization of forest resources, (3) the employment of water power in the manufacture of wood products and paper, and (4) the construction and operation of resorts that attract thousands of summer vacationists.

Ice scour was somewhat different in regions where bedrock differed. In the horizontal sedimentary strata of western New

York, a portion of the Allegheny hill region was glaciated. Hills were subdued, and valleys were partially filled with glacial moraines and outwash sediments. Such valleys are much more suited to agriculture (Fig. 229). In several north-south valleys south of Lake Ontario, morainal dams have obstructed the southward flow of preglacial streams and thus have created valley lakes which are called the *Finger Lakes* (Fig. 230). These long, slender lakes add much to the beauty of landscape in western New York.

Summary

Plateaus are large areas that have considerable elevation above sea level, usually 2,000 feet or more. They are of three types, called intermontane, piedmont, and continental.

The highest plateau in the world is Tibet, located north of India. Much of Mexico is a plateau. Southern Africa provides the best example of a large continental plateau. The Grand Canyon of the Colorado River has been cut in the arid Colorado Plateau of southwestern United States. Greenland and Antarctica are examples of ice plateaus.

Hill lands have a local relief of some 500 to 2,000 feet. The Allegheny-Cumberland hill region is noted for its extensive coal deposits. In the Appalachian ridge-and-valley region, certain antecedent rivers, such as the Susquehanna, have cut water gaps through the parallel ridges. In the California Coastal Ranges, much faulting has occurred. Some hill regions, such as the Adirondacks and certain parts of New England, have been modified by ice scour.

In most of the continents are to be found comparatively small areas where the local relief is greater than that in hill country. These are the mountains of the earth and will be considered in our next chapter.

Questions

1. What are the elevation and local relief of most plateaus?
2. What is an intermontane plateau? Name and locate seven. Which two are the highest?
3. What is a piedmont plateau? Give two examples.
4. Patagonia and the Great Plains both lie east of great mountain systems. How do they differ?

5. What mountains partly border the Colorado plateaus?

6. What is a continental plateau? Name and locate five. Which is largest?

7. What is the nature of the shoreline of Africa? In what way is it a handicap to commercial activities?

8. Name and locate the great African rivers. In what respect are they similar?

9. What is meant by the cataracts of the Nile? How many are there?

10. Locate Victoria Falls. By what river are they formed? How do they compare with Niagara Falls?

11. Mention one or two reasons why Africa was the last of the continents to be penetrated by Europeans.

12. The Colorado plateaus are composed mainly of what rocks?

13. Locate the Columbia Plateau. It is composed mainly of what rock? It is noted for production of what cereal?

14. What river has cut a canyon in the Columbia Plateau? Where does this river originate? Into what river does it empty?

15. Give four reasons why many plateaus are arid or semiarid.

16. What are exotic streams. Their valleys in plateaus are usually of what topographic age?

17. What conditions are best for the development of canyons?

18. Why are canyons not favorable to various means of transportation?

19. Locate Grand Canyon National Park of the United States.

20. Where is the source of the Colorado River? Into what body of water does it empty?

21. Describe the walls of the Grand Canyon. How deep is it? How wide?

22. What principal geological processes were involved in formation of the Grand Canyon?

23. What is a mesa? How is it formed? Where are many located? What is an arroyo?

24. How do buttes differ from mesas?

25. What is meant by interior drainage? Where is it found in plains?

26. What basin plateau of the United States has interior drainage? Between what mountains does it lie?

27. Why are salt lakes common in interior basins? Give examples.

28. Locate Lake Titicaca and Lake Utah. Why are they not salt lakes?

29. What is a playa lake?

30. With respect to dissection, how do plateaus of humid regions differ from those of arid lands? Why?

31. Name and locate the two great ice plateaus.

32. Describe briefly the antarctic ice plateau.

33. Why are icebergs from Greenland a greater menace than those from Antarctica?

34. What are the three main characteristics of hill lands?

35. Locate the Allegheny-Cumberland hill region. What is the nature of bedrock? Of surface drainage? For what natural resource is this region noted?

36. Locate and briefly describe the Ozark hill region.

37. Locate the Appalachian ridge-and-valley region. By what processes were the parallel ridges formed?

38. What is a water gap? Of what economic importance is it? Name and locate four rivers that have formed water gaps in the Appalachian ridges.

39. What is one explanation offered for the formation of water gaps?

40. Sketch stream patterns to illustrate dendritic and trellis drainage.

41. Locate the Tennessee and Shenandoah valleys. For what is each noted?

42. Locate the crystalline Appalachian highland commonly known as the Blue Ridge Mountains. Briefly describe this region.

43. What is the origin of each of the following hill regions: The Black Hills? The California Coastal Ranges? The central highland of France and Eifel of western Germany?

44. What and where is Mt. Capulin?

45. Where is the most extensive hill region in the world?

46. Describe the surface of ice-scoured hills.

47. Is farm land in ice-scoured hills scarce or plentiful? Why?

48. What is the nature of surface drainage in ice-scoured hills?

49. Name and locate five regions of ice-scoured hills. What are the principal occupations in such regions?

50. Locate the Finger Lakes. How were they formed?

Suggested Activities

1. Learn the exact location of the more important places and regions mentioned in this chapter.

2. Contrast in as many ways as possible the Columbia and Colorado plateaus of the United States.

3. Review the reports of expeditions to the antarctic ice plateau.

4. Study the plateau of Tibet from the standpoint of elevation, climate, and drainage.

5. The region of the Black Hills of South Dakota is not only interesting but of considerable economic importance. A detailed survey of this area may be made by studying the geological folio that can be secured from the Superintendent of Documents, Washington, D.C.

6. On a map of the United States, outline, label, and color the plateaus and hill regions discussed in this chapter.

7. Using the Bright Angel, Arizona, quadrangle (U.S. Geological Survey), mold a relief model of the portion of the Grand Canyon shown. Exaggerate the vertical scale. If desirable, make the relief model twice the size of the quadrangle.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. The Plateau of Tibet
2. The Plateau of Mexico
3. The Deccan Plateau of India
4. The Plateau of Bolivia
5. The Columbia Plateau of the United States
6. The Colorado Plateaus of the United States
7. The Grand Canyon of the Colorado River
8. The Great Basin of the United States
9. Water Gaps of the Appalachian Ridges
10. The Tennessee Valley
11. The Blue Ridge Region of North Carolina and Virginia
12. The Adirondacks of New York

REFERENCES

CASE, EARL C., and A. E. BERGSMARK: *Modern World Geography*, Chapter 25, J. B. Lippincott Company, Philadelphia, 1938.

FENNEMAN, N. M.: *Physiography of Western United States*, McGraw-Hill Book Company, Inc., New York, 1931.

———: *Physiography of Eastern United States*, McGraw-Hill Book Company, Inc., New York, 1938.

LOBECK, A. K.: *Geomorphology: an Introduction to the Study of Landscapes*, McGraw-Hill Book Company, Inc., New York, 1939.

MILLER, GEORGE J., and A. E. PARKINS: *Geography of North America*, Chaps. 13 and 16, John Wiley & Sons, Inc., New York, 1934.

SMITH, J. RUSSELL: *Men and Resources*, Chaps. 7–11, 23–26, Harcourt, Brace & Company, Inc., New York, 1937.

Chapter XIII. Mountains

Many of the most interesting and awe-inspiring features of the earth's surface are exhibited within some of the great mountain masses of the various continents. Especially in high, glaciated mountains, features resulting from long-continued ice scour are sharp and bold; and almost vertical walls of solid rock may rise abruptly for several thousand feet. In some such localities are to be observed glaciers, or remnants of glaciers, whose melting ice feeds clear, sparkling mountain streams which cascade over numerous rapids and waterfalls. In a single glaciated valley there may be several small, mirror-like lakes whose perfect reflection of pine, spruce, and mountain top is the delight of artist and cameraman. Truly the scenery of such regions is among the most beautiful in the world.

Mountains are the highest lands of the earth. In area, they constitute a much smaller percentage of the total land surface of the continents than do plains. Compared with hills, mountains are more massive, rugged, and complicated. In general, true mountains may be considered as having a local relief (from the lowest to the highest point) in excess of 2,000 feet. This figure eliminates from the list of mountain regions many areas of rough surface that locally are called mountains.

The greatest mountain mass in the world lies in southern Asia, north of India. Here, in the Himalayas, rises Mt. Everest, elevation 29,140 feet, the highest mountain in the world. Just east of the Philippines is the deepest place in the ocean, 35,400 feet. The vertical distance from the top of the highest mountain to the greatest depth of the ocean, over 11 miles, is called the *total relief of the earth*. Even this great vertical distance, however, is extremely small when compared with the earth's diameter.

Distribution of Great Mountains. The borders of the Pacific Ocean are characterized not only by great mountains but also, in places, by occasional earthquakes and volcanic activity. This suggests a probable relationship between crustal disturbances and mountain growth. A long and almost continuous line of mountains extends for thousands of miles from Alaska to Cape Horn. Across southern Europe and Asia, from Spain to French Indo-China, stretches another vast area characterized by great mountains. A glance at the map shows that the East Indies not only are larger but also are far more mountainous than the West Indies. Africa, which consists largely of plateau

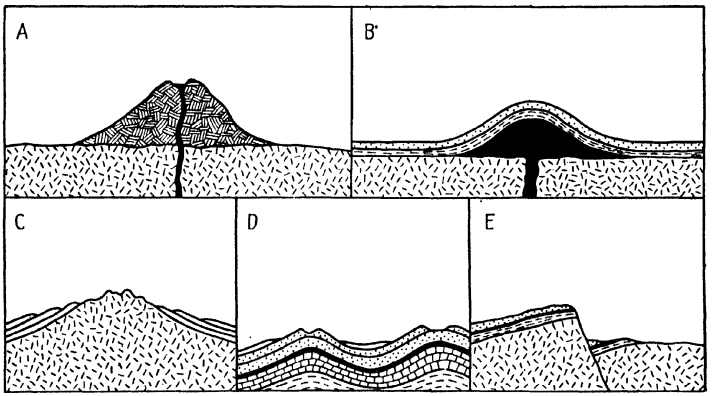


FIG. 231.—Various ways in which mountains may be formed: *A*, volcanic cone; *B*, laccolith; *C*, uplifted igneous rock from which the sedimentary rocks have been partially eroded; *D*, folded mountains; *E*, block mountains caused by faulting. The steep face (*E*, center) is called the *fault scarp*.

and tableland, has a few small, isolated areas of high mountains, especially in Ethiopia (Italian East Africa) and in the vicinity of Lake Victoria. Australia is bordered by hill lands along its eastern margin but, like Africa, lacks any extensive area of high mountains.

How Mountains Are Formed. The processes by which mountains are formed may be summarized briefly as follows: (1) Volcanic cones are formed by the eruption of great quantities of lava, ash, and other materials. (2) The uplift of huge masses of igneous rocks, especially granite, gives rise to many mountains. Some laccoliths form dome mountains, an example being the Henry Mountains of Utah. (3) Folding may cause rock strata to be bent upward several thousands of feet. (4) Some block

mountains are caused by faulting, the uplifted block of rock usually having on one side a steep face called a *fault scarp* and on the other a more gently sloping surface (Fig. 231).

Classes of Mountain Features. The processes described above have produced mountain uplifts of great variety in shapes, sizes, and arrangements. These are attacked by wind, water, and ice, even as they grow, and are carved into equally varied features. The more important features may be defined.

1. *Peaks* are the highest points in a mountain mass.
2. *A range* is a somewhat continuous arrangement of peaks, ridges, and included valleys.
3. *A system* is a group of mountain ranges.
4. *A cordillera* is a large regional grouping of mountain systems.
5. *A volcanic cone* is a form of mountain peak that in some cases is entirely isolated from a range or system.

Cordilleran Regions. Most of the great mountains of the earth are found in four cordilleran regions. They are (1) the North American cordillera, which includes the Rocky Mountain system, the Sierra Madre in Mexico, the Basin Ranges, the Alaska-British Columbia Coast Mountains, the Cascade-Sierra Nevada systems, and the Coast Ranges of the United States; (2) the cordillera of the Andes; (3) the cordillera of southern Europe, which includes the Carpathians, the Alps, the Pyrenees, and the mountains of Spain and northern Africa; (4) the Asian cordillera, which is comprised of the Himalaya, Kunlun, Tien Shan, Hindu Kush, and the Pamirs, together with the Caucasus Mountains and other smaller ranges. The arrangement of these mountains should be studied with the aid of an atlas. In these great mountain masses, faulting, earthquakes, and volcanic activity frequently occur. This indicates that many, if not most, of them are young and even now in the process of growth. In other parts of the same continents certain ancient mountains, now reduced by erosion, indicate the existence of other cordilleran groups in earlier periods of earth history.

Mountain systems are sometimes important elements of environment. They may act as barriers to the movements of people. They affect human life indirectly through their influence on climate. The effectiveness of mountain barriers depends

largely upon the height, continuity, number, and arrangement of the mountain forms. Perhaps the most notable of these barriers is that formed by the Andes Mountains of South America, which make a natural boundary between Chile and Argentina. A railroad was built across this highland from Buenos Aires to Valparaiso at enormous expense. Another good example of a mountain boundary is that formed by the Pyrenees between France and Spain.

Mountain Ranges. Some mountains consist of roughly parallel ranges. In many cases the ridges are formed of more or less continuous masses of resistant rock. Certain ranges that trend from north to south in the *Rocky Mountains* show a somewhat parallel arrangement. Between the front, or eastern range, of the Rockies in Colorado and those farther west are broad basins, called *parks*, some 8,000 to 9,000 feet above sea level (Fig. 232). About 100 miles west of Colorado Springs is the great Sawatch Range in which are several magnificent peaks such as Mt. Harvard, Mt. Princeton, and Mt. Yale. During the summer months thousands of sheep graze on these high mountain tops where the cooler weather causes the lambs to mature rapidly and to put on heavier coats of wool. Throughout the Rockies many names are applied to individual ranges, and this also is true of other mountain systems.

The *Sierra Nevada Mountains* of California are block mountains. They form a range some 400 miles in length. The steep face of the block, which we have called the fault scarp, faces the east, or the state of Nevada, and in places is 2 miles high. The more gently sloping surface faces the west and provides abundant supplies of water for the irrigation of the numerous alluvial fans along the eastern side of the Great California Valley. Glaciers and streams have deeply eroded the higher portions of this range. One of the canyons is the famous valley of Yosemite National Park, located almost due east of San Francisco (Fig. 233).

The bold, west-facing front of the *Wasatch Mountains*, just east of Great Salt Lake, Utah, is likewise the result of the breaking and slipping of huge masses of rocks. This western slope, like that of the Sierras, provides irrigation water for the alluvial deposits at the base of the mountains. These irrigated slopes

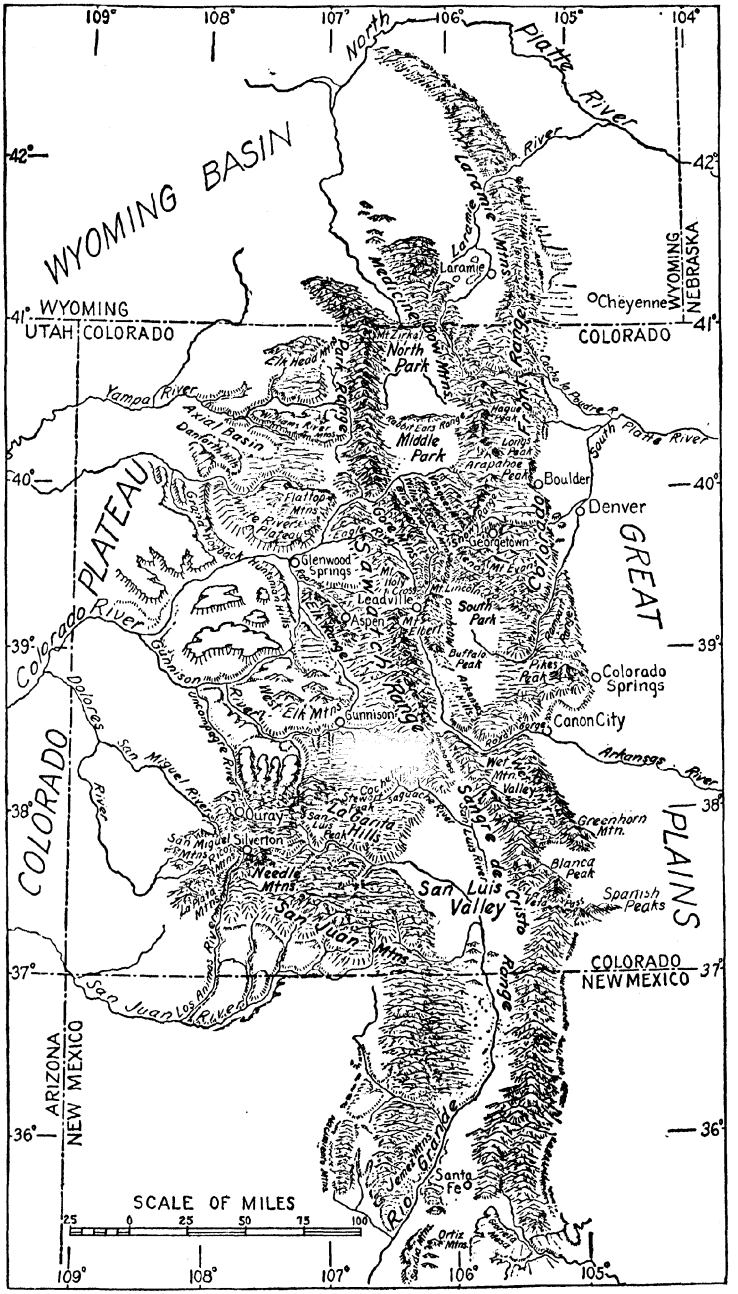


FIG. 232.—Index map of the Southern Rocky Mountain province. (*Drawn by Guy-Harold Smith. Courtesy of N. M. Fenneman, from "Physiography of Western United States."*)

form a highly productive region which extends for many miles north and south of Salt Lake City. Some of the many Basin Ranges in Utah and Nevada also are eroded fault blocks. They show a general north-south arrangement and often are separated by interior basins.

Certain mountain ranges are largely composed of materials erupted from beneath the earth's surface. The volcanic cones



FIG. 233.—Yosemite Valley, Yosemite National Park, California. This is a glaciated valley. Some of the huge granite mountains rise 3,000 feet above the valley floor. (*Courtesy of U.S. Department of the Interior.*)

thus formed sometimes are arranged in a more or less straight line, and the ranges thus formed may be considered volcanic, even though they rest upon rocks of greater age. The islands of Java and Sumatra and others of the East Indies are of that origin. Several of the principal peaks, such as Mt. Baker, Mt. Rainier, and Mt. Hood, and many of the lesser ones of the *Cascade Mountains* located in Oregon, Washington, and British Columbia also are volcanic cones roughly arranged in this manner.

Volcanic Cones. The general distribution of volcanic regions has been noted previously. In these regions are to be found both

active volcanoes and many volcanic cones built during former periods of activity (Fig. 234). Some of the great volcanoes are surrounded by lesser cones and also by mountain peaks carved by erosion in the massive uplifts of which the volcanoes are a part. Others stand alone upon lowlands and are noted for their beauty of form. The volcano Fuji, which is not now active, is located in Japan. This high peak rises over 12,000 feet above the sea and is a more striking landscape feature because it attains its full height within 15 miles of the sea (Fig. 235).

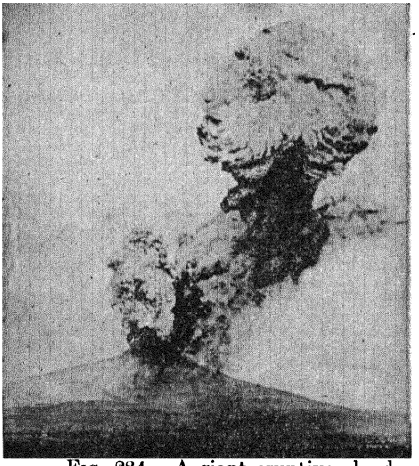


FIG. 234.—A giant eruptive cloud hanging above Colima volcano, Mexico. (*Photograph by José Maria Arreola.*)

Other cones of great summit elevation are less conspicuous because they are located in highland regions. Some volcanic peaks of great fame and beauty are Mt. Egmont, not active, in New Zealand; Mt. Mayon, in southern Luzon; Mt. Etna, in Sicily; and Mt. Vesuvius, near



FIG. 235.—The symmetrical cone of Fuji Mountain rises more than 12,000 feet above Suruga Bay and its bordering alluvial plains. (*Photograph by H. Suito.*)

Naples, Italy. Such famous American volcanic cones as Mts. Rainier, Hood, Shasta, Popocatepetl, and Chimborazo, with an elevation of 20,700 feet, are much higher than Fuji but are not

more inspiring sights. The Hawaiian cones reach elevations of between 10,000 and 14,000 feet above sea level.

Most volcanoes are composed of layers of lava interbedded among layers of ash and other forms of volcanic products erupted at different times. The layers are penetrated by dikes of lava which arise from the central duct. Through some of the crevices thus opened, materials reach the surface and form

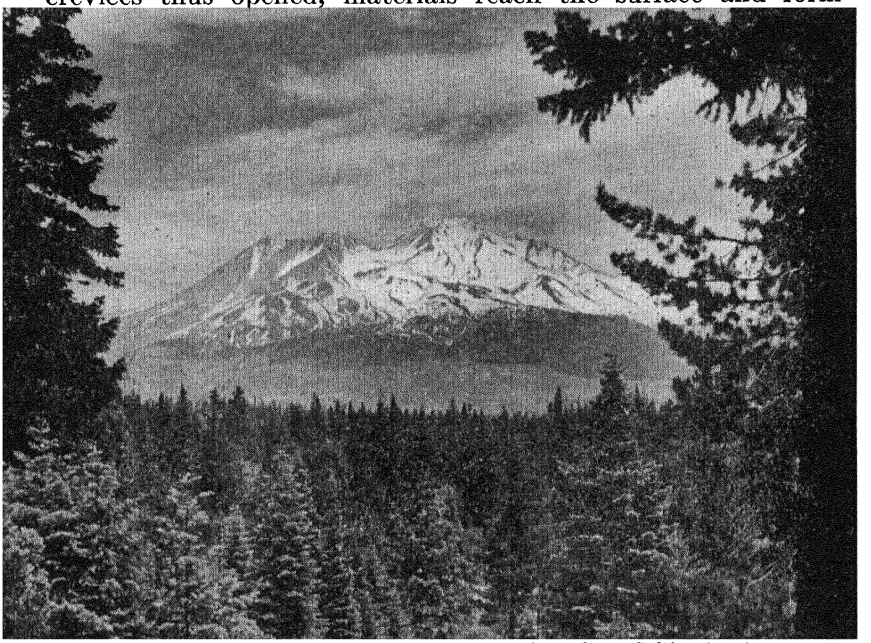


FIG. 236.—Mt. Shasta, snow-capped landmark of northern California, rises 14,161 feet above sea level. Melted snow from this peak is the principal source of supply for the Sacramento River. A great dam, now under construction on this river by the Bureau of Reclamation, will store much of this water and that of the Pit and McCloud rivers which flow into the Sacramento above the dam. The new dam, named Shasta, will greatly aid navigation and flood control. Its waters will also be used for irrigation. (*Courtesy of U.S. Bureau of Reclamation.*)

Certain long-extinct volcanoes, like Mt. Shasta and Mt. Rainier, have their flanks deeply scarred by glacial and stream erosion (Fig. 236). On the flanks of Mt. Rainier are to be found the longest valley glaciers in the United States (Fig. 237).

The vent through which the volcanic products are erupted is called the *crater*. Craters differ greatly in form. Some are small and funnel-shaped; others are of considerable diameter. Certain large craters, called *calderas*, are believed to be the result of the sinking in or subsidence of the top of the cone, caused by with-

drawal of lava from beneath. *Crater Lake*, in the Cascade Mountains of Oregon, occupies such a caldera (Fig. 238). The lake is 4 to 5 miles in diameter and almost 2,000 feet deep. Near the west margin is Wizard Island, a perfect volcanic cone with a small crater in its top. Crater Lake, because of its great beauty, has long been one of the national parks.



FIG. 237.—Emmons Glacier, on the eastern slope of Mt. Rainier, Washington. This is the largest glacier in continental United States. Much larger and longer glaciers are found in Alaska. (*Courtesy of U.S. Department of the Interior.*)

Stream-eroded Features of Mountains

Valleys. Mountain streams generally have high velocities. The water is usually clear, except after heavy rains. Especially in their lower courses, such streams have considerable eroding power because of greater volume and because of the sand and gravel that are rolled along the stream bed. Unlike the quiet streams of plains, those in mountains are noisy and turbulent as they tumble down narrow valleys. Their courses in many instances consist of almost continuous rapids and small waterfalls. Such are the home of mountain trout.

Because of high velocity, it is evident that downward erosion by mountain streams will be more rapid than side cutting. The

result is the formation of many V-shaped valleys. Where rocks are resistant, the valley walls may be steep and close together, forming a gorge, or canyon (Fig. 239). Examples of the narrow and steep-sided type of valley are provided by the Royal Gorge of the Arkansas River and several other canyons that cut through the front range of the Rocky Mountains in Colorado. These particular valleys are of importance especially in three

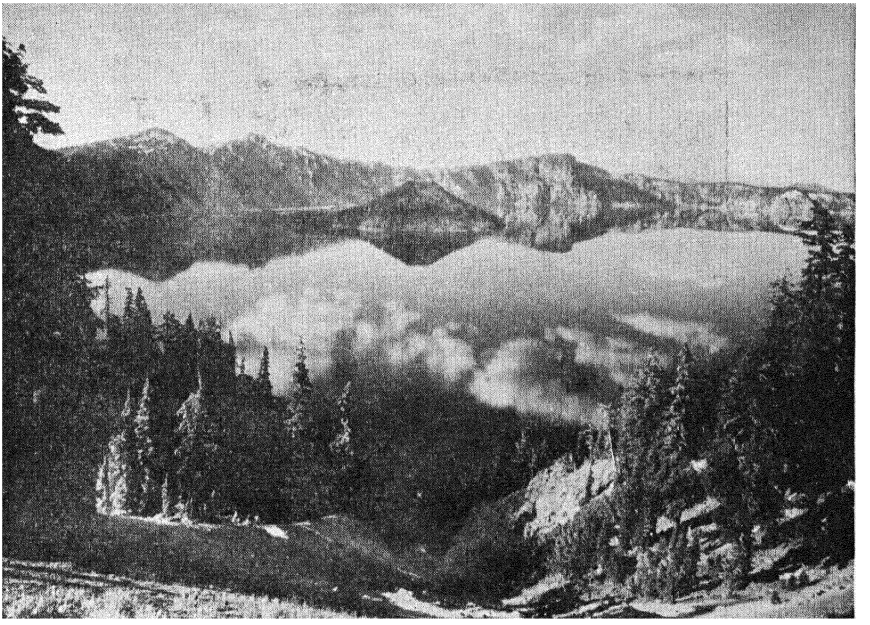


FIG. 238. Crater Lake, Oregon. The surface of the lake is about 6,000 feet above sea level. Wizard Island, silhouetted against the far shore, is an extinct volcanic cone. (*Courtesy of U.S. Department of the Interior.*)

ways: (1) They are routes of a number of roads that penetrate the mountains. (2) Their streams provide the all-important water that is needed to irrigate the plains immediately east of the mountains. (3) Dams built across the valleys provide storage water for several hydroelectric plants which furnish power for Denver, Colorado Springs, Boulder, and other cities located along the eastern base of the Rockies.

In some places, a fairly broad mountain valley may change suddenly to a narrow gorge. Such a gorge is sometimes utilized as a site for the economical construction of a dam to impound

water in a great reservoir. An excellent example of such construction is shown by the Shoshone Dam, west of Cody, Wyo. Here, where the Shoshone River flows through an extremely narrow canyon, has been built one of the highest dams in the world. The waters impounded are used for irrigation in the Big

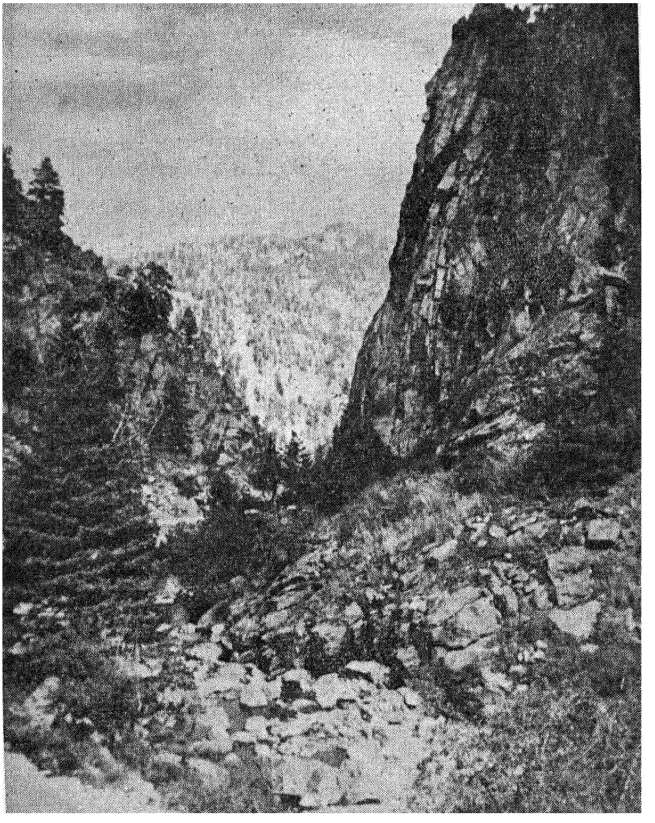


FIG. 239.—Boulder Canyon, west of Boulder, Colo. This picture illustrates the steep-sided, V-shaped type of valley that may be observed in many mountains.

Horn Basin, which lies between the Big Horn Mountains on the east and the Absaroka Range on the west.

In many mountain valleys are waterfalls of considerable size. Such falls often are suitable sites for the location of hydro-electric plants. In the Cascade Mountains, numerous streams with falls and rapids result from abundant precipitation. These mountains are noted for their tremendous potential, or "stored-up," water power.

Divides. Between mountain valleys are uplands which are the remnants of the original elevation. When rain falls on these uplands, the water separates according to the surface slopes and descends by countless rivulets into adjacent valleys. These rivulets are tiny tributaries of a large drainage system. A crooked line that connects the highest points between two drainage systems is called a *divide*. We must not think of divides as being limited to mountains. They are present also in plains, plateaus, and hill regions. Some divides are more conspicuous than others. The continental divide of the United States follows the Rocky Mountains from north to south, passing through western Canada and the states of Montana, Idaho, Wyoming, Colorado, and New Mexico, and on southward through Mexico. It separates waters that flow ultimately to the Atlantic and Pacific oceans (Fig. 240). In places, this divide is unusually high; and its lowest points, called *passes*, must be utilized by transportation routes. Such passes often are the result of vigorous erosion by opposing headwater streams or by glaciers (Fig. 241).

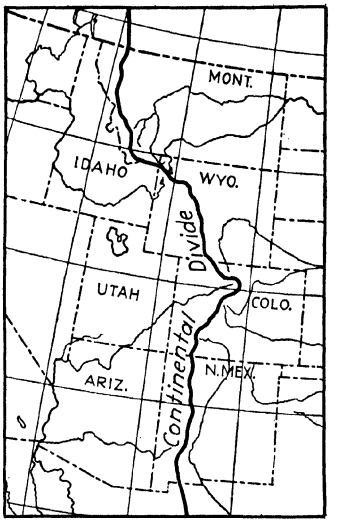


FIG. 240.—The heavy line shows the approximate location of the continental divide.

West of Denver, Colo., where the continental divide is crossed by U.S. Highway 40 at Berthoud Pass, the elevation is over 11,000 feet. Not far from this pass is the Moffat Tunnel, 6 miles long and about 9,000 feet in elevation (Fig. 242). By using the tunnel, trains between Denver and Salt Lake City are saved the slow and expensive climb over the continental divide. Paralleling and only a few feet from the Moffat Tunnel is another one of much smaller size (Fig. 243). It is used during a part of the year to conduct water from the western slopes of the Rockies to the eastern slope. This water is conveyed to the city of Denver for domestic and commercial use.

The longest railway tunnel in North America is the Cascade Tunnel on the Great Northern Railroad about 75 miles east of

Seattle, Wash. (Fig. 244). It was built at a cost of 14 million dollars, is over $7\frac{1}{2}$ miles long, and is cut through a portion of the Cascade Mountains. It differs from the Moffat Tunnel in two respects: (1) Available hydroelectric power makes it possible to use electrical locomotives. This eliminates the considerable expense of continually blowing smoke out of the tunnel, which is necessary at the Moffat Tunnel. (2) The Cascade Tunnel is

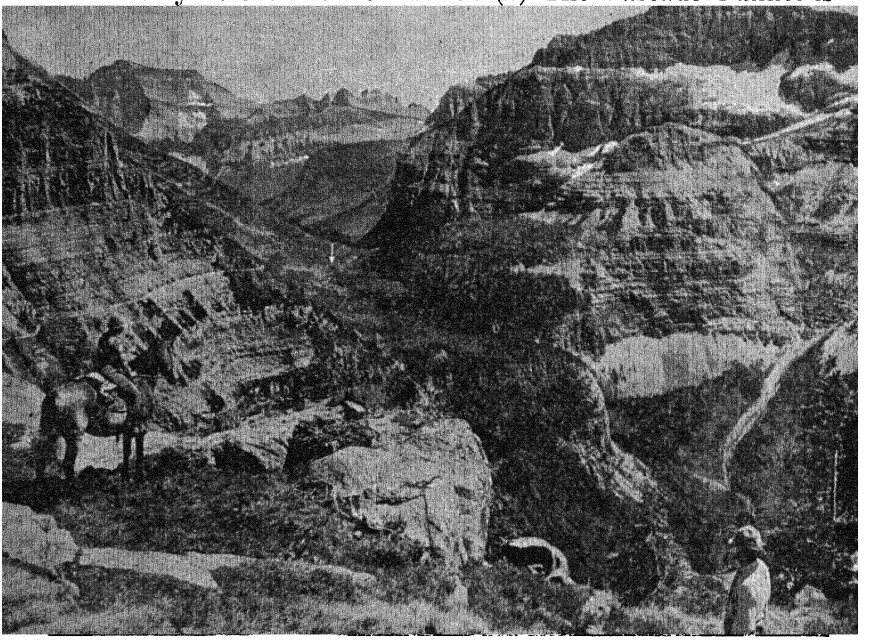
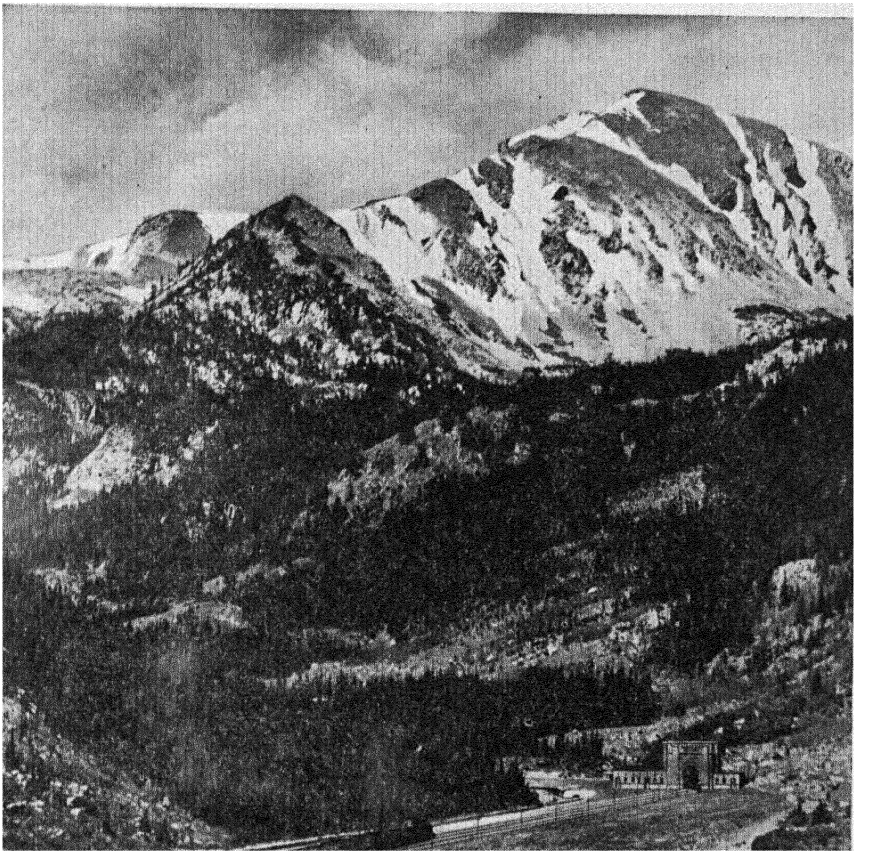


FIG. 241.—Brown Pass, in Glacier National Park, viewed from a higher pass. The saddle shape of this notch is distinct. The white arrow point touches the crest of the pass, which also is a part of the continental divide. (*Courtesy of National Park Service.*)

about 2,800 feet above sea level, whereas the Moffat Tunnel is over 9,000 feet. In the Alps the famous St. Gotthard and Simplon tunnels, both longer than the Cascade Tunnel, are used by railway lines between Switzerland and Italy.

Mountain Peaks. These are the distinguishing features of mountain uplands. Their varied forms hold much of the attractiveness of mountain scenery. Some mountain peaks are the result of faulting, and many are volcanic cones. By far the greater number of the countless peaks of the earth, however, are the result of erosion in the upland of which they are a part. Owing to superior resistance, to conditions of structure, to

accident of position, or to other causes, peaks have been protected from erosion while adjacent rocks have been reduced to lower levels. Such are well-known Pikes Peak, near Colorado



the continental divide. The trees are coniferous, mainly pine and spruce. The timber line can be clearly traced across the center of the photograph. The upper slopes of these mountains exhibit features caused by glacial erosion and deposition. (*Courtesy of Denver and Rio Grande Western Railroad.*)

It is a rather remarkable fact that all the highest peaks in the United States are between 14,000 and 14,500 feet in elevation.

Mountain Glaciers and Glacially Eroded Mountain Features

When We Look at Mountains. High mountains, even in the tropics, project above the line of perennial snow. Others, not so high, were snowcapped during the most recent glacial

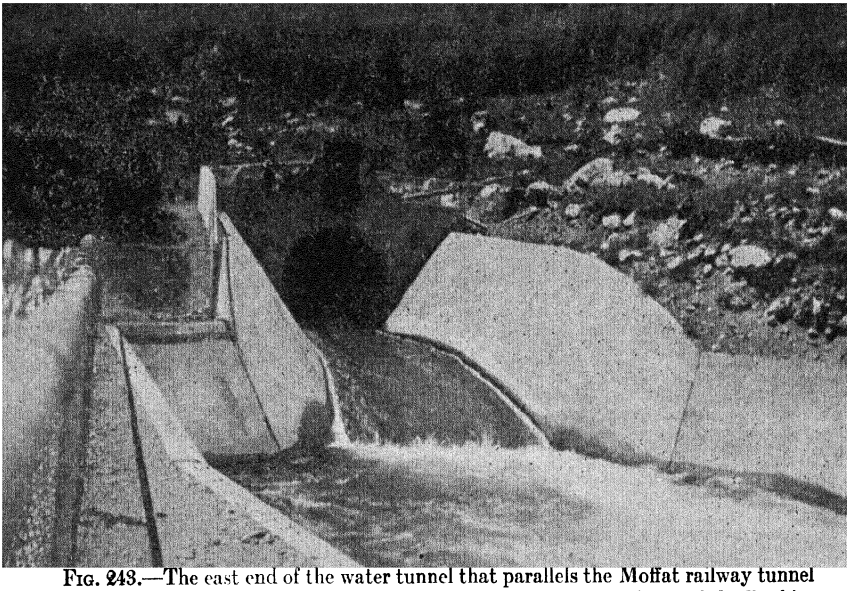


FIG. 243.—The east end of the water tunnel that parallels the Moffat railway tunnel west of Denver, Colo. Water flows from the western to the eastern slopes of the Rockies through this tunnel and ultimately reaches Denver.

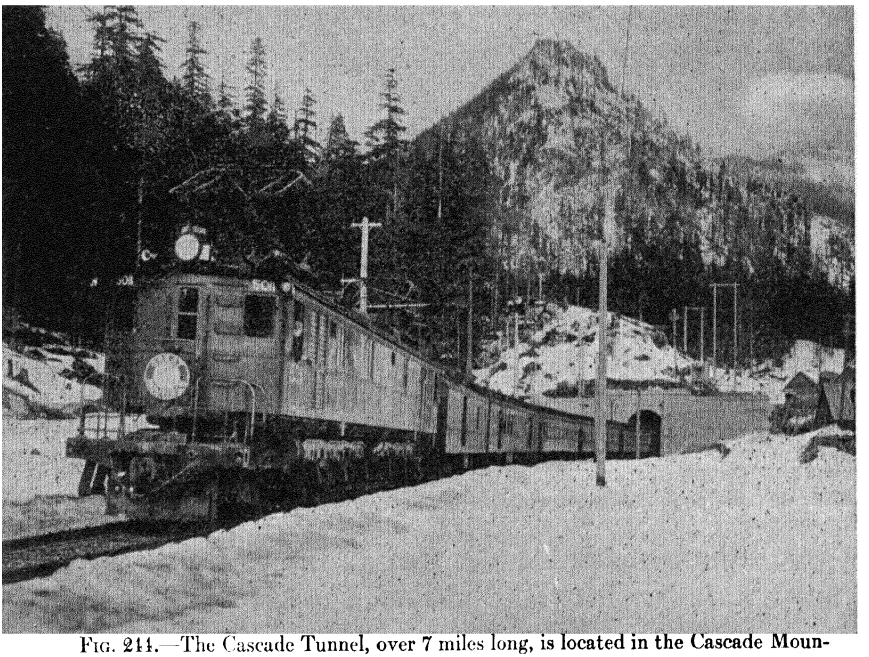


FIG. 244.—The Cascade Tunnel, over 7 miles long, is located in the Cascade Mountains east of Seattle, Wash. The Pacific Northwest is noted for its great water-power resources. The water power is employed to generate electrical energy, part of which is used by certain railroads. (*Courtesy of Great Northern Railway.*)

period. So common are the forms of mountain glaciation that they have greatly influenced popular ideas concerning the features of mountains in general and of the grandeur of mountain scenery. The snowcapped peak, the ice-filled valley, and the carvings and fillings of former glaciers attract and inspire the mountain visitor as other kinds of mountain features cannot.

Even to the casual observer, two "lines," often well defined, may be observed in high mountains. Ascending the mountain slope, the first encountered is the *timber line*, which is the upper limit of tree growth. The next is the *snow line*, which is the lower limit of perennial snow. Above the snow line are snow fields and glaciers. Some valley glaciers, however, extend below both the snow line and the timber line.

Mountain Snow Fields. Snows are common to all high mountains. In middle and high latitudes, the seasonal alternation from winter white to the variety of warm-season colors, produced by rocks and vegetation, works a profound change in the landscape. The snows of many mountains are, however, permanent. They owe their preservation to the decrease of temperature with altitude. The snow line, therefore, in the tropics is high, but in subpolar regions it approaches sea level. It is lower on shady than on sunny mountain slopes. In regions of similar temperature, the snow line is lower where snowfall is abundant and higher where it is not abundant. If these variations are allowed for, it may be said that the lower limits of snow fields are as follows:

1. In the tropics: 14,000 to 20,000 feet above sea level
2. Middle latitudes: 5,000 to 10,000 feet above sea level
3. Subpolar regions: 0 to 2,000 feet above sea level

Barring certain exceptions caused mainly by climatic conditions, the following rule holds true: *As latitude increases, timber line and snow line decrease in elevation.*

Mountain Glaciers. Apart from the mountain forms caused by their erosion, mountain glaciers are themselves important relief features. Fed by frequent snowfall, a highland snow field becomes heavy. Portions of it slip and plunge by avalanche into the nearest valley head (Fig. 245). There the deepening mass changes, first into granular ice, then by melting and refreezing into solid ice.

Ultimately, however, the main accumulation in a valley head grows to such proportions that, under its own weight, it moves. In the form of an ice tongue, it pushes down its valley and becomes a valley glacier. It progresses in its own peculiar way, its lower edge melting and providing water for a mountain stream. In its course, the surface of the ice undergoes considerable change. Irregularities of the valley floor bend and twist

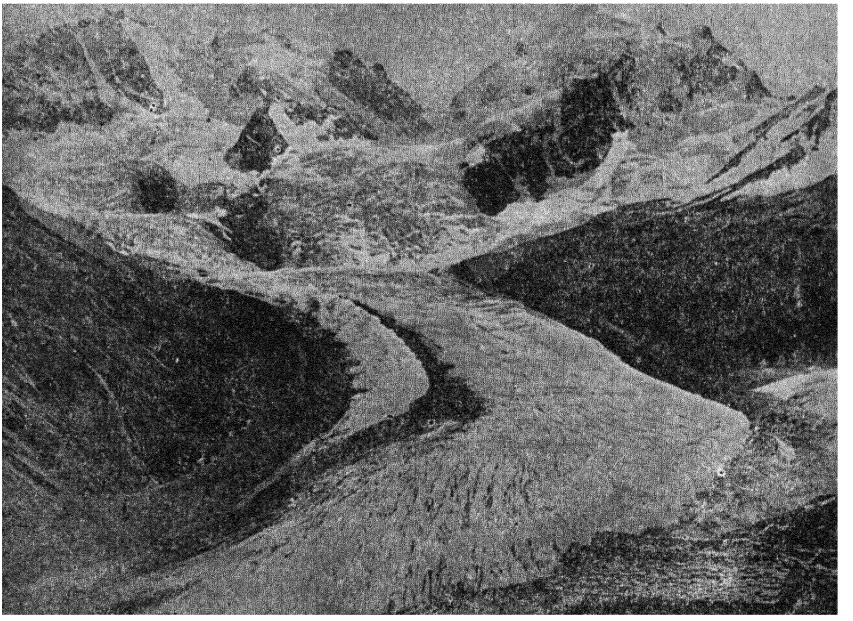


FIG. 245.—A mountain glacier and its snow fields. Crevasses are visible in the nearer ice. Ridges of lateral moraine flank the ice tongue, and moraine streaks its surface. (*Ewing Galloway.*)

the solid ice. This causes the ice to break, forming deep cracks known as crevasses.

Rock waste accumulates along the sides of the glacier to form lateral moraines. Where two valley glaciers join, a streak of rock waste may mark the center line along which the two ice tongues meet.

At the lower end of the glacier, wastage by melting is rapid. Here the rock waste carried and pushed along by the ice accumulates, in some cases, to such an extent that the ice is covered. This material forms an end moraine. When the glacier disappears, this end moraine appears as a ridge across the valley.

Some mountain valleys, formerly occupied by valley glaciers, now exhibit a succession of several such end moraines, a few of which may form natural dams.

Certain valley glaciers, especially those of coastal mountains in high latitudes and in regions of marine west-coast type of climate, are so abundantly provided with snow that the ice tongues extend to the sea. This is notably true at present of a part of the coast of Alaska (Fig. 246), and it has been true of more extended coasts in the past. Sometimes great masses of



FIG. 246.—In the foreground is floe ice. It has toppled off the front of this Alaskan glacier which descends to sea level. The separation leaves the ice front sheer. (*Courtesy of U.S. Geological Survey.*)

ice break off from the front edge of the glacier and float away as icebergs. Some glaciers, like those which descend from the ice plateaus of Greenland and Antarctica, are the source of many icebergs.

Glaciated Mountain Valleys. The typical ice-scoured valley is deepened, its sides are made steeper, and its bottom widened and broadened. Compared with the stream-eroded valley, it is U-shaped rather than V-shaped. Ice scour tends to smooth and straighten the valley (Fig. 247).

Glaciated valleys seldom have a continuous, uniform slope downward from the valley head. The glacier gouges basins in the valley bottom which become the sites of small lakes when the ice disappears. In addition to these basins, others are formed by

morainic dams across the valley. Most glaciated valleys have one or more such basins, and some have a succession of them. In

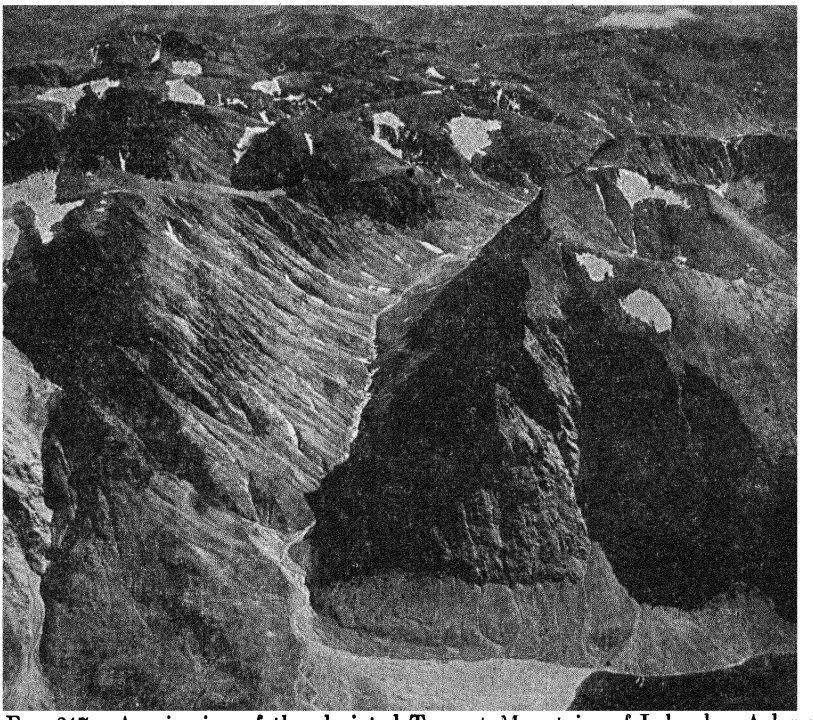


FIG. 247.—An air view of the glaciated Torngat Mountains of Labrador. A long ice-scoured valley curves into the distance where it is flanked by cirques. Other cirques are to be seen at the right center and in the background. An alluvial delta fan and lake are visible in the foreground. (*Ewing Galloway.*)

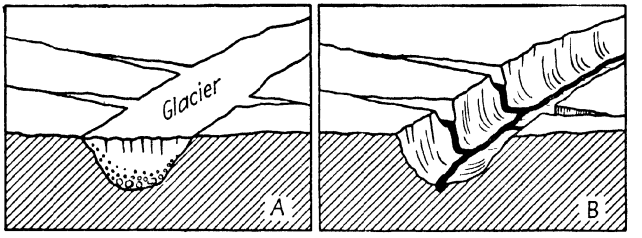


FIG. 248.—The formation of hanging valleys. In diagram *A*, glaciers are shown occupying all valleys. Glacial erosion is more effective in deepening the main valley than the tributary valleys. In diagram *B*, the ice has disappeared. Two hanging valleys and waterfalls are to be seen on the far wall of the main valley. Waterfalls developed in this manner sometimes make advantageous sites for the building of hydroelectric plants.

these basins, water collects to form lakes, ponds, or marshes. In valleys of flat gradient, especially near the margins of moun-

tain regions, glacial deepening and morainic dams are capable of providing basins of large size. The basins of the beautiful Lakes Maggiore, Como, and Garda at the southern base of the Alps are of that origin. So are those of several long lakes in Glacier National Park, Lake Louise in the Canadian Rockies, and many lakes in the Andes of southern Argentina.

In the process of glaciation a main valley may be more deeply eroded than its tributary valleys. After the withdrawal of the

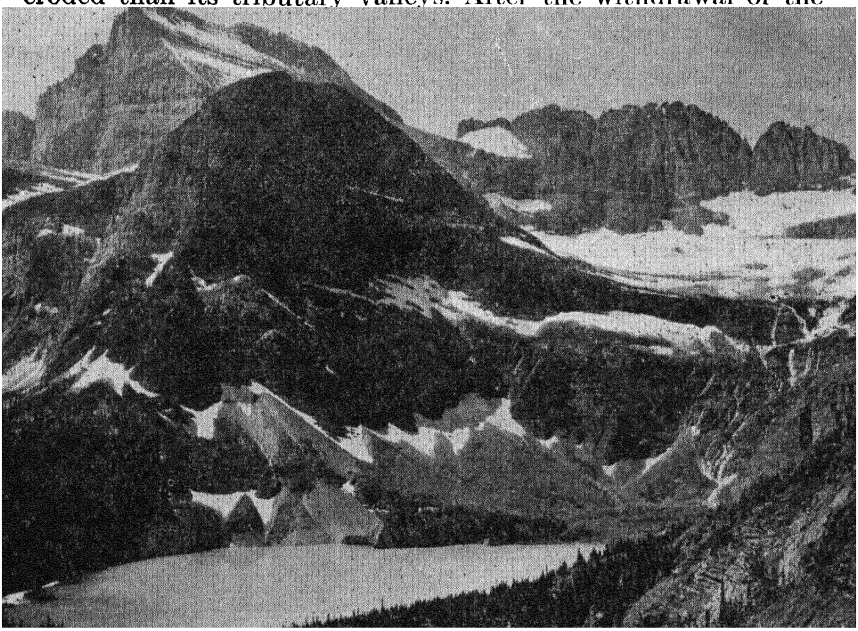


FIG. 249.—Grinnell Lake and Glacier in Glacier National Park, northwestern Montana. The ice occupies the lower portion of a large cirque. Streams cascade down from the glacier to the lake. The sharp, bold mountain features were produced by glaciation. (*Courtesy of Great Northern Railroad, photograph by Hileman.*)

ice from the region, the level of the main valley floor may lie tens or even hundreds of feet below the ends of its tributary valleys. These tributary valleys then appear as notches upon the side of the wall of the steepened main valley and are called *hanging valleys* (Fig. 248). The streams issuing from them must plunge in rapids or waterfalls to reach the main valley floor. Falls of that kind are of great scenic attraction. Examples are the falls of Yosemite Valley, California, and many others in the Rocky Mountains, Switzerland, Norway, and other regions of mountain glaciation. They also are most convenient places for the develop-

ment of water power. Even a small stream, with so great a fall as some hanging valleys provide, can develop an astonishing quantity of power.

The valley head, in a region of mountain glaciation, is the collecting ground for the snow that crystallizes into a glacier. Erosion beneath the forming ice broadens and sharply steepens the valley head until it is rounded, steep sided, and amphitheater-



FIG. 250.—Scenery of glacial origin in the Canadian Rockies. At the right is a cirque lake. Its drainage falls to the level of the second lake, and from that it must fall far below to the level of Lake Louise, part of which may be seen at the left in the main valley. (*Photograph by De Cou, from Ewing Galloway.*)

shaped. It is called a *cirque* (Fig. 249, 250). In the bottom of many cirques are rock basins containing lakes. These add beauty to this huge erosional feature with its steep rock walls. Hundreds of such cirques, large and small, may be observed in the glaciated mountain regions of North America, Europe, Asia, South America, and New Zealand.

It should be emphasized that glaciated mountains exhibit features of much greater sharpness of detail than those resulting from stream erosion (Fig. 251). Glacial scour may produce a "knife-edge" divide. So close is the approach of some opposing cirques that in places the thin divide between them crumbles

through, leaving the crest merely a row of alternating pinnacles and notches. The *Garden Wall* in Glacier National Park is such a formation, and it happens also to be the continental divide. Some high mountain peaks, their bases whittled by ice erosion, are reduced to sharpened remnants. They commonly appear steep and angular. A good example is provided by the Matterhorn in the Alps.



FIG. 251.—The rugged, glaciated Sierra Nevada Mountains, in Yosemite National Park. Glacial erosion on opposite sides of a rocky ridge produces a saw-tooth divide. The steep slopes shown here are in contrast to the more gentle slopes of water-eroded mountains. (*Courtesy of U.S. Department of the Interior.*)

Value of Mountains. The narrow valleys, steep slopes, and thin soils of mountain regions are not favorable to dense human occupance. On the other hand, mountains are valuable to mankind in many ways. (1) The great expanses of grassy slopes serve as grazing lands. (2) The abundant precipitation in many mountains creates streams whose waters may be used for irrigation or power (see Chap. XV). (3) The forests of certain mountains provide excellent sources of lumber (see Chap. XVI). (4) The complicated structure of mountains is largely responsible for the formation of valuable ore deposits (see Chap. XVIII). (5) Mountains adjacent to great centers of population on

plains attract many vacationists, especially in summer. The reasons for such attraction are the cooler climates at higher elevations, the variety and beauty of scenery, and mountain sports of various kinds.

Summary

True mountains may be considered as having a local relief of 2,000 feet or more. A group of mountain systems is called a cordillera. One system, such as the Rockies, consists of many ranges. Mountains may be formed by uplift of great masses of igneous rocks, by volcanic activity, by folding, and by faulting. Mountains sometimes serve as natural boundaries between countries. They often contain rich mineral deposits. They are eroded by streams and glaciers. On some high mountains both timber line and snow line may be observed.

In the last few chapters we have given our attention mainly to the lithosphere, or the solid rock crust of the earth, and its covering of mantle rock. In the next chapter we shall consider the hydrosphere, or the giant oceans that cover so much of the earth's surface.

Questions

1. In general, what may be considered as the local relief in true mountains?
2. What is the total relief of the earth? How is it calculated?
3. Locate Mt. Everest. What is its elevation above sea level?
4. Locate the East and West Indies. Name several islands in each group. Compare the two groups with respect to height and area of mountain masses.
5. Explain and diagram the four principal ways in which mountains are formed.
6. Define the five major classes of mountain features.
7. Name and locate four principal cordilleran regions.
8. Why are mountain systems sometimes important elements of environment?
9. In the Rockies, where is the front range? The Sawatch? Why are huge flocks of sheep taken to the mountain tops for the summer months?
10. Describe the Sierra Nevada Range. Which slope, east or west, receives the heavier precipitation? Why? What use is made of the water of numerous streams?

11. Where are the Wasatch Mountains? How were they formed? Surface streams are used to irrigate what area?

12. Locate Java and Sumatra. How were these mountainous islands formed?

13. Locate Mt. Baker, Mt. Rainier, and Mt. Hood. Explain how they were formed.

14. The only active volcanic mountain in the United States is Mt. Lassen. Exactly where is it?

15. Why are some volcanic cones more conspicuous features of the landscape than others? Give an example.

16. Name and locate 10 volcanic peaks.

17. Explain what is meant by a parasitic cone.

18. What is a crater? A caldera? How are calderas thought to have been formed?

19. Locate and briefly describe Crater Lake.

20. Contrast mountain streams with those of plains.

21. What is the characteristic shape of stream-eroded mountain valleys? Why?

22. Locate the Royal Gorge. By what river has it been eroded? What uses are made of some valleys in the front range of the Rockies?

23. What is the advantage of the location of Shoshone Dam? The impounded water is used for what purpose?

24. What is meant by "the Cascade Mountains are noted for their tremendous potential water-power resources"?

25. Define divide. Where is the continental divide of the United States?

26. Mention several ways in which the continental divide of South America differs from that of North America.

27. Why cannot the Appalachian divide be called a continental divide?

28. In what country is the divide between the Danube and Rhine rivers?

29. What is a mountain pass? In what ways may mountain passes be formed? What use is made of them? Give an example.

30. Where is the Moffat Tunnel? Why was it constructed? What is the purpose of the water tunnel that parallels the railway tunnel?

31. Using a map of Switzerland, determine the exact location of the St. Gotthard and Simplon tunnels. Why were they constructed?

32. Most mountain peaks are a result of what process?

33. Locate Pikes Peak and Longs Peak. How high are they?

34. What is the range of elevation of the highest peaks in the United States?

35. What is meant by the timber line? The snow line?

36. How does increase in latitude generally affect the snow line? Why?

37. Describe the origin of a valley glacier.

38. Where do lateral moraines form? End moraines? How do end moraines appear when the glacier has disappeared?

39. Account for the fact that many valley glaciers in Alaska extend to the sea. In what two localities do similar glaciers produce great icebergs?

40. How are valleys changed by glacial erosion?

41. In what two ways are lake basins formed in a glaciated valley?

42. The glaciers on Mt. Rainier are much larger than those in Glacier National Park. Explain why.

43. Only a few small glaciers exist today in the Rocky Mountains of Colorado. Explain why.

44. Why are glaciers in the Alps much larger than those in the Rocky Mountains of the United States?

45. Why are there no glaciers in some high mountains? Give an example.

46. Explain how hanging valleys are formed. Why are they of economic importance in some localities?

47. Locate Yosemite Falls. If possible, study a topographic map of the Yosemite Valley to determine the height of the falls.

48. What is a cirque? How is it formed? If possible, study topographic maps of Rocky Mountain and Glacier National parks. You will find that many cirques, large and small, are clearly shown.

49. How do the features of glaciated mountains differ from those produced by stream erosion?

50. Would you expect weathering to be more or less rapid in glaciated than in stream-eroded mountains? Why?

51. Locate the Matterhorn. Account for its steep and angular appearance.

52. Mention several ways in which mountains are of value to man.

Suggested Activities

1. On a map of the world, locate and label 15 mountain systems. Label a number of the highest peaks in the world, noting the elevation of each.

2. On a map showing many rivers in western United States, draw the continental divide. Name the states and national parks through which it passes. On the same or a similar map, trace the Appalachian divide.

3. Sketch a large map of Switzerland. Label the larger glacial lakes, the important railway tunnels, and other features of interest.

4. Plan a trip during which you would visit Glacier, Yellowstone, and Rocky Mountain national parks. Make a list of the interesting features that you would want to observe. Do the same for a trip that would include the Sierra Nevada and Cascade Mountains.

5. Secure post route maps of several Western states from the Superintendent of Documents, Washington, D.C. These are large maps and are reasonable in price. They can be used for many purposes. On the map of Colorado, for example, color the national parks. Use a method to emphasize the interesting mountain features of the state. Draw a heavy red line over highways that would enable you to visit most of the designated places.

6. Learn to locate exactly every mountain system, range, peak, or other feature mentioned in this chapter.

7. Using the Mt. Shasta, California, quadrangle (U.S. Geological Survey), make a profile drawing of a typical volcanic cone.

8. Using a contour map of Crater Lake, Oregon, and proper molding materials, make a relief model of the region.

9. Make a rough relief model of Mt. Rainier (use contour map). Paint the glaciers white and the mountain slopes green.

10. Make a relief model of South America. On a piece of cardboard, trace the shoreline of the continent. An inexpensive molding material may be made of flour and water. Exaggerate the height of the Andes Mountains and the Brazilian Highlands. When dry, use fine blue lines to show the principal rivers.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Rocky Mountain National Park
2. Mt. Rainier National Park
3. Glacier National Park
4. Yosemite National Park
5. Crater Lake National Park
6. The Royal Gorge of the Arkansas River
7. The Shoshone Dam and Irrigation Project
8. Volcanic Cones of the United States
9. Mountain Ranges as Boundary Lines
10. The Canadian Rockies
11. The Sierra Nevada Mountains
12. The Glaciers of Alaska

References

FENNEMAN, N. M.: *Physiography of Western United States*, Chaps. 2, 4, 5, and 9, McGraw-Hill Book Company, Inc., New York, 1931.

HUNTINGTON, ELLSWORTH, and S. W. CUSHING: *Principles of Human Geography*, Chap. 4, John Wiley & Sons, Inc., New York, 1924.

TARR, R. S., and LAWRENCE MARTIN: *College Physiography*, Chap. 15, The Macmillan Company, New York, 1927.

Chapter XIV. Oceans and Their Shores

It has been noted earlier that the oceans occupy about 71 per cent of the surface of the earth. They are so unsuited to human habitation that they are, in a sense, great deserts. However, they are both interesting and useful to man in many ways.

At times the ocean surface is smooth and inviting; at others its great waves are extremely dangerous. Yet man has long since learned to conquer these and to make use of the oceans as convenient avenues of transportation rather than to accept them as permanent barriers between the continents. Ships now move freely over the important lanes of ocean traffic. Airplanes seek the shortest routes between seaports or make use of intervening islands as landing bases.

The climatic effects of the ocean and the actual resources of the sea and its shores are of the utmost economic importance. The ocean water contains a vast assortment of animal life. Strange, highly colored, phosphorescent fish occupy the ocean depths. In the surface waters are larger marine animals, including a variety of edible fish of great value as human food. These resources are treated more fully in Chap. XVIII.

The shores of the oceans also vary greatly in their usefulness to man. Some are regular in outline or bordered by shallow water and are difficult or dangerous to approach in ships. Others are deeply indented or are carved by waves and currents into peculiar features, some of which provide shelter for ships, others considerable scenic attraction for man. Cool sea breezes, rocky promontories, or sandy beaches are resources no less real than the fish of the sea. They attract to the seashores of the world thousands of visitors and millions of dollars of income each year for those who live there.

Composition of Ocean Water. The oceans have from the beginning of the world received the streams that drain the land and have returned the water to the land again through evaporation and winds. Thus there is left in the sea water all the mineral substance carried by river waters in solution. Some of these substances, such as lime, are used continually by marine animals in making their bones and shells and so do not accumulate in the ocean water. Some other minerals, however, are not so readily taken out of solution. Ocean water now contains about 3.5 pounds of dissolved mineral matter per 100 pounds of water. About three-fourths of this is common salt. In some localities, sea water is evaporated, and the salt obtained for human use.

Tiny particles of air also exist in sea water. It is this air which supplies the oxygen for marine life. When sea or lake water is heated, the air particles expand and can be seen coming to the surface before the water reaches the boiling point. If boiled water is immediately cooled and put in an aquarium, the fish will suffer from lack of air. In the ocean, considerable air is whipped into the water by wave action. Of great importance also are certain water plants whose leaves give off oxygen into the sea water.

Only the upper layers of ocean water are warmed to any extent by the sun. The temperature of surface waters near the equator may reach 80°F.; in the vicinity of the poles it may be as low as 29°F., which is about the freezing point of ocean water. Most of the subsurface water of the ocean is very cold, having a temperature of less than 45°F.

The pressure of ocean water at great depths is enormous. It is about 1 ton per square inch at a depth of 1 mile. In the deepest parts of the ocean it is about 6 tons per square inch at a depth of 6 miles. Unlike air, water is only slightly compressed by great weight. Consequently, water at great depths has about the same density as the upper layers. Therefore any object that will sink in the surface water will go to the bottom of the ocean.

Depth of the Ocean. The depth of the ocean is usually expressed in fathoms. One fathom is 6 feet. There are two methods of ascertaining the depth. In shallow water, a weight fastened to a line is lowered until it rests on the ocean floor, and

the length of the line is noted. A faster method is provided by an instrument called a *fathometer*, which makes use of the fact that sound waves travel through water at the rate of about 4,840[1] feet per second. This is about four times as fast as sound waves travel through air. A flexible drum is exposed to the ocean water in the stern of the ship. A sound wave from this drum goes to the ocean floor and is reflected back and received by a hydrophone in the bow of the ship (Fig. 252). If the time interval between broadcast and reception of the sound wave is 6 seconds, then the depth of the ocean is 14,520 feet, or 2,420 fathoms. Numerous measurements have shown that the average depth of the ocean is about 2 to $2\frac{1}{2}$ miles. The deepest parts of the ocean basins are called *deeps*. The greatest depth known is 35,400 feet and is just east of the Philippine Islands. One of the deepest parts of the Atlantic Ocean lies just north of Puerto Rico.

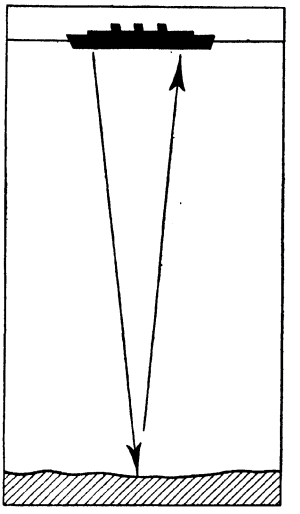


FIG. 252.—A sound-wave broadcast from the bottom of the ship, traveling at the rate of about 4,840 feet per second, reaches the ocean floor and is reflected back. By using the time interval between broadcast and reception, the depth of the ocean can be quickly calculated.

Movements of Ocean Water. The waves of the ocean are caused by the friction of wind with its surface. Winds of gale velocity may cause waves to reach a height of 25 to 50 feet (Fig. 253). Huge waves driven by hurricane winds have invaded the coasts of Florida and Texas and have done tremendous damage, especially in cities located near sea level. Big waves traveling at high speed have great power. They pound against rocky coasts. They dislodge and toss rocks into the air. Such wave-tossed rocks have been known to break windows in lighthouses more than 100 feet above the ocean surface.

The wave motion is principally an up-and-down movement of the water. However, surface water moves slowly in the direction toward which the wind is blowing. As a wave comes into the

[1] This velocity varies somewhat, being influenced by temperature, depth, and salinity of the water.

shallow water near the shore, its lower part may be retarded by the ocean floor. The top of the wave, having greater momentum, pitches forward, causing the *breakers* that may be observed on many coasts. From the line of breakers, smaller waves move onshore as far as possible and return to the ocean as an undercurrent known as the *undertow* (Fig. 254). The incoming waves on Waikiki beach near Honolulu (Fig. 255) are so pronounced that expert surfboard riders are able to enjoy a ride of about a quarter of a mile at a speed of 25 miles per hour or more.

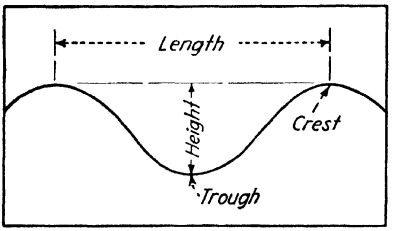


FIG. 253.—The parts of a wave and the names used in referring to them.

Tidal waves, as explained in a previous chapter, are due to earthquakes on the ocean floor. These are the largest and most destructive of all waves. They have caused disaster on many shores but especially along those of the Pacific Ocean in eastern Asia and among the islands of the East Indies and Philippines.

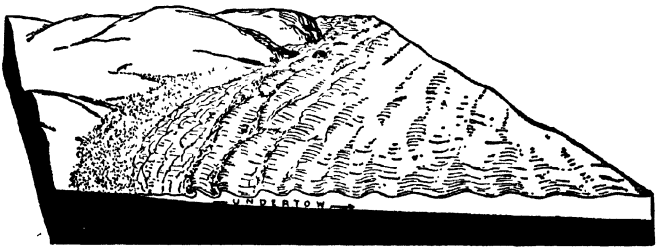


FIG. 254.—This diagram illustrates the change in form and final toppling of waves in shallow water. In the foreground the line of breakers is some distance from the shoreline, and a beach has been formed. In the background waves break directly upon a headland, and a cliff has been cut.

Tides

What Are Tides? The regular rise and fall of the level of the sea is called the *tide*. Tides are caused mainly by the attraction of the moon and to a lesser extent by that of the sun. The attraction of the moon causes the ocean water to bulge out on the side of the earth facing the moon. This "bulge" causes the high tide. There is a similar bulge on the side of the earth away from the moon. Thus are created on opposite sides of the earth two

high tides between which are two low tides. As the earth rotates on its axis once every 24 hours, it is evident that any given shore point might be expected to have two high and two low tides per day. The time between high and low tide, therefore, would be approximately 6 hours. However, the moon travels around the earth in its orbit in about 28 days, and its advancement in its orbit each day influences the time of tides. Thus the time

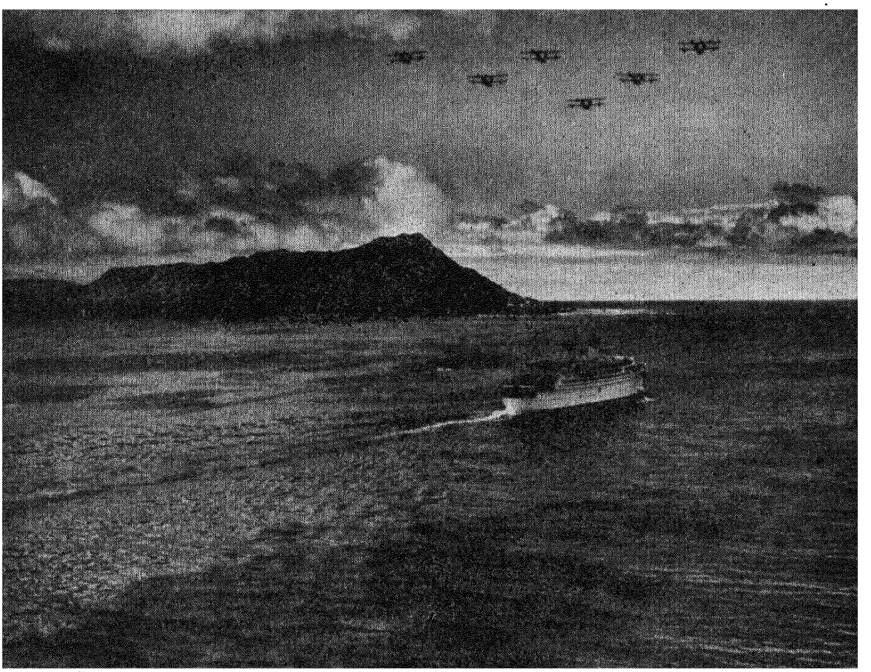


FIG. 255.—Not far from this headland of igneous rock, on the island of Oahu, is the beach of Waikiki. The Hawaiian Islands, 20° to 22°N. Lat., are in the northeast trades. (*Courtesy of U.S. Navy, official photograph.*)

between high, or flood, and low, or ebb, tide is usually about 6 hours 13 minutes and from high to high tide 12 hours 25 minutes.

During new moon and full moon, the earth, sun, and moon are almost in a straight line. At such times the tide-producing forces of the moon and sun combine to produce a higher flood tide, and consequently lower ebb tide, than usual (Fig. 256). Such are called *spring tides*, but it should be remembered that they have no relation whatsoever to the season called *spring*. The vertical distance, measured in feet, between high and low

tide is called the *tidal range*. It is evident, therefore, that the greatest tidal range occurs at the time of spring tides.

At the time of first and third quarter phases of the moon, the forces of the sun and moon are acting at right angles with relation to the earth. As a result the tidal range is reduced. Tides at such times are referred to as *neap tides* (Fig. 256). Since the phases of the moon are about 1 week apart, it follows that the time interval between spring tides is approximately 2 weeks. The same is true of neap tides.

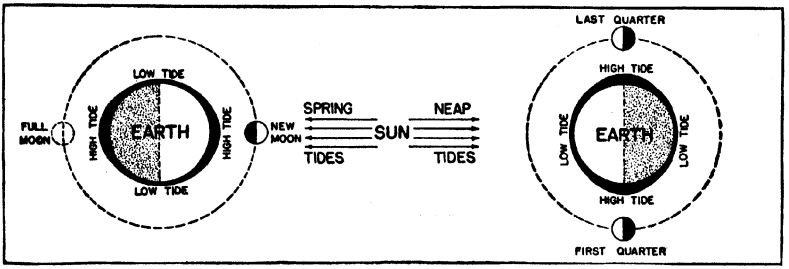


FIG. 256.—This diagram shows the relation of the moon, in its different phases, and of the sun to the occurrence of ocean tides.

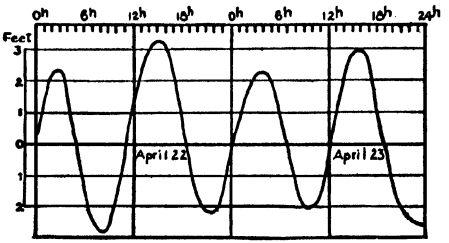


FIG. 257.—The intervals and amounts of tidal rise and fall at New York during a 48-hour period. (*After H. A. Marmer.*)

Tides Vary Greatly on Different Shores. Under ideal conditions, equal high tides should succeed each other at intervals of 12 hours 25 minutes. However, that is not the actual condition in many places. At any given station there is a considerable variation in the height of successive tides and in the intervals between them. This is due to the trends and outlines of different coasts, the depth of coastal waters, the shapes and sizes of the several oceans, and other causes. In general the tides of the Atlantic Ocean are most nearly like the ideal type. This may be illustrated by a curve showing the actual rise and fall of the tide at New York (Fig. 257). On some shores, notably parts of

southern Asia and the Caribbean and Gulf shores of America, there is but one high tide per day. The shores of the Pacific Ocean generally are characterized by what may be called *mixed tides*. In them each alternate high tide is much lower than the preceding one. This condition may be illustrated by a curve showing the actual tidal rise and fall at Honolulu (Fig. 258).

Variation in Tidal Range. In the open ocean the tidal range is so slight as not to be noticeable. As the tidal bulges, or waves, approach coasts, however, they tend, like other waves, to increase in height. The amount of the increase is determined by a number of factors. The tides of nearly enclosed bodies of water, such as the Mediterranean and Baltic seas, are so slight as to be negligible. In sheltered waters, such as the Gulf of Mexico and the Caribbean Sea, the range is small, usually less than 2 feet.

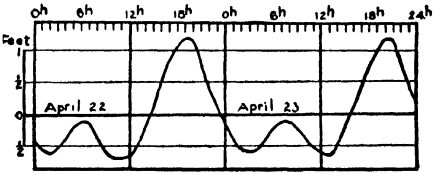


FIG. 258.—The intervals and amounts of rise and fall of a tide of mixed type at Honolulu. The period is the same as that in Fig. 257. (*After H. A. Marmer.*)

Common tidal ranges on exposed coasts are between 5 and 10 feet, though in some places less and in others more. In a few localities, some of them the sites of important commercial ports, the tidal range is so great that it is a distinct handicap to the use of the shore. Some harbors, notably Liverpool, England, have required expensive improvements to offset the disadvantages of the continuous rise and fall of the water level while ships are loading and unloading cargo at the wharves. Places of great tidal range are mainly situated upon funnel-shaped bays where the tide wave tends to pile up as it moves landward. Cherbourg, France, has an average tidal range of 17 feet; and Liverpool, 29 feet. The head of the Bay of Fundy, Nova Scotia, has 42 feet and, at time of spring tide, sometimes as much as 50 feet of extreme tidal range.

Tidal Behavior in Rivers. The incoming high tide advances up many rivers that empty into the sea. This is known as the *tidal bore*. Depth of water is thus increased, not only at the

mouth of the river but in some cases for many miles upstream. This increased depth facilitates the navigation of larger ships. A most pronounced tidal bore is observed in the Petitcodiac River of New Brunswick, where the tide advances upstream in the form of a noticeable wave. Among other rivers exhibiting similar tide behavior, but less pronounced, are the Hudson, St. Lawrence, Amazon, Seine, and certain rivers along the coasts of China and India.

Ocean Drifts and Currents

The movement of most of the surface water of the ocean is extremely slow, averaging about 2 miles per hour. This slow movement is referred to as a *drift.* The term *ocean current* is applied to the more rapidly moving waters which sometimes attain a rate of two or three times that of a drift (Fig. 259).

Ocean drifts and currents are caused mainly by the prevailing winds of the earth. Since the trade winds blow from easterly to westerly directions, they cause the surface waters of the ocean to drift toward the west. In higher latitudes the stormy westerlies cause the surface waters to move toward the east. Of lesser importance in causing movement of ocean waters is the difference in density of water itself caused by differences in temperature and salinity, or saltiness. The path, of course, that an ocean current follows may be modified by one or more of the following: (1) the shape of the ocean basin, (2) submarine barriers, (3) the trend of the coastline, and (4) the rotating of the earth on its axis.

On either side of the equator are the *North* and *South Equatorial drifts* which move slowly toward the west owing to the friction of the trade winds with the ocean surface. This drift, with the accompanying steady trade winds, is utilized by sailing vessels when traveling from east to west. In the Atlantic Ocean the Equatorial Drift flows toward South America where it divides, part flowing south as the *Brazil Current,* and part moving north into the Caribbean Sea, then through the Yucatan Channel into the Gulf of Mexico.

The basin occupied by the Gulf of Mexico is continuously receiving enormous quantities of water from two sources: (1) the Equatorial Drift and (2) numerous rivers, of which the

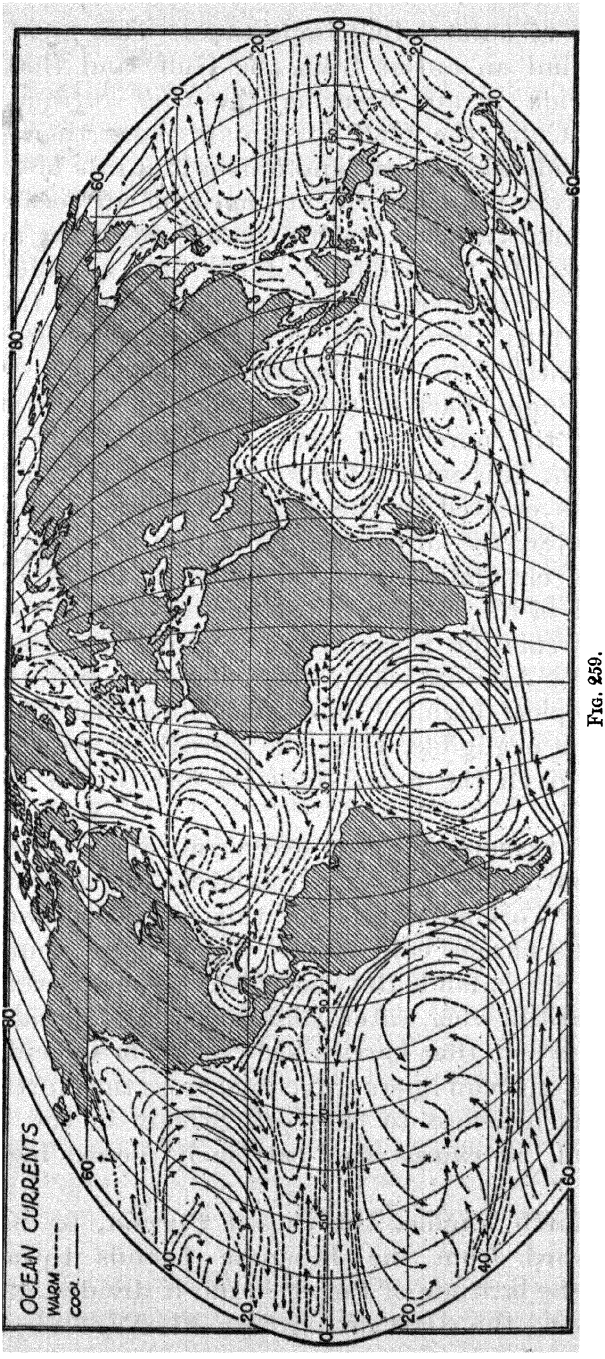


FIG. 259.

Mississippi is of outstanding importance. This great inflow of water must find an outlet from the Gulf, and that outlet is through Florida Strait, creating the *Gulf Stream.* Between Florida and Cuba the Gulf Stream is more than 100 miles wide, has considerable depth, and moves at a rate of 4 to 5 miles per hour. This is probably the strongest of all ocean currents. Leaving Florida Strait, the Gulf Stream joins other northward-moving waters. In the vicinity of the 40th parallel of north latitude these waters are driven eastward across the Atlantic by westerly winds, forming the *North Atlantic Drift.* This drift reaches the British Isles and the coast of Norway.

Opposite Spain, part of the eastward-moving waters turns south. Along the northwest coast of Africa it is called the *Canary Current.* This current finally rejoins the North Equatorial Drift. Thus is created in the North Atlantic a huge circular motion of water, the direction of rotation being clockwise. A corresponding circulation may be noted in the North Pacific, whereas south of the equator in the Pacific, Atlantic, and Indian oceans the circulation is counterclockwise. Near the center of the great North Atlantic whirl, which coincides with the location of the subtropical high, or horse latitudes, the movement of ocean water is negligible. Here the growth of seaweed, or sargassum, has given the name *Sargasso Sea* to this part of the ocean.

The Gulf Stream and its extension, the North Atlantic Drift, are continually carrying relatively warm water to the Arctic Ocean. To compensate for this receipt of warm water, the Arctic discharges cold water which flows southward on either side of Greenland. Between Canada and Greenland, this cold, southward-flowing water is known as the *Labrador Current.* This is the current that carries icebergs from Greenland south into the paths of ocean liners traveling across the North Atlantic. Because of its nearness to the Gulf Stream in the vicinity of Newfoundland, it causes the extremely dense fogs in that locality.

In the North Pacific, the *Japan Current,* or Kuro Siwo, moves eastward from the Japanese Islands toward North America. In the latitude of Puget Sound it divides, part flowing northward along the coast of southern Alaska, and part south-

ward off the coast of California, where it is known as the *California Current.*

In the Southern Hemisphere, the westerlies drive surface waters completely around the world in the vicinity of the 50th and 60th parallels. This is the *West Wind Drift* and is a cold current because of its high latitude and its contact with the glaciers of Antarctica. Two offshoots of this great current turn northward toward the equator, forming the *Peruvian,* or *Humboldt, Current* along the coast of Chile and Peru and the *Benguela Current* along the west coast of southern Africa. These are cold currents, since their waters are relatively colder than adjacent ocean water.

By observing the map of ocean currents (Fig. 259) it will be noticed that the surface waters are pulling away from the coast of California and the northwest coast of Africa. When surface water flows *away* from a shoreline, deeper and colder water moves upward to take its place. This is called the *upwelling* of subsurface waters. California coastal waters are several degrees colder than adjacent water a few miles offshore. Thus moist air moving from the ocean toward California must cross the belt of upwelling cold water alongshore and is chilled sufficiently to cause condensation of water vapor which produces dense fogs.

The discussion so far and observation of the map make it apparent that, in general, warm currents flow toward the poles, and cold currents toward the equator. If reference is now made to isothermal maps of the world for January and July (see pages 39 and 40), it will be noticed that certain ocean currents decidedly influence the course of isotherms in some localities. For example, isotherms, especially on the January map, are bent northward over the North Atlantic Ocean as a result of the relatively warm water carried northward by the Gulf Stream. In the Southern Hemisphere it will be noticed that isotherms bend equatorward over both the Peruvian and the Benguela currents.

The principal climatic effects of ocean currents are as follows:

1. Where warm currents lie offshore and winds blow from sea to land, temperatures on the land are considerably moder-

ated. Thus winter temperatures in northwestern Europe are much less severe than in corresponding latitudes in Labrador. A similar condition exists along the Pacific Coast from Oregon to Alaska. The warm currents also tend to increase atmospheric humidity which in turn causes an increased amount of cloudy and rainy weather, especially in the cooler seasons.

2. Where warm and cold currents come close together, the moist air from over the warm current may be chilled by colder air over the cold current, causing fogs. A good example, previously mentioned, is the region of dense fogs around Newfoundland.

3. Cold currents along shores in low latitudes (10° to 30°) have the peculiar effect of producing much foggy weather but little rain. Such is the case along the coast of Peru and northern Chile and the southwestern coast of Africa. The fogs are caused by the chilling of ocean breezes as they pass over the cold ocean current near shore. When the cool air comes onshore, it is heated by the much warmer land. As air is heated, its capacity for water vapor increases, a condition that is just the reverse of that necessary to produce rain.

Features of the Ocean Shore

Importance of Shore Features. The line at which the sea meets the land is a line of considerable importance. On its two sides are different scenes and different methods of communication. At that line the flow of trade from one country to another must be handled because of the change in transportation. Most countries export certain surplus commodities. These commodities are shipped from the *hinterland*, or land adjacent to a seaport, to the ocean shore by means of railroads, truck lines, or river barges. There they are placed on board ocean vessels. It is a well-known rule that at certain favored places where a break in transportation takes place, cities tend to develop.

Movements of the earth's crust over long periods of time have caused the ocean shore in many places slowly to fall or rise. During the time of such movement, a coastline moves *landward* as land is *submerged*. It creeps *seaward* as land *emerges*. Thus two principal classes of shorelines are recognized. They are

1. Shorelines of submergence
2. Shorelines of emergence

The major shapes of shore outlines are due to sinking or rising of the land, but more detailed features result from changes caused by any one or several of the following: (1) wave work, (2) shore currents, (3) wind action, (4) glaciation, and (5) stream deposition. Consequently a shoreline undergoes a slow

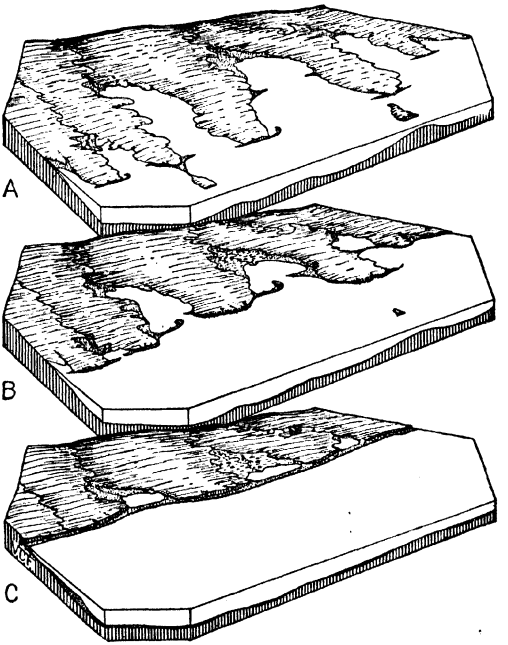


FIG. 260.—Stages in the development of a shoreline of submergence. *A*, Erosion of the headlands has begun, and beaches, spits, and hooks are forming; *B*, depositional features are extensive, shoreline is retreating; *C*, shoreline is worn well back, and all features are approaching old-age stage.

development during which projecting headlands may be worn back and bays slowly filled.

SHORELINES OF SUBMERGENCE

Major Features. The slow submergence, or sinking, of lowland coasts results first in the formation of shorelines of considerable *irregularity*, especially where the coastal plain has been eroded by streams (Fig. 260). Wide, shallow valleys are separated by broad, low areas between the streams. Valleys of that kind have such low gradients that even slight submerg-

ence permits the sea to enter them for some distance, forming bays. The higher areas between streams, at the same time, are only partly submerged and appear as irregular peninsulas or as islands. The sinking of a main valley with its tributaries produces a very irregular coast, as shown by Chesapeake Bay. In other cases only the lower portion of the main valley is

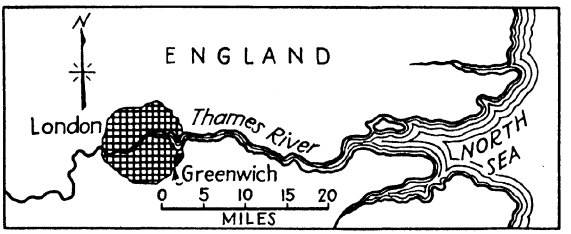


FIG. 261.—The estuary of the Thames River in southeastern England. Numerous dams and locks on the 200-mile river control the depth of water. Note the location of Greenwich through which passes the zero meridian of longitude.

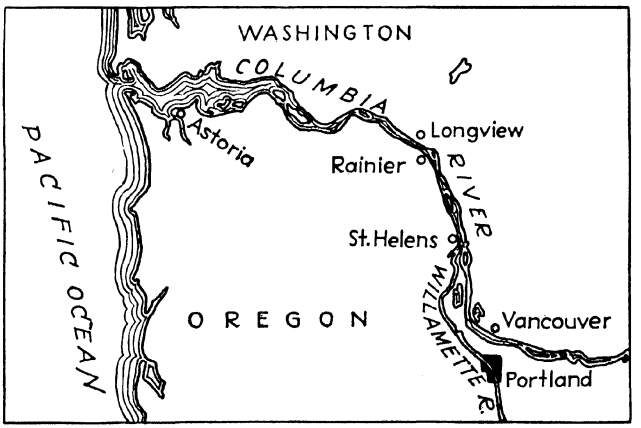


FIG. 262.—The estuary of the Columbia River provides deep water for ocean vessels that reach Portland. Considerable dredging of the channel, however, is necessary in places to maintain sufficient depth of water. (*Courtesy of Puget Sound Navigation Co.*)

submerged. The drowned mouth of a river is called an *estuary* (Fig. 261, 262). Many estuaries form excellent harbors and are the sites of important commercial cities.

Most of the eastern shore of the United States is one of submergence and contains a number of important estuaries. Chesapeake Bay (Fig. 263) is an example of the branching type of estuary. Some, like Delaware Bay, the Hudson River, the lower St. Lawrence, and others of smaller size, are simple in

outline. Estuaries abound also on the shorelines of western Europe. The coasts of the North Sea and the Baltic in general have shorelines of submergence, as their irregular outlines show. The estuaries of the rivers Mersey, Thames, Elbe, Seine, and Gironde are the sites of great commercial ports. Submergence provides the deep water necessary for ocean vessels. An important estuary of South America is that of the Plata River on which the city of Buenos Aires is located.



FIG. 263.

Other Shore Features. A shoreline is subject to attack and modification by the erosion of waves and currents. Such erosion produces certain characteristic shore features. Wave erosion is most effective near average sea level. A notch is cut in the rock at this point. This notch is enlarged by undercutting; and where the forces of erosion are strong, sea cliffs and bold headlands are

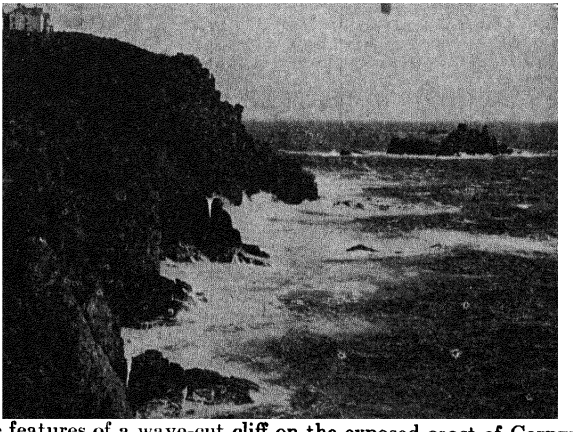


FIG. 264.—The features of a wave-cut cliff on the exposed coast of Cornwall, England. (*Photograph by Burton Holmes, from Ewing Galloway.*)

produced. The erosion of cliffs composed of a single kind of weak rock is likely to proceed with comparative evenness. In resistant rocks of unequal hardness, however, erosion is not uniform. The

less resistant rocks wear away more rapidly than the more resistant ones. As a result, peculiar and interesting shore features are formed. Among them are sea caves, detached chimney-like pinnacles of rock, and half-submerged projections upon the sea floor (Fig. 264). Obviously, such a coast is extremely dangerous during stormy weather, and lighthouses are often built to warn navigators to keep a safe distance from shore. In some places the erosion of a sea cliff results in a gently sloping shore called a *wave-cut* terrace. Offshore and below sea level, the rock waste accumulates to form a *wave-built* terrace (Fig. 265).

The sand, gravel, and other material eroded from rocky shores are moved about by waves and currents. Especially in the quiet waters of protected bays, this sediment accumulates

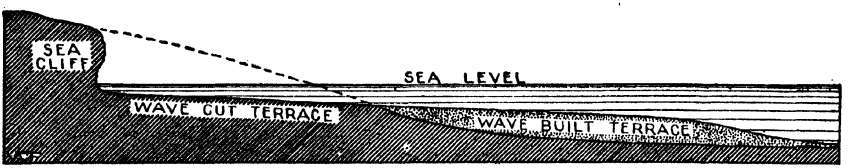


FIG. 265.—The association of features on an eroding shoreline is shown in this profile drawing.

to form beaches. Currents moving alongshore may carry the sediment across the entrance to a bay. Here it gradually accumulates as a ridge on the ocean floor. Eventually the ridge is built above the water to form a point of sand and gravel. Such are called *spits*. In the mouth of a broad bay, the inward movement of waves and currents past the projecting point of a spit may cause it to curve toward the shore. Then it is called a *recurved spit*, or *hook*. Examples of such features are shown by Sandy Hook, at the entrance to New York Bay, and the curved tip of Cape Cod (Fig. 279). The entrance to a narrow bay may be completely sealed by a sandbar deposited by waves and currents. In many harbors, dredging is necessary to maintain sufficient depth to accommodate ocean vessels.

As soon as beach sands begin to be thrown up by waves, they are readily dried and are then slowly moved by the wind. On some low, flat coasts the sand forms into low hills called *shore dunes*. Where the supply of sand is abundant and strong onshore winds exist, shore dunes may migrate inland for a mile or more

(Fig. 266). The southeast shore of Lake Michigan, from Gary, Ind., to Michigan City and northward, is noted for such sand hills. Considerable areas of dune sand are found on the low coastal margin of Cape Cod, parts of New Jersey, Virginia, and other sections of the east-facing coast of the United States. In general these are not so large in area and do not move so far inland as the dunes of the low, west-facing coasts of southwestern France, Belgium, Netherlands, and Denmark. In those countries attempts at checking the migration of the dunes have involved great expense.

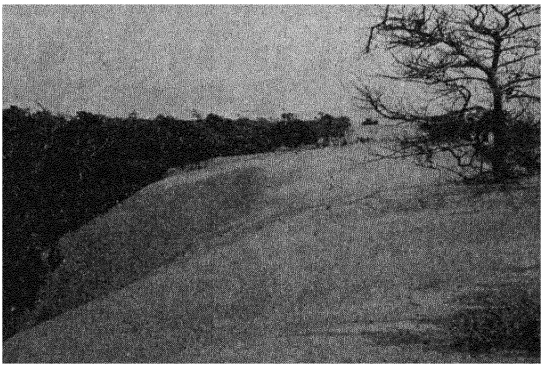


FIG. 266.—A shore dune in North Carolina encroaching upon woodland. Its steep leeward slope is clearly shown. (*Courtesy of U.S. Geological Survey.*)

Submerged Mountain or Hilly Coasts. Mountains and hills of stream erosion, when partially submerged, have shorelines of great irregularity. As on a submerging plain, the sea creeps into every coastal valley, forming a bay. Stream-eroded slopes or small delta plains furnish excellent locations for commercial seaports. However, the inferior productivity and difficulty of penetration of rough hinterlands do not favor seaport development. Examples of the irregular shores of submerged highlands are shown by the coast of northwestern Spain, the shores of the Aegean and Adriatic seas, the coast of Japan, the hilly coast of south China, and others.

Glaciated mountain coasts are characterized by long, steep, peninsular headlands which alternate with narrow, deep, and steep-walled bays, some of which are unusually long. The bays are of great variety in shape. Some are submerged, glaciated, U-shaped mountain valleys. To these long, narrow arms of the

sea, the Norwegian name *fiord* is applied. Fiorded coasts provide some of the finest scenery in the world. High and rocky walls, mist shrouded, rise on either hand, and occasional cascades plunge from the mouths of hanging valleys. Sharp bends and rocky islands obstruct the view, and a narrow horizon seems to shut out the world and to create complete isolation. Yet the quiet, gray waters of the fiord are easily accessible, since they are so deep that they may be navigated in safety, even by ocean-going ships (Fig. 267).



FIG. 267.—A view from the head of a fiord in Norway. The village occupies a small delta; but the rocky island, the steep walls, and the presence of a ship indicate deep water. (*Ewing Galloway.*)

The principal regions of fiorded mountain coasts are in the higher middle latitudes. Here, during the glacial period, many valley glaciers descended to sea level. The fiords are best developed in highlands that are characterized by the marine west-coast type of climate. In such localities abundant orographic snowfall fed the many individual glaciers that occupied, deepened, and reshaped numerous valleys. Coasts having deep fiords are (1) the west coast of Norway, (2) the west coast of North America from Puget Sound to Alaska, (3) the coast of southern Chile, and (4) the west coast of South Island, New Zealand

(Fig. 268). Others of lower altitude and less grandeur are parts of the coasts of Scotland, Iceland, Greenland, Labrador, and the arctic islands.

It is probable that many fiords are ice-scoured valleys that have been submerged by sinking of the shoreline since the time of their formation. In some, the great depth of water can hardly be explained otherwise. It is probable also that mountain-valley

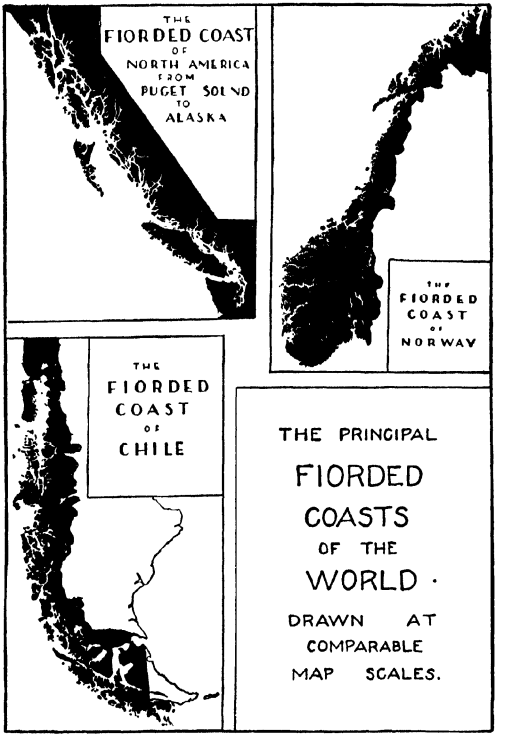


FIG. 268.

glaciers that reach the sea are able, by reason of the great depth or thickness of the ice tongues, to erode their valley floors well below sea level. After the disappearance of the ice, the valley floor is occupied by sea water, sometimes deeply and far inland.

The dimensions of some fiords are indeed interesting. Portland Canal, a fiord that forms part of the boundary between Alaska and British Columbia, is 90 miles long; from $\frac{1}{2}$ to 2 miles wide; and, in mid-channel, has water ranging from 90 to 1,250 feet in depth. The Sogne Fiord, the longest in Norway, has a

length of 112 miles and an average width of 4 miles, and its water reaches a maximum depth of 4,000 feet. As harbors, fiords seldom suffer from shallow water. Instead, the great depth of water may be a handicap in that it prevents the anchor chains of ships from reaching bottom.

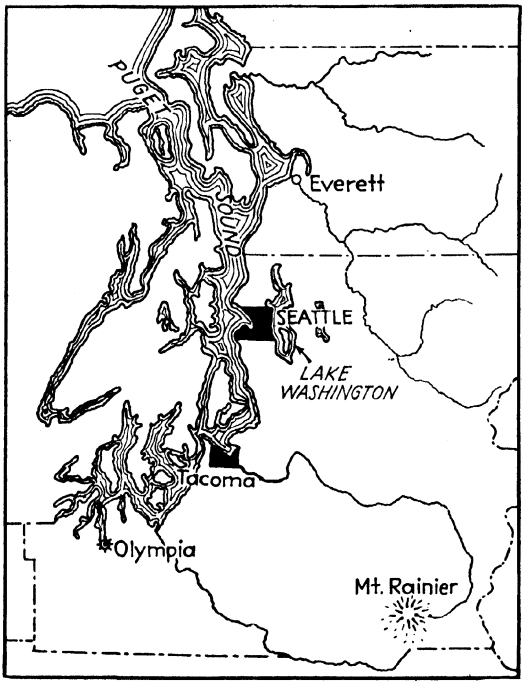


FIG. 269.—Puget Sound is a glaciated and partially submerged coastal area in Washington. Seattle and Tacoma are busy commercial cities. Farther north is Vancouver, B.C., one of the principal seaports of Canada. (*Courtesy of Puget Sound Navigation Co.*)

Puget Sound, located in western Washington, is a glaciated and submerged coastal region (Fig. 269). Glacial ice scoured deep valleys and left great deposits of morainic materials. The deep valleys, partially submerged, account for the fact that in some places the waters of Puget Sound are almost 1,000 feet deep.

SHORELINES OF EMERGENCE

Major Features. Bordering many coastal plains are submerged continental shelves which are essentially flat or slightly

inclined toward deeper water. When such a flat sea bottom slowly emerges, the shoreline creeps seaward ahead of a newly forming land. Such a shoreline is fairly straight. Seaward, shallow water covers the gently inclined ocean floor. Landward stretches a very flat coastal plain, possibly crossed by shallow valleys of streams from near-by highlands. This simple shoreline, however, is in time changed by the action of waves and currents.

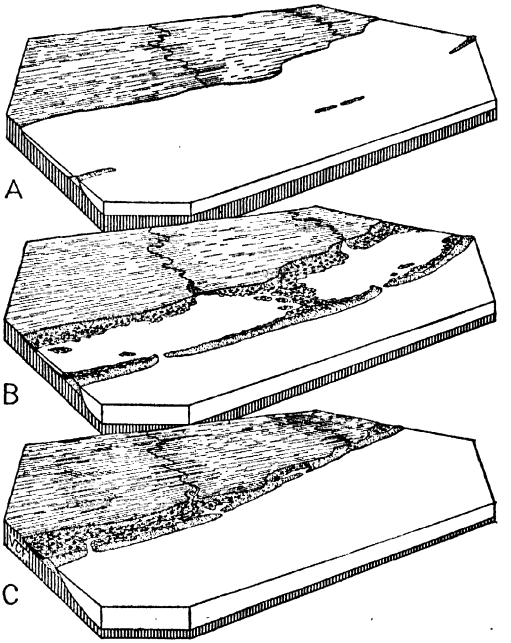


FIG. 270.—Stages in the development of a shoreline of emergence. *A*, the new shoreline is little eroded before a protecting bar begins to form; *B*, the growth of an offshore bar flanked by lagoons; *C*, owing to wave pounding the bar migrates shoreward and the lagoons narrow, fill, or disappear.

Offshore Bars and Related Features. In the shallow waters of a recently emerged coast, the waves that approach shore change form and eventually topple over or break. The line of breakers may be several hundreds or even thousands of feet from the shoreline. As the waves break, they wash forward loose bottom materials only to drop them just landward of the line of breakers, forming a submarine ridge nearly parallel to the coast. As this feature grows in height, it appears first above sea

level as a series of narrow islands. Further deposition by waves and the drift of alongshore currents fill gaps between some of the islands and connect them into long, low bars. Such are called *offshore bars* (Fig. 270). Between these and the mainland are long, shallow bodies of water called *lagoons*. Drainage from the mainland discharges into the lagoons. Narrow openings called *tidal inlets* develop in the offshore bars. Through these inlets the sea water flows landward with the coming of high tide and seaward as the tide ebbs. The rushing of tidewater through such small openings or through narrow straits between islands is termed the *tidal race*. Such a tidal race may scour a tidal inlet to such an extent that it is deep enough to accommodate ships of moderate size.

Such coasts are of little value for commercial shipping, mainly because of shallow water. During severe storms, ships that are too close to shore may be driven aground. The lagoons are so shallow as to accommodate only small craft. In time, the lagoons are filled by sediment carried by inflowing streams and tidal currents. As salt-water vegetation spreads in the lagoon, it may appear at low tide as an expanse of featureless marshland. Ultimately the depression may be filled, and the seaward side of the offshore bar may become the ocean shoreline. In time, the work of shore currents and waves may entirely remove the offshore bar and the sediments deposited in the lagoon. Thus it is seen that the ocean shore is a place of ceaseless but extremely slow change.

Examples of Low Coasts of Emergence. The South Atlantic and Gulf coasts of the United States, except for the Mississippi River delta, show generally the features of young coasts of emergence. Padre and Matagorda islands, on the coast of Texas, are offshore bars. Behind them are extensive lagoons. The city of Galveston, Tex., is built on a low island (Figs. 271, 272). Indian River, on the east coast of Florida, is a long, narrow lagoon. Beyond it lies an offshore bar which extends coastwise for more than 100 miles, interrupted only by narrow tidal inlets. This bar broadens northward to form the dune-covered projection of Cape Canaveral (Fig. 273). Similar features are found on many other lowland coasts. Atlantic City, N.J., is built on an offshore bar. The North Sea coast from the Netherlands to

Denmark is fringed by the long chain of the Frisian Islands which are separated from the mainland by shallow lagoons. The

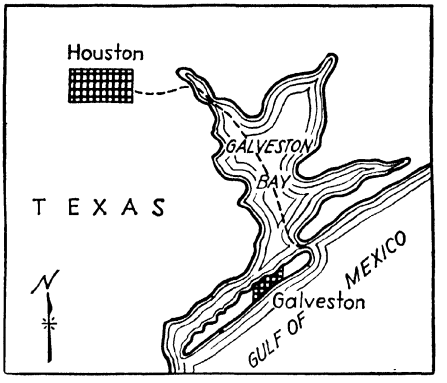


FIG. 271.—A break in the shoreline of Texas provides the sites of two important seaports, Galveston and Houston. The distance between the two cities is about 40 miles. The broken line is the route of the Houston Ship Canal. In the city of Houston is a turning basin for ships that use the canal.



FIG. 272.—The Galveston, Tex., sea wall, built to protect the city from damage by high waves.

large coastal lakes, or "Haffs," on the coast of eastern Germany are cut off from the Baltic by long, curving bars.

Although low coasts of emergence are not favorable for commercial shipping, they nevertheless have certain advantages. The construction of railroads and highways along such coasts is not a difficult matter. The sandy nature of the soil in many places makes vegetable gardening a profitable occupation. The shallow water and long, smooth, sandy shoreline encourage the building of seaside resorts.

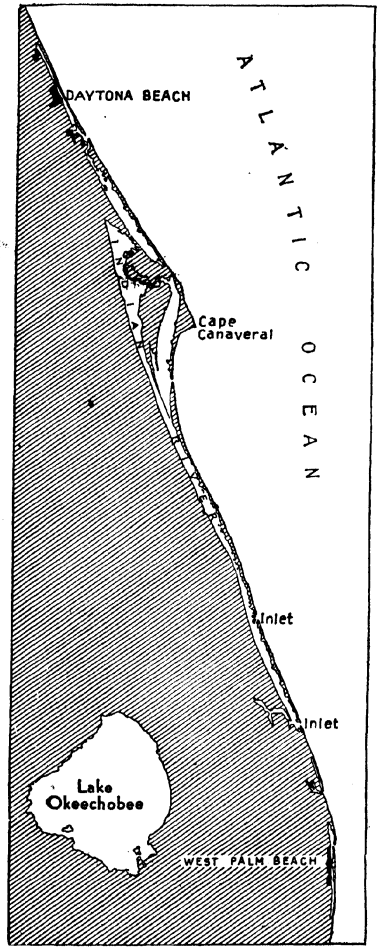


FIG. 273.—The offshore bars and lagoons of the eastern coast of Florida.

Emerged Mountain Coasts. Shorelines of emergence bordering mountain coasts, like those bordering plains, are simple and regular in outline. The 6,000 miles of shore bordering the growing mountains and coastal hills between Oregon and the 40th parallel in Chile is remarkable for its regularity. In that entire distance there are only a few coastal indentations sufficiently large or well protected to be good commercial harbors. One of these indentations, caused by sinking of the land, is San Francisco Bay, today an extremely important commercial region (Figs. 274, 275).

Along most of this coast the continental shelf is narrow or lacking, and depth of water is great. Huge waves break directly onshore in many places. Bold, rocky capes and wave-eroded cliffs feature such a coast. Onshore are to be observed marine terraces, now far above sea level, which give evidence of successive uplifts (Fig. 276). In one section of the California coast 10 or more such terraces exist, the highest ones being more than 1,500 feet above present sea level.

Miscellaneous Shorelines and Shore Features

Shorelines Exhibit Great Variety. Some shorelines exhibit features of submergence; others, of emergence. Some extensive shores have prominent features of both classes. Others show the effects of delta building, glacial erosion, glacial deposition, or coral growth. Let us consider only a few of the many combinations in which these things are associated in the formation of different shorelines.

The Carolina-New Jersey shoreline is one in which the features of both emergence and submergence are prominent. During the period of the emergence of this low coastal plain, offshore bars and extensive lagoons were developed. Subsequently, a considerable submergence has resulted in the drowning of the lower river valleys and the formation of branching estuaries such as Chesapeake Bay. The submergence, however, has not been sufficient to destroy the bars. On the North Carolina coast, the submergence, together with the preservation of the bars, has produced Pamlico, Albemarle, and Currituck sounds and has resulted in a shoreline of a high degree of irregularity. Under the influence of various currents, the offshore bars there have become angular in outline, but those of New Jersey have remained nearly straight (Fig. 270).

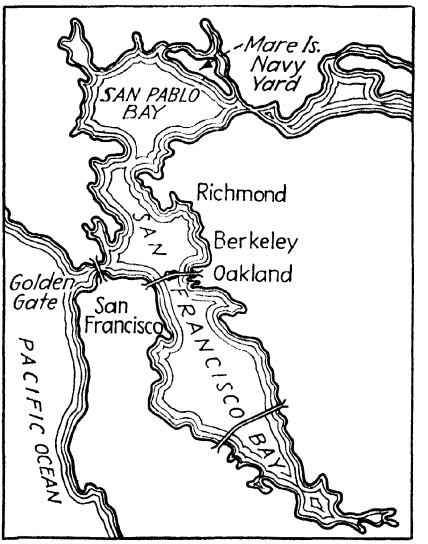


Fig. 274.—San Francisco Bay, created by sinking of the land, is one of the few breaks in the Pacific shore from Oregon to central Chile. San Francisco is an important seaport. The Golden Gate, a strait leading from the ocean to San Francisco Bay, is about 1 mile wide. Three great bridges are shown: the Golden Gate Bridge, the San Francisco-Oakland Bridge, and farther south the San Francisco Bay Bridge. About 1,500,000 people live in this area.

The New England shoreline is one of great irregularity. The coast of Maine is largely the result of (1) stream erosion, (2) glacial scour, and (3) submergence. The sea penetrates inland by

filling submerged valleys that were deepened by glacial erosion. Between the valleys, the uplands of hard crystalline rocks form peninsulas and islands. This is indeed a picturesque shore. A portion of it has been set aside as Acadia National Park (Fig. 277).

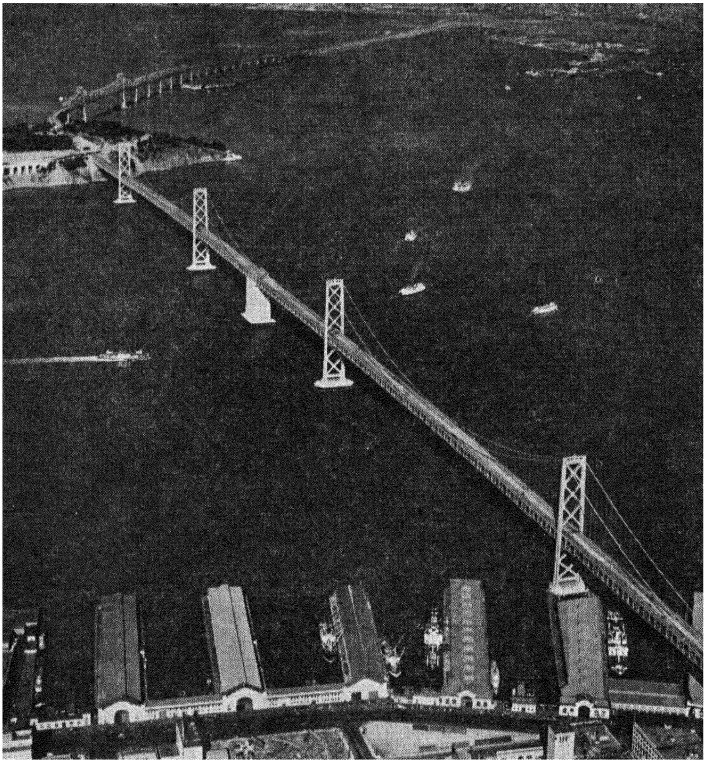


FIG. 275.—Aerial view of San Francisco Bay, looking east from San Francisco toward Oakland along the San Francisco-Oakland Bridge, which spans 4½ miles of water. The San Francisco docks are in the foreground. (*Courtesy of California Toll Bridge Authority.*)

The shoreline of most of New England and eastern Canada is very irregular. Many of the features of submergence have been somewhat modified by wave and current action. Some of the embayments, or indentations in the shore, are of great size. Such, for example, are Long Island Sound, the Bay of Fundy, and the lower St. Lawrence. Glacial scour played an important part in the formation of the Maine coast. Cape Cod and Long



FIG. 276.—Marine terraces on the coast of California, in Santa Cruz County. The steplike profiles of the terraces may be seen in the background, and the surface of one of the terraces in the foreground. (*Courtesy of U.S. Geological Survey.*)

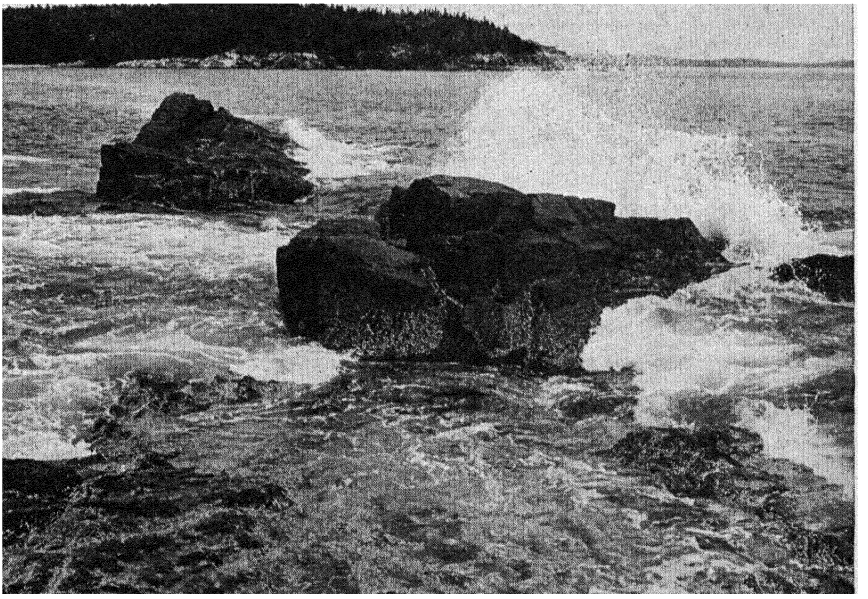


FIG. 277.—The picturesque coast of Maine, Acadia National Park. (*Courtesy of U.S. Department of the Interior.*)

Island, on the other hand, are largely the result of deposition of moraines and outwash plains. In Boston Bay are islands created by the partial submergence of a group of drumlins.

Coral-reef Shorelines. The shallow waters of many tropical coasts are characterized by reefs of limestone. A *reef* is a ridge of rock at or near the surface of the water. Limestone reefs are composed of the crumbled skeletal structures of tiny marine

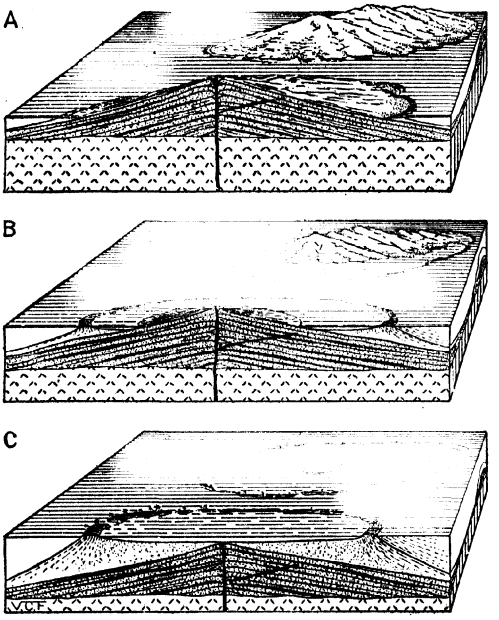


FIG. 278.—These diagrams illustrate the development of atolls. *A*, fringing coral reefs about islands; *B*, growing coral deposits keep pace with submerging islands; *C*, atolls fringed with growing corals replace the mountainous islands.

animals called *corals*. There are many kinds of coral. The tiny animals, or polyps, live on the outer surface of the coral mass. During its lifetime, each animal adds its limey skeleton to the bulk of the mass. In time, the accumulation may form an island or a reef. Warm ocean currents with temperatures above 70°F. carry abundant food to the polyps.

The Great Barrier Reef off the northeast coast of Australia is the longest coral reef in the world. It parallels the shore for 1,000 miles. Between the reef and the mainland is a broad lagoon. Ships under the guidance of special pilots are able to navigate

the lagoon and thus to be sheltered from the stormy seas beyond the reef. A barrier reef is somewhat similar to an offshore bar with the exception that its lagoon is usually deeper.

Many tropical islands are formed of corals. Some small islands, perhaps volcanic and with coral reefs built around their shores, seem to have undergone slow submergence. At the same time that the island was slowly sinking, fringe continued to grow. Circular coral reefs resulted. Such encircling reefs now appear at the surface as low, and more or less complete, coral rings, called *atolls*, which enclose circular lagoons (Fig. 278).

A *fringing* reef is built on or very near shore. Such a reef may grow so rapidly that the shoreline is pushed seaward in spite of wave and current erosion. Many islands off the southern Atlantic Coast of the United States have shorelines fringed with coral. Such are the Bermudas and the Bahamas. The *Florida Keys* are partly of coral origin. These islands are probably remnants of a once continuous limestone-coral peninsula. The city of Key West, situated at the end of the Keys, is the southernmost point of the United States. By bridging from one island to the next, a railroad and automobile highway have been built from the southern tip of Florida to Key West.

Harbors and Canals

Harbors. Most of the important harbors of the world, which are the sites of great seaports, were caused by sinking of the land. Some, however, were produced in other ways. Great commercial cities are located on the shores of many estuaries whose rivers sometimes offer the added advantage of water transportation inland for many miles. A good harbor must meet several requirements, some of which are as follows:

1. Depth sufficient to accommodate large vessels
2. Protection from storms at sea
3. Size large enough to allow ships to move about easily
4. Relative freedom from ice most of the year
5. A deep channel leading to the sea wherein tidal currents are not too strong
6. A moderate tidal range
7. A shoreline of sufficient length and character to permit the building of numerous docks

In addition to the foregoing requirements, a harbor in order to become the site of an important seaport must have the following:

1. A good location with respect to the flow of trade between nations

2. Excellent transportation facilities to the interior



FIG. 279.—Map showing upper and lower New York Bay. Sandy Hook extends northward into the lower bay. Lower Manhattan, shown here, is the heart of New York City. The Hudson River is so deep that ocean vessels reach Albany, N.Y.

3. An adjacent interior region, or hinterland, that is rich and productive and that not only furnishes many commodities for export but also requires numerous imports

New York harbor may be taken as an example of one of the world's great harbors (Fig. 279). It has several hundred miles of shoreline. The width of the Hudson River, about 1 mile, makes it possible to build docks on both the east, or Manhattan, and the west, or New Jersey, shores. The river is so deep that vessels of fair size may go upstream to Albany. The East River,

between Manhattan Island and Long Island, also is wide and deep enough to accommodate docks on opposite shores (Fig. 280). Upper Bay and Lower Bay are connected by The Narrows. The deep channel leading to the ocean is the drowned valley of the Hudson River and lies about midway between Sandy Hook and Coney Island. New York harbor is one of the few harbors of the world that is capable of accommodating the largest

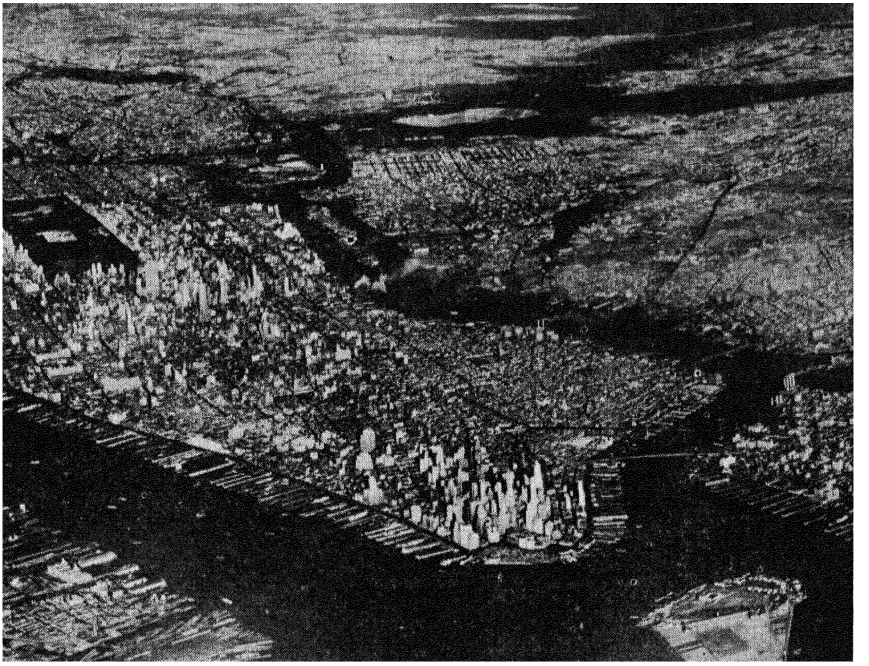


FIG. 280.—Aerial view of New York City, showing the Hudson River on the left and the East River on the right. Docks extend from both shores of the two rivers. (*Courtesy of Eastern Air Lines.*)

passenger vessels, such as the *Normandie* and the *Queen Mary*. The harbor has facilities for handling practically all kinds of ocean traffic. Leading from New York into a rich and productive interior are numerous railways, highways, and air lines and the water route via the Hudson River and Erie Canal to the Great Lakes. The city lies in the path of trade between the United States and Europe. All these factors combine to make New York City by far the leading seaport of the United States.

More good harbors are found on the Atlantic than on the Pacific Coast of the United States. Many eastern seaports, such

as Philadelphia, Baltimore, Charleston, Savannah, Jacksonville, and others, are situated on estuaries. On the West coast, the two largest harbors are provided by San Francisco Bay, on which San Francisco and Oakland are located; and Puget Sound, with its two important seaports Seattle and Tacoma. Less spacious are the harbors of Los Angeles and San Diego. Portland utilizes the estuary of the Columbia River. On the Gulf of Mexico are the important ports of Galveston, Houston, and Tampa. New Orleans, on the Mississippi River, is some 90 miles from the Gulf.

Canals. In a few places in the world, opposite shorelines are separated by relatively narrow strips of land, an example being the Isthmus of Panama. These strategic points have become the sites of important canals.

The Panama Canal (Fig. 281) was made possible (1) by building a dam across the Chagres River, creating a large lake about 85 feet above sea level, and (2) by constructing canals from the lake to the Caribbean Sea on one side and the Pacific Ocean on the other (Fig. 282). Between the lake and the sea, locks are required to raise and lower ships. The Panama Canal has so shortened the water route between the East and West coasts of the United States that a tremendous amount of freight between the two coasts is shipped by water. This has resulted in a decreased amount of freight carried by certain transcontinental railroads. The canal also shortens the ocean route from the west coast of South America to ports in eastern United States and western Europe. Ships moving from New Zealand and Australia to England are able to avoid the stormy waters around Cape Horn by using this canal.

The Suez Canal connects the Mediterranean Sea and the Gulf of Suez, which is an arm of the Red Sea. Unlike the Panama Canal, the Suez is a sea-level canal, having no locks. Just as the Panama Canal was built to make unnecessary the long trip around Cape Horn, so the Suez provides a route that makes it possible to avoid the journey around the Cape of Good Hope, southern Africa. The two most heavily traveled ocean routes in the world are (1) from western Europe to eastern United States and (2) from western Europe to southeastern Asia and adjacent islands. It is the second of these two routes that makes use of the Suez Canal.

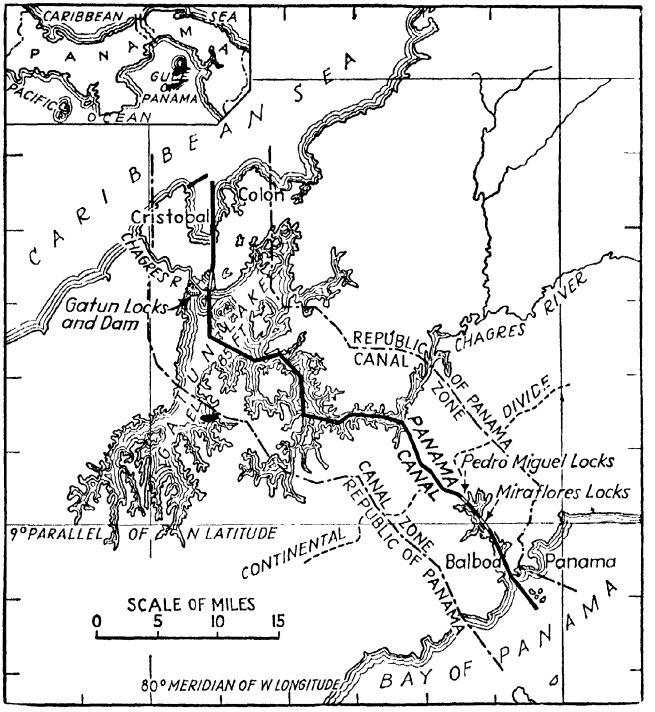


FIG. 281.—Map of the Panama Canal region. (*Courtesy of W. O. Blanchard.*)

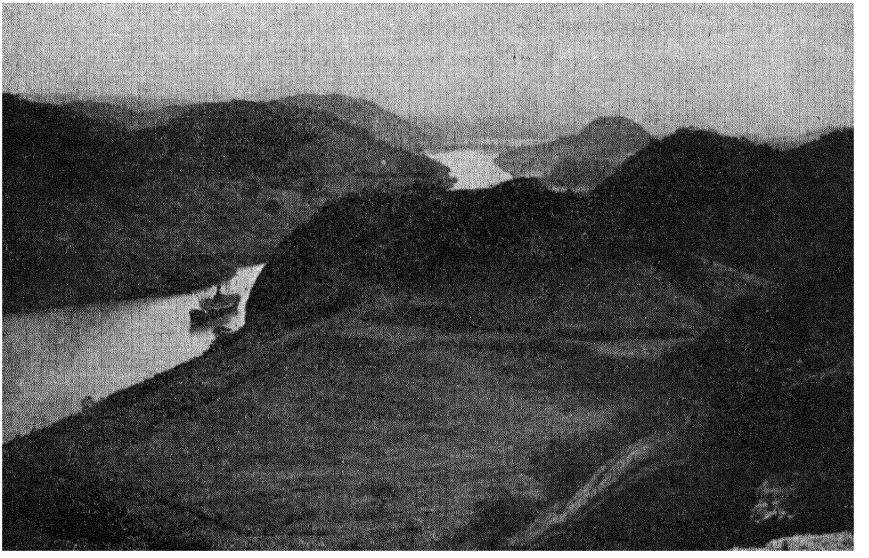


FIG. 282.—Panoramic view of the Panama Canal. (*Courtesy of The Panama Canal, Washington Office.*)

Summary

Ocean water contains about 3.5 per cent mineral matter, mostly salt. At a depth of 1 mile the pressure of ocean water is about 1 ton per square inch. Tides in the ocean are due mainly to the attraction of the moon. Tidal waves are caused by earthquakes on the ocean floor. In general, warm ocean currents move poleward; cold currents, equatorward. These currents are due mainly to friction of prevailing winds on the surface water.

Some ocean shores are the result of submergence of the coast; others, of emergence. Submerged shores are likely to be irregular. Estuaries are the drowned mouths of rivers and often make good harbors. An emerged continental shelf usually produces a rather straight shoreline with relatively shallow water offshore. Coral produces limestone islands and reefs in tropical waters.

More good harbors are found on the Atlantic Coast of the United States than on the Pacific. The Suez Canal shortens the sailing route between Europe and eastern Asia; the Panama Canal, that between the East and West coasts of the United States.

Man has learned to make use of many things found on or in the earth's crust. Such are water, vegetation, soils, fuels, and minerals. They are part of our environment and will be discussed in the following chapters.

Questions

1. Mention several ways in which oceans are of considerable importance to man.
2. What mineral matter is in solution in ocean water? Of what importance is it?
3. What is the source of oxygen required by marine animals?
4. Discuss the pressure and density of ocean water.
5. What methods are used to find the depth of the ocean? Where is the deepest known point of all oceans? What is the depth?
6. The time interval indicated by a fathometer test is 10 seconds. What is the depth of the ocean?
7. Explain the cause of waves. Breakers. Undertow. Tidal waves.
8. What is the principal cause of tides?
9. Define tidal range. How does it differ at the time of spring and neap tides?

10. Under ideal conditions, what is the time interval between high and low tides? Between successive high tides?

11. What is the tidal range in the Gulf of Mexico? In the Bay of Fundy? At Liverpool? Where is the Bay of Fundy?

12. Explain what is meant by the tidal bore. Name and locate several rivers where the bore is noticeable.

13. What is the principal cause of ocean currents?

14. Account for the strength of the Gulf Stream in Florida Strait.

15. In what direction do ocean waters circulate in the Northern Hemisphere? In the Southern Hemisphere?

16. Name and locate three warm and three cold currents.

17. Mention several climatic effects of ocean currents.

18. Why do cities tend to develop where there is a break in transportation?

19. What causes the major shapes of shore outlines? The more detailed features?

20. Explain how an estuary is formed. Name and locate ten. Name one city on each.

21. What states border Chesapeake Bay? On what estuary is Washington, D.C.?

22. Are eroded shore features more likely to develop on a coast of uniform rocks or on one composed of rocks of unequal resistance? Why?

23. What damage may be done by shore dunes?

24. Explain the formation of wave-built terraces. Sandy Hook.

25. Describe a submerged, glaciated, mountainous coast.

26. Name and locate several coasts having deep fiords.

27. What are the dimensions of the Sogne Fiord? Where is it?

28. Describe briefly the Puget Sound region.

29. Describe a coastline that may result from the emerging of a continental shelf.

30. Explain the formation of an offshore bar. The causes of a tidal race.

31. Does the uplifted continental shelf produce a coastline useful to commercial shipping? Locate several such coastlines.

32. What is the general character of the Pacific shoreline from Oregon to central Chile?

33. Describe briefly the San Francisco Bay region.

34. What major influences have shaped the coastline from South Carolina to New York harbor?

35. Describe briefly the New England shoreline.

36. What is coral? Coral deposits result in the formation principally of what rock?

37. Locate the Great Barrier Reef. What is an advantage of the lagoon formed by this reef?

38. Explain the formation of an atoll. A fringing reef.

39. Mention several requirements of a good harbor.

40. Why are some fairly good harbors not the sites of important cities?

41. Mention several advantages of New York harbor.

42. Locate the principal seaports of the United States.

43. Contrast the Panama and Suez canals from the standpoint of problems of construction caused by land relief.

44. Why is control of the Panama Canal advantageous to the United States?

45. How have the Panama and Suez canals influenced certain major routes of ocean vessels?

Suggested Activities

1. Write to the U.S. Hydrographic Office, Washington, D.C., for a list of publications. Excellent maps of important harbors may be purchased at a reasonable cost.

2. Your class or school may wish to secure back copies of pilot charts of the various oceans by making the request through a congressman. These charts are issued every month by the U.S. Hydrographic Office. They are excellent for the study of oceans.

3. If you live near the ocean or a large lake, make field trips to study shoreline features and the work of waves and currents.

4. On a large map of New York harbor that shows the depth of water, sketch in a few contour lines to show the submerged valley of the Hudson River.

5. Make a list of the requirements of a good harbor.

6. Draw a large map of the coastline from Maine to Miami, Fla. Indicate the Cape Cod Canal. Label the various shore features mentioned in this chapter that are illustrated by this coastline.

7. Secure a large map of Long Island. The southern part of the island consists of an outwash plain. Note its shoreline. Contrast with that of Maine.

8. Mold a relief model showing a shoreline with a narrow coastal plain, continental shelf, and one or two valleys leading into the sea. Fix the model in such a way that water can be poured on it. Increasing the depth of water will illustrate submergence; decreasing it will illustrate emergence.

9. Mold a relief model of a glaciated, mountainous coast. Waterproof the surface. Arrange the model so that by using water the ocean

shore can be shown. The water will extend inland in the deep glaciated valleys, illustrating the formation of fiords.

10. Secure a set of slides or a motion picture dealing with the Panama Canal. An interesting class report can be made on the history of this canal.

11. If possible, purchase from the U.S. Geological Survey the four topographic maps that when properly glued together will show New York City and vicinity. Do the same for other important seaports.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Harnessing the Tide
2. New York Harbor
3. The Chesapeake Bay Region
4. Delaware Bay and the Port of Philadelphia
5. The Coast of Florida
6. The Coast of Texas
7. Important Estuaries of Europe
8. The Pacific Coast of the United States
9. Acadia National Park
10. The Great Barrier Reef of Australia
11. The Panama Canal

REFERENCES

BRANSON, E. B., and W. A. TARR: *Introduction to Geology*, Chap. 8, McGraw-Hill Book Company, Inc., New York, 1935.

JOHNSON, D. W.: *Shore Processes and Shore-line Development*, John Wiley & Sons, Inc., New York, 1919.

MARMER, H. A.: *The Sea*, D. Appleton-Century Company, Inc., New York, 1930.

Chapter XV. Water Resources of the Land

The good earth provides many natural resources that contribute greatly to man's enjoyment of life. The early pioneers of America cut the forests, plowed the virgin soil, and pushed onward to newer frontiers. The desire to seize new lands and new resources resulted in much careless treatment of soil and forest. Witness, for example, the numerous badly eroded farm lands in certain parts of the United States and the many square miles of cut-over forests.

Our problem today is one of conservation. The days of "new frontiers" are gone forever. One step toward conservation is a certain amount of government regulation, wisely administered. Another step is education. People must be taught to appreciate the value of wise use of our natural resources.

We should all desire to improve the living conditions of future generations. Can such be the case if we are careless, reckless, and wasteful with the earth's resources? A glaring and disheartening example of waste is shown by the enormous loss of natural gas. This gas has been pronounced by some engineers as the most perfect fuel known to man. And yet in the effort to secure petroleum, which occurs with natural gas, millions of cubic feet of the gas has been allowed to escape into the atmosphere. This is only one of several examples that could be cited.

The next few chapters in this book deal with the natural resources of the earth. As we study the occurrence and uses of these resources, we should keep in mind the needs of future generations. First, let us consider the resources of the earth as a whole. Then we shall give our attention to individual resources, *viz.*, (1) the water supply of the land; (2) vegetation and animal life; (3) soils; and (4) coal, petroleum, and other minerals.

Earth Resources as a Whole. Many materials of the earth's composition or of its natural vegetable or animal life are used by man. Because they are obtained from the natural earth or exist in or upon it, they are called *natural*, or *earth*, *resources*. The number of such resources used by primitive man was not large. The advance of material civilization, however, has greatly increased the list. Because of their vital importance in modern affairs, an understanding of the occurrence and distribution of these resources is fundamental when considering the human activities and problems of countries and regions.

The natural resources available for the use of man are of two principal classes:

1. *Inorganic*, such as water, mineral fuels, metallic ores, building stones, and the valuable chemical raw materials of earth or air
2. *Organic*, such as wood, natural pasture, wild game, and fish

The soil, a resource of tremendous importance, is made up of both inorganic and organic materials. With the inorganic rock fragments, which are the basis of soils, are mingled variable quantities of plant and animal remains and a world of microscopic organisms.

Some organic forms in the natural environment of man can hardly be called resources. Worthless or poisonous plants and certain forms of insect or of microscopic life are found in many regions. They constitute hazards of life and often hinder man in his efforts to make a living.

Earth resources may be classified further according to their permanency, or lasting qualities, as follows:

1. *Inexhaustible* resources, such as air, sand, and common clay
2. *Renewable* resources, such as wood, water, and natural pasture
3. *Nonrenewable* resources, such as coal, iron, petroleum, and chemical salts

People today are dependent upon a variety of important earth resources. There is nothing to indicate that future generations will *not* need most of these resources. Consequently, it is clear that present generations are charged with a responsibility

toward the future. Particularly is this true with respect to the nonrenewable resources that now are being produced or wasted in large quantities. It is, in fact, the responsibility of the present generation to secure to society, both now and in the future, the maximum benefit from the use of those materials provided by nature. The discharge of that responsibility calls for much knowledge and planning. Efforts to gather information and solve problems concerning this complicated matter may be considered a part of the field of the conservation of natural resources.

Water Resources

The Uses of Water. Water, like air, is a natural resource demanded in great quantity by both plant and animal life. The waters of the land are derived, either directly or indirectly, from atmospheric precipitation. For that reason, regions of abundant precipitation usually, but not always, have abundant supplies of water, and their inhabitants are able to use it lavishly. In arid regions, water is the element of first importance in restricting the settlement and use of land, and the supply of it is used with utmost economy.

Water supplies and water bodies are useful to man in many different ways, some of the more important of which are

1. For numerous uses around the home
2. For industrial purposes
3. For the irrigation of crops
4. For the production of mechanical power
5. As routes of inland transportation
6. As added attractiveness to scenic or recreational areas

The amount of water used for drinking and household supply varies greatly. Among desert peoples it is small. On the other hand, in modern cities the daily per capita allowance may be 15 or 20 gallons.

Industrial establishments vastly increase the quantity of water needed. Great manufacturing cities must supply several times as much water per capita of their population as actually is used in the homes. The average total consumption of water for all kinds of uses, in 90 cities of more than 100,000 population in the United States, amounts to about 125 gallons per day per

inhabitant. The municipal system of Chicago supplies each day to its homes and factories a quantity of water amounting to about 270 gallons for each of its residents.[1] This city has the highest rate of consumption of any in the United States, and doubtless much of it is wasted because of the abundant supply close at hand in Lake Michigan.

Sources of Water Supply. The large quantities of water required by modern urban and industrial centers are obtained from (1) wells, (2) springs, (3) large lakes, (4) large rivers, and (5) reservoirs formed by dams built across small streams. Only about one out of four of the principal American cities obtains its water supply from wells. The remainder, and especially the largest cities, use surface waters. However, about two-thirds of the total population of the country live in small cities, in villages, and on farms. In these localities, ground water, obtained from wells and springs, is the principal source of supply. For the irrigation of crops, surface waters supply about three-fourths and ground water one-fourth of the total quantity of water used.

Ground-water Supply

What Is Meant by the "Water Table." Rain water runs off the land surface in streams, seeps into the ground, or evaporates. That which seeps into the ground is the source of underground water. It percolates slowly downward and eventually fills all pore space in a portion of the ground. The top surface of the layer that is saturated with water is called the *water table* (Fig. 142). The water stored below the water table is the source of supply for springs and wells. In regions of abundant and well-distributed precipitation, the pore space in the earth is likely to be well filled. In arid regions, however, the rapid evaporation of moisture and the light or infrequent rains do not permit of a deep penetration of water. Subsurface waters in arid regions are, therefore, mainly those which have moved slowly, deep underground, from more humid regions.

The supply of ground water in any given locality depends upon (1) the nature of rainfall, (2) the kind of earth materials that underlie the region, and (3) the amount of pore space or

[1] *Report on National Planning and Public Works in Relation to Natural Resources*, p. 332, National Resources Board, Government Printing Office, Washington, D.C., 1934.

other openings in the earth's crust. More abundant pore space is provided by beds of gravel or sand, porous sandstones, and some limestones in which there are many cavities. Such may be called *cavernous* limestones. Compact clays and shale, little broken igneous rocks, and some other formations provide but little storage capacity for water. Neither are they favorable for the flow of underground water. Sandstone is notable among the rocks for its ability to carry ground water (Fig. 135). Its pore space commonly exceeds 25 per cent and sometimes reaches 40 per cent of the volume of the rock. In massive limestones there often is 10 per cent of pore space, and in cavernous limestones there is much more. In solid granite it is seldom more than 1 per cent. Numerous cracks, however, in igneous and metamorphic rocks greatly increase their water-holding and water-yielding capacities.

Qualities of Ground Water. No ground water is free from dissolved minerals. However, the nature and quantity of the chemical matter carried in solution differ widely from region to region. A few dissolved minerals, such as sulphur and iron, impart to water a disagreeable taste or render it unfit for certain industrial processes. Some mineral waters have tonic, laxative, or other desirable medicinal qualities. Among the most abundant of the soluble substances found in ground water are compounds of calcium or lime, sodium, and magnesium. In desert regions, seepage waters commonly are charged with compounds of these and other substances to a degree that renders them almost, if not quite, unfit for human use. In the United States these are known as *alkali waters.*

In humid regions, limestone and certain other rocks furnish to ground water supplies of calcium and magnesium which cause hard water. This quality does not much change the taste of water but does affect its domestic and industrial utility. Hard waters require softening when they are used with soap. In some localities, city water obtained from deep wells is so hard that most of the residences are provided with cisterns in which rain water is collected. The rain water is soft water and can be used for washing and other purposes for which the city water is ill suited. Hard water presents many problems in various kinds of industries. When used, for example, in steam boilers, it causes

chemical reactions and deposits of chemical substances that are harmful. Railroads often have water tanks located near streams where a supply of soft water is available. Some cities have spent large sums of money for equipment necessary to soften water before it is pumped through the supply lines.

Springs. A spring is a concentrated natural outflow of water from underground. It may flow either continuously or only occasionally. Its water may be either cold or warm, hard or soft. Sometimes a spring occurs on the side of a valley that has been

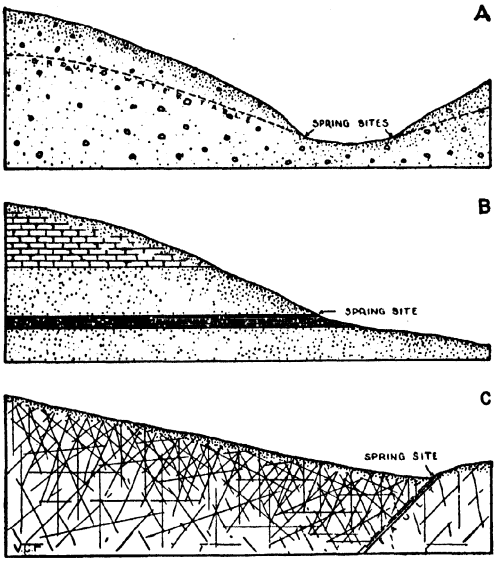


FIG. 283.—Some of the many possible conditions of surface, material, and structure that are related to the occurrence of springs.

eroded below the level of the local water table (Fig. 283*A*). Springs of that type are common in glacial drift and often are the main sources of supply of small streams at the headwaters of rivers. After a period of prolonged drought, the level of the ground water that supplies such a spring may be lowered. Then it will cease to flow until the water level is raised by the downward seepage of additional rains.

The site of a spring may be caused by the movement of water downward through a porous rock and then horizontally along the top of an impervious rock layer (Fig. 283*B*). Sands, sandstones, or porous limestones, underlain by compact clays

or shales, supply conditions of that kind and often produce many springs, all at about the same level.

In some cases water from a wide area of rocks may be concentrated upon a spring by means of many cracks in the rocks (Fig. 283*C*). In some regions water thus collected is conveyed deep underground where it comes under the influence of hot igneous rocks. Then it may come to the earth's surface as a hot spring. In Yellowstone National Park, the erupting hot

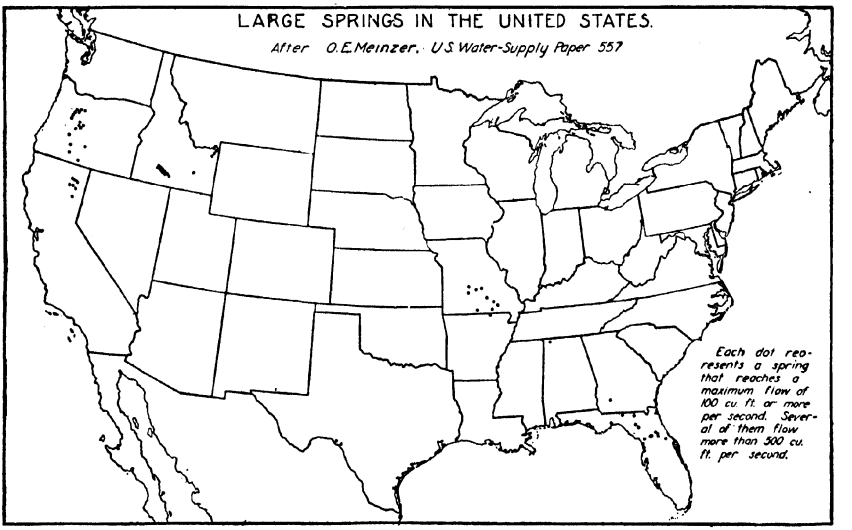


FIG. 284.—Most of the large springs of the United States occur in a few regional groups. Those in Florida, Missouri, and Texas are mainly associated with areas of cavernous limestones; those of Idaho, Oregon, and California occur more largely in porous lava formations.

springs, or geysers, are resources of considerable value because of the tourist business that they bring.

Under certain conditions of underground drainage, springs attain the proportions of considerable rivers. That is notably true in regions of cavernous limestones or of porous lavas. In such rocks, ground water descends from the surface through numerous openings and ultimately collects in an underground channel in some volume. There are in the United States about 60 springs with sufficient flow so that each would supply all the water required by a city of $\frac{1}{2}$ million people. Most of these large springs are concentrated in the limestone regions of northern Florida; in the Ozark region of southern Missouri;

and in the porous lava regions of southern Idaho, western Oregon, and northern California (Figs. 284, 285).

In the United States are thousands of farmhouses and not a few villages located upon sites originally chosen because spring water was found there by a pioneer settler. Some of these springs are still in existence; others have disappeared largely because of the lowering of the water table. Some spring waters, because of purity or reputed medical properties, are bottled and sold

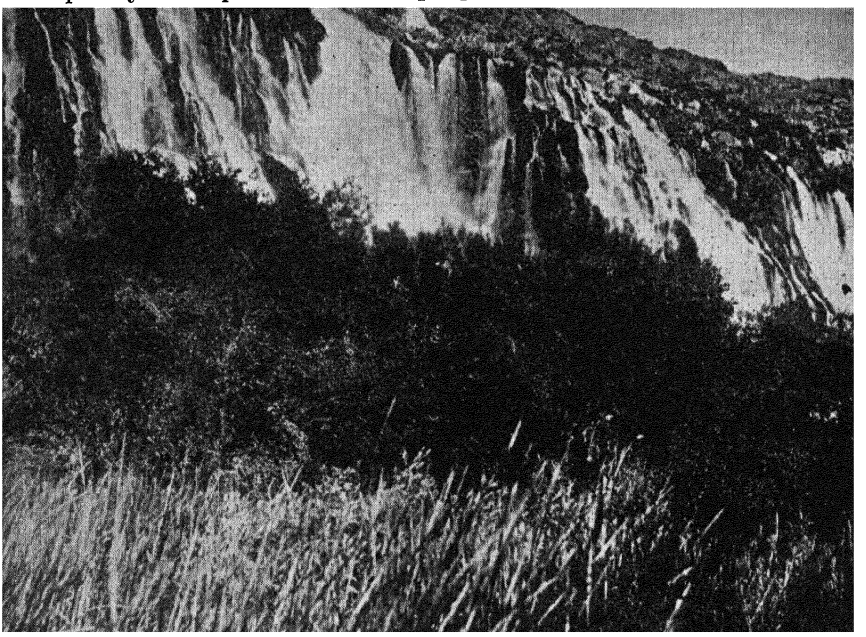


FIG. 285.—Some of the "Thousand Springs" that issue from beds of broken or porous lava in the Snake River Canyon, southern Idaho. (*Courtesy of U.S. Geological Survey.*)

commercially. Health resorts have been established in regions where certain types of springs exist. Such are Hot Springs, Ark.; Hot Springs, S.D.; Excelsior Springs, Mo.; and Saratoga Springs, N.Y. There are many such spots in Europe.

Wells. A well should be dug below the water table so that ground water may be collected in sufficient quantity to be lifted, usually by pumps, to the earth's surface. Many dug wells have only temporary supplies of water, but others are permanent. Figure 286 shows the relation of three wells to a fluctuating or changing water table. Well No. 1 is a modern

drilled well that reaches below the lowest possible position of the water table and has never run dry. Well No. 2 is a dug well that reaches below the ordinary water table and has water at all times except after periods of prolonged drought. Well No. 3 is dry except for a short time after a long period of rains which considerably raise the water table.

A modern deep well, like No. 1, is made by drilling a small hole scores or hundreds of feet into the deeper waters of some known water-bearing formation, such as a porous sandstone. Steel pipe usually is placed in the hole to prevent surface waters from seeping into the deep well and contaminating the deep-water supply. A smaller pipe, through which the water is pumped to the surface, extends below the ordinary level of water in the well.

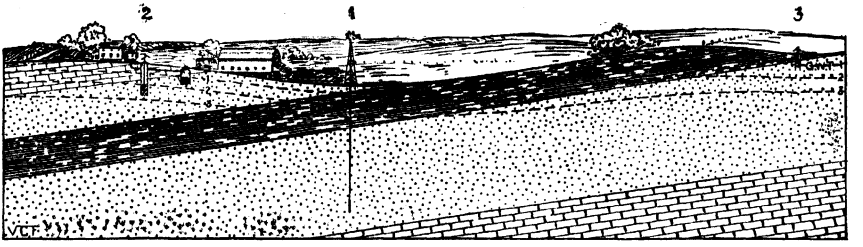


FIG. 286.—Well No. 2 is higher than No. 1 and appears to be a safer water supply, but in fact it is not so because of the rock structures concerned. The stippled horizons indicate porous, water-bearing formations. The dashed lines show positions of the ground-water table: 1, in wet seasons; 2, ordinary level; 3, in dry seasons.

Note the arrangement of wells in Fig. 286. Well No. 2 is situated higher up the slope than No. 1 and appears to be in a safe position with respect to pollution. Such, however, is not the case. The porous rock formation below the surface carries seepage from barns and cesspool directly toward the house well rather than away from it, as the surface slope would indicate. Many wells are located badly because of ignorance of the nature of ground-water movement and of the structure or porosity of the rocks that govern ground-water movement in the locality in which they are constructed. Certain diseases are spread rapidly by polluted water. To prevent epidemics due to such a cause, it often is advisable to have water tested for the quantity and nature of bacteria present.

Artesian Wells. Deep wells that have an abundant supply of water are called *artesian* wells. Some artesian wells overflow on the earth's surface. Many, however, that are drilled and furnish a water supply for towns or cities require pumping. Figure 287 illustrates a situation favorable to the occurrence of artesian wells. Such a situation includes the following conditions: (1) A water-bearing formation of sandstone or some other porous material must be present; (2) the porous formation must outcrop or be exposed at the surface in a region of sufficient precipitation to fill it with water; (3) the formation must dip slightly downward beneath a capping layer of some impervious rock, such as shale; (4) it must lead toward a region where the

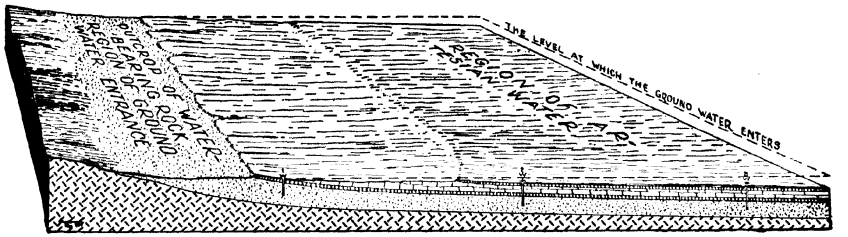


FIG. 287.—One type of artesian structure is shown in this diagram. Well No. 1 (left) reaches the water-bearing formation, but its top is as high as the level of ground-water entrance, and it would require pumping. The others should provide flowing water.

land surface is lower than the exposed end of the porous formation; and (5) there must be no free exit from the porous rock at an elevation lower than the region of the wells. A well drilled through the impervious layer and into the water-bearing formation taps a supply that is under pressure owing to the weight of the water that is backed up in the higher end of the porous formation.

A large region of artesian wells is located in the northern Great Plains of the United States. There a series of water-bearing formations, especially the Dakota sandstone (Fig. 135), outcrop at considerable elevation near the Rocky Mountains and Black Hills. These formations dip eastward under suitable capping layers toward the lower plains. They yield artesian waters far out in the eastern part of the Dakotas. In general this water is pure but extremely hard. The town of Artesian, S.D., was so named because of a number of flowing wells, many of which have now ceased to flow. The degree to which a water-bearing

formation may be tapped depends much upon the quantity of water supplied by rain, especially where the porous rock outcrops. So many wells have been drilled into the Dakota sandstone that towns and cities thus supplied are giving much attention to economy in water usage. Other artesian regions that deserve mention are (1) the Paris Basin in France, (2) the vast area lying west of the east Australian highlands, (3) central Argentina, and (4) the Atlantic Coastal Plain of the United States. There are many limited artesian structures and spring sites in American dry lands, and in those of other countries as well, that furnish water for the irrigation of a few acres of crops in addition to that required for other uses.

Conservation of Ground-water Supply. Several factors make for the lowering of the water table. Some of these are

1. Excessive pumping of ground water for city use or for irrigation
2. The draining of lakes and swamps to provide more land for cultivation
3. Removal of forests
4. Droughts

Man has no control over the fourth item listed here. The first three, however, deserve serious consideration. In areas where much ground water is pumped, the depth of the water table should be watched closely. If the demands on the supply are excessive, the water table is likely to become steadily lower. Then communities and individuals must cooperate in (1) reducing the amount of water used or (2) securing new supplies.

Lakes act as basins in which to catch rain water and surface drainage. Water from these basins seeps downward and replenishes the supply of ground water. There are localities where men have drained numerous lakes and near-by swamps, and it is believed by some that such drainage may have caused a lowering of the water table. In contrast to this policy of surface drainage, the people in some communities, especially in semiarid lands, have been encouraged to build numerous earthen dams across small streams. These dams create hundreds of small ponds. Such ponds serve as (1) storage basins for surface drainage, (2) a source of supply for ground water, and (3) watering places for livestock.

Forests check the force of a heavy rain and retard the rapid runoff of water. More rain water will seep into the ground in a forested area than in one where trees are absent.

Conservation of ground water also demands a careful watch over the causes of pollution. Care must be exercised in the disposal of sewage, the waste products of factories, and farm manures.

Surface-water Supply

The surface waters of the earth in streams and lakes constitute a natural resource of great importance. This is because of their relation to the following:

1. Municipal water supply
2. Irrigation
3. Hydroelectric projects
4. Inland navigation
5. Flood control
6. Soil erosion
7. Recreation

People who live in humid lands give little thought to the supply of water. They turn on the faucet, let the water run, and carelessly waste several gallons per day. Multiply this waste by millions of users, and the total is staggering. In arid and semi-arid lands, water is so valuable that efforts are made to reduce waste to a minimum. In many localities, both arid and humid, the surface waters are used for several of the purposes listed above. Hence strict laws are necessary to govern the amount of water that may be used for each purpose or the amount that may be used by different communities located on the same stream or lake.

Surface Waters for Municipal Supply. Of the 300 principal cities of the United States, three-fourths are supplied with surface waters obtained from large lakes, rivers, or, more commonly, relatively small streams.[1] Generally, surface waters are not so hard as ground waters of the same region, because they are derived in part from the immediate runoff of rain water.

[1] *Report on National Planning and Public Works in Relation to Natural Resources*, p. 330, National Resources Board, Government Printing Office, Washington, D.C., 1934.

During droughts the surface supply fails, and the streams, fed mainly by springs, have increased hardness. This works to the disadvantage of certain industries that require relatively soft water. Underground waters are fairly clear as the result of filtration caused by seepage through rock materials. Surface waters, on the other hand, are likely to contain large quantities of sediment and organic matter, including bacteria. For that reason many cities find it necessary to treat their water supplies (1) for the destruction of bacteria and (2) for the removal of sediment by some method of filtration. Chlorine gas is widely used for killing bacteria. Alum is added to dirty river water. It serves to increase the rapidity of sedimentation in settling basins and, therefore, to decrease the amount of filtration necessary. When one considers that many cities dump their sewage into large rivers whose waters are used by other cities farther downstream, the necessity of excellent methods of purification and of daily bacteriological testings becomes evident.

The Great Lakes supply water for several cities. Chicago and Milwaukee use water from Lake Michigan; Cleveland and Buffalo, from Lake Erie; Detroit, from Lake St. Clair; and Duluth, from Lake Superior. This lake water is relatively soft compared with the deep-well water of many midwestern towns. Some cities dump sewage and industrial wastes into the very lakes from which drinking water is secured. In some cases the sewage is treated chemically. Nevertheless, contamination results. This is detrimental to the fish resource of the lakes and demands more careful and expensive methods of purification of the water before it can be used as a city supply. The contamination or pollution of lake and river water presents one of the serious problems in the field of conservation of natural resources.

Waters Used for Irrigation. The soils of arid lands generally are abundantly supplied with the mineral elements of soil fertility and require only water to make them productive. Adequate supplies of water are not easy to obtain, for the actual water requirement of crops is large. Also, much water is lost by seepage and evaporation in the course of getting it to the crops. To secure so much water, every type of source is drawn upon.

However, surface waters provide most of the supply. Except in the monsoon countries of southeastern Asia, irrigation is most practiced in lands that have less than 20 inches of average annual precipitation.

The surplus rainfall of a large area is necessary to irrigate a small area, for the reasons mentioned above. From this fact it is necessary to conclude that only a small part of the dry lands of the earth ever can be irrigated. Where ground water is used for irrigation, the dissolved minerals contained therein may in time make the soil unfit for agricultural use. Waters derived directly from mountain precipitation and the melting of mountain snows are particularly free from this defect and are much employed in the irrigation of alluvial fans and near-by plains.

Physical Conditions Favorable to Water-power Production. The capacity of water to do work is attained by virtue of the sun. Solar energy causes the winds that evaporate and transport water from sea to land. Then the water flows from land to sea under the force of gravity.

The essential conditions required to produce water power are water and fall. A small volume of water falling a great distance may have the same capacity to do work as a large volume of water falling a short distance. A small stream having considerable fall usually is capable of being more economically harnessed for power than is a large stream of low gradient.

An ideal situation for water-power production might include the following conditions of physical environment:

1. The stream should be (*a*) of large size; (*b*) its drainage region should be large; (*c*) rainfall over the drainage region should be abundant and uniformly distributed throughout the year; and (*d*) the flow of the stream should be regulated by the presence of forests, swamps, or lakes.

2. A precipitous fall is necessary in the lower course of the stream where the entire weight of the falling water may be harnessed at low cost.

Land Relief and Water-power Development. Formerly, usable water-power sites were limited to those available in regions where power was wanted. The power had to be used at the place of its production. Today much water power is used for the generation of electrical energy. The two essential ma-

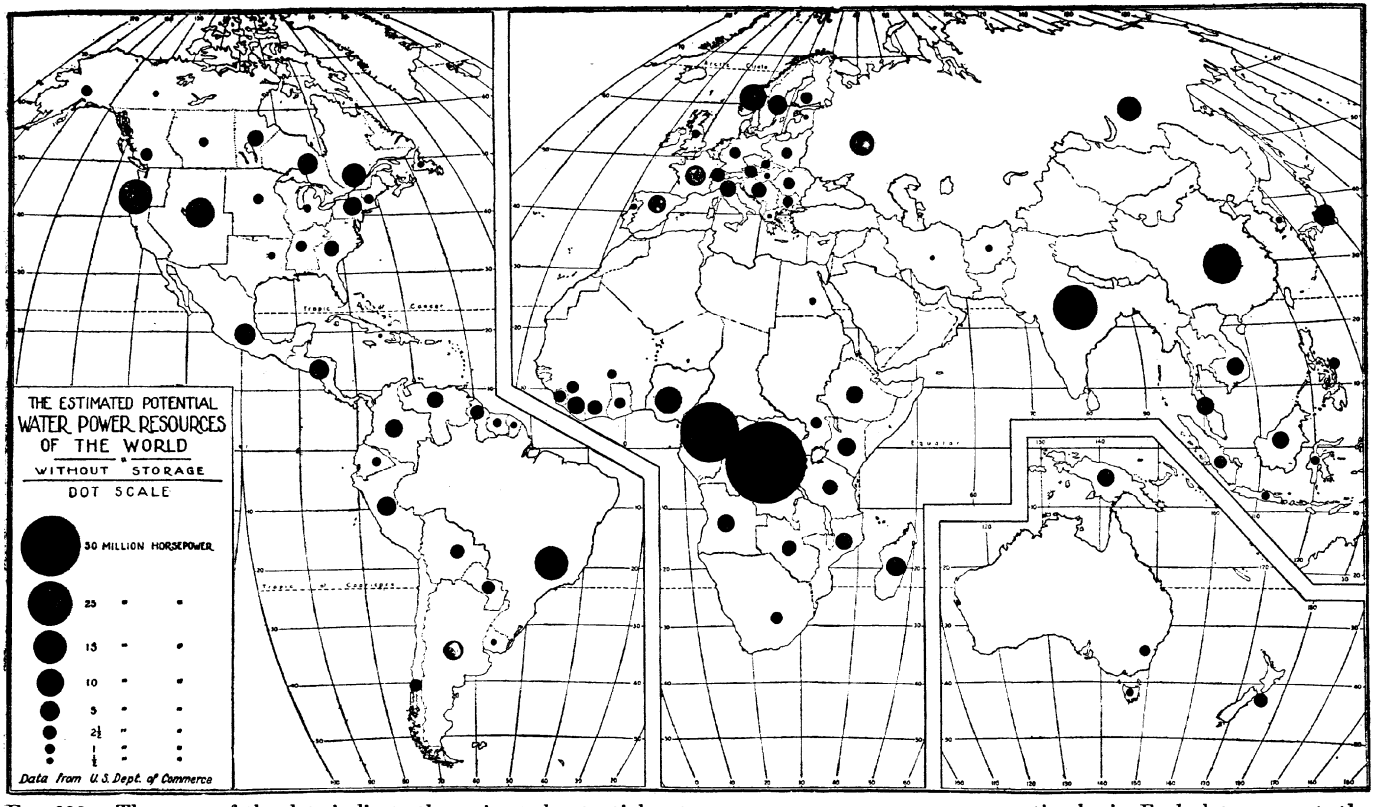


FIG. 288.—The areas of the dots indicate the estimated potential water-power resources upon a comparative basis. Each dot represents the total figure for the entire area within the boundaries of which it is placed.

chines in any hydroelectric plant are (1) a water turbine, or enclosed water wheel, and (2) a dynamo, or electrical generator. Electricity may be conveyed many miles over great transmission lines. This to some extent has made the place of power production independent of the place of its use. It is not yet economical, in most regions, to send electricity by wire more than 300 or 400 miles.

Most power sites are chosen because of the benefit of some natural advantage such as (1) waterfalls or (2) narrows, which provide an economical location for a dam. Glaciated regions and mountain valleys furnish numerous sites for water-power development. Many of these are not used because of the distance from suitable market. The construction of hydroelectric plants in the United States is increasing. They are located on advantageous sites and in many cases provide relatively cheap electricity.

Figure 288 shows the distribution of potential or possible water-power resources for the world. It will be noted that Africa outranks other continents in this respect. This is largely due to the fact that several large rivers descend in falls or rapids from the interior plateau to the coast. In North America the glaciated western mountains, especially the Cascades, have the greatest water-power possibilities. Next in rank is the glaciated region of eastern Canada and northeastern United States. In Europe the glaciated highland regions of Scandinavia and the Alpine countries are outstanding; in Asia the southern slopes of the Himalayas and the hill region of China; and in South America the highlands of eastern Brazil and the slopes of the Andes Mountains.

Irrigation and Hydroelectric Projects in the United States

Location of Irrigated Lands and Irrigation Projects. The total area of irrigated lands in our western states is not great when compared with the total area of the states themselves (Fig. 289). Yet these irrigated regions produce great quantities of agricultural products. Especially is this true in the Southwest where mild winter temperatures make crop production possible the year round. In most of the irrigated areas, water is stored in large reservoirs by means of dams. The water is then released as

needed. The dams also provide water power for the generation of electrical energy.

The accompanying map (Fig. 290) shows the location of the federal irrigation projects. It should be remembered, however,

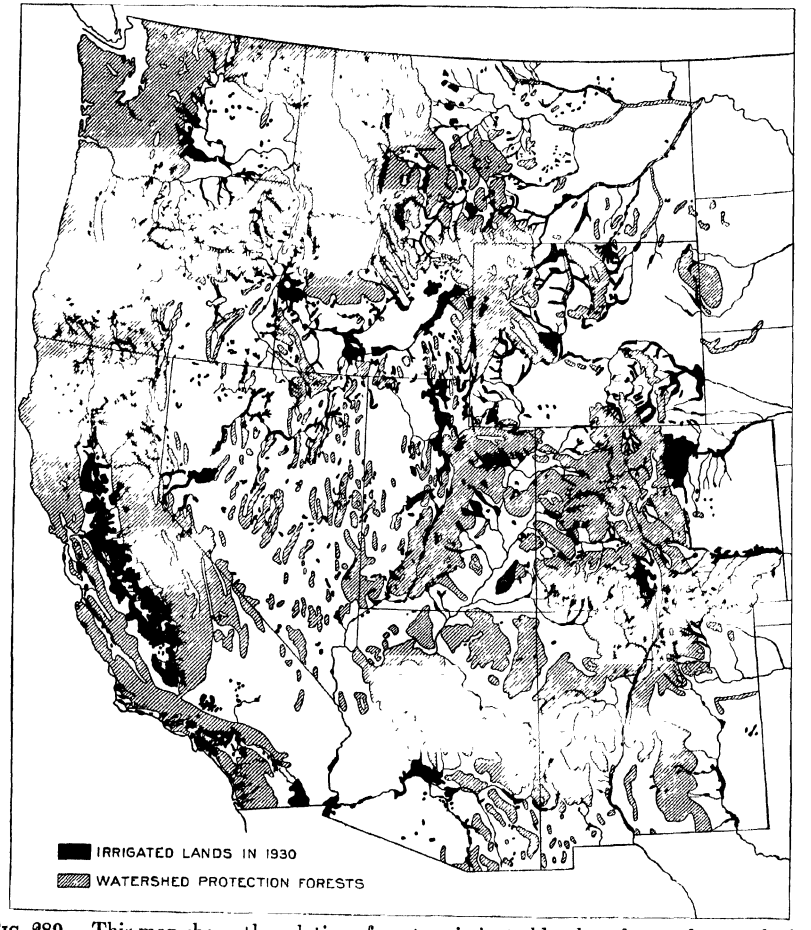


FIG. 289.—This map shows the relation of western irrigated lands to forested watersheds. (*Courtesy of U.S. Forest Service.*)

that thousands of square miles of irrigated lands are not connected with these projects. Such may be financed by states, cities, individuals, or groups of individuals.

The waters of the Colorado River are used extensively for irrigation. This river has its source in Rocky Mountain National Park, northern Colorado. It has hundreds of tributaries, many

of which are fed by the melting snows of the Rocky Mountains. The three major dams on the Colorado are (1) Boulder Dam, on the boundary between Arizona and Nevada; (2) Parker Dam,



FIG. 290.—Western part of the United States showing location of federal irrigation projects. (*Courtesy of U.S. Bureau of Reclamation.*)

about 150 miles farther south; and (3) Imperial Dam, just north of Yuma, Ariz.

Boulder Dam. This huge dam, 727 feet high, is the highest in the world (Fig. 291). It cost more than 100 million dollars and required about 5 years for completion. The lake formed by

this great structure is called *Lake Mead* and is about 115 miles long. At the dam are two spillway tunnels, each having a diameter of 50 feet.

Boulder Dam and Lake Mead illustrate how one project in the field of water conservation may serve several purposes. These are

1. *Flood Control.* The Colorado River in the past was a treacherous stream. Its floods formerly caused great damage. Now the floodwaters are stored in Lake Mead.

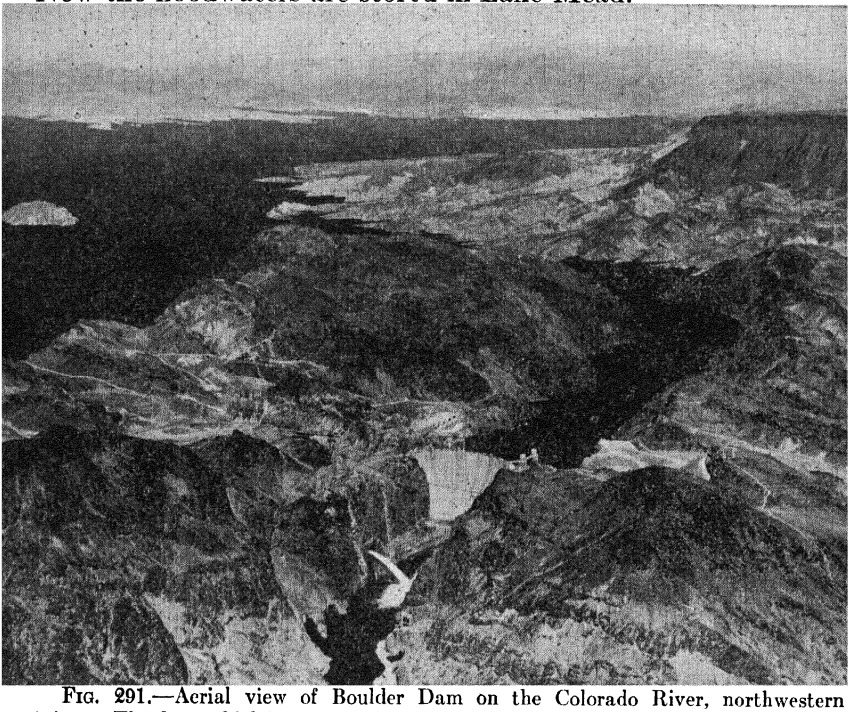


FIG. 291.—Aerial view of Boulder Dam on the Colorado River, northwestern Arizona. The dam, which is more than 700 feet high, was completed in 1935. Lake Mead, formed by the dam, is about 115 miles long. (*Courtesy of U.S. Bureau of Reclamation.*)

2. *Hydroelectric Power.* The electricity generated at the dam is used over a large area (Fig. 292). Transmission lines carry it to Los Angeles. Power generation was begun September 11, 1936, when President Franklin D. Roosevelt in Washington pushed a key that started the first generator. The location of Boulder Dam is typical of many hydroelectric plants in that it is far from the densely populated areas that it serves. The necessary long-distance transmission lines are costly.

3. *Irrigation.* Lake Mead serves as an enormous reservoir for storing irrigation water.

4. *Conservation of Wild Life.* Lake Mead is well stocked with fish and is a haven for numerous wild fowl.

5. *Recreation.* The region has become a recreational area of considerable importance.

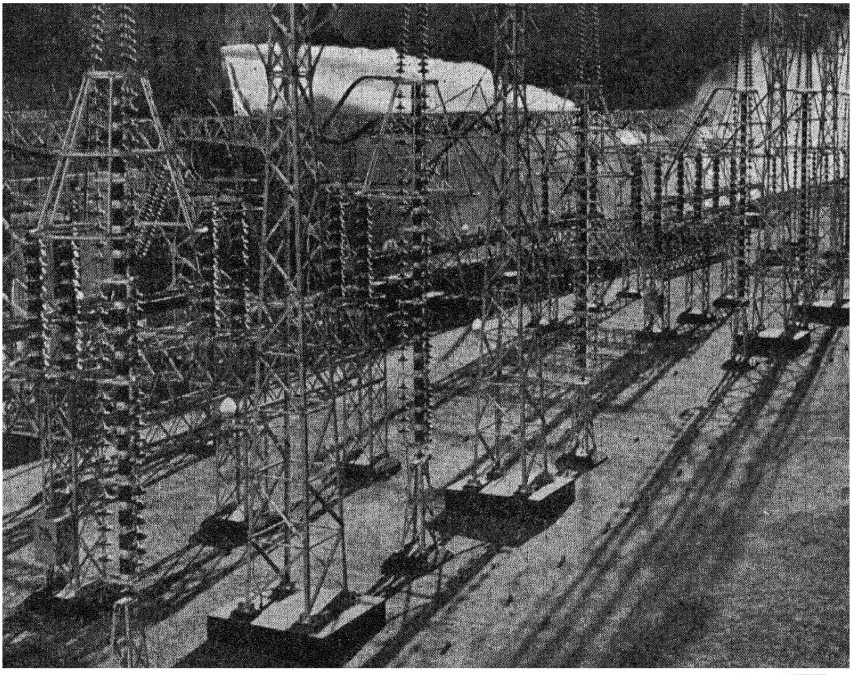


FIG. 292.—Poised on the roof of the Nevada wing of the power plant at Boulder Dam are the take-off structures for electrical current. Electricity generated here travels as far west as Los Angeles, Calif., a distance of 250 miles. It is said that income from the sale of electricity will pay for the cost of the dam in about 50 years. (*Courtesy of U.S. Bureau of Reclamation.*)

Parker Dam. About 15 miles north of Parker, Ariz., is Parker Dam. From the reservoir formed by this dam, the water of the Colorado River is taken to Los Angeles and other cities in a large aqueduct. This aqueduct is about 250 miles long. In several places it passes through tunnels. The route of the aqueduct is by no means a level one. Therefore it is necessary to lift the water at a number of points. This is accomplished by powerful pumps driven by motors that use electrical energy from Boulder Dam.

Imperial and Laguna Dams. Just north of Yuma, Ariz., are the Imperial and Laguna dams. The All-American Canal carries irrigation water from the Imperial Dam to Imperial Valley (Fig. 293). Other canals carry water to irrigated lands east and south of Yuma. As stated before, mild winters in this region make crop production possible the year round. The variety

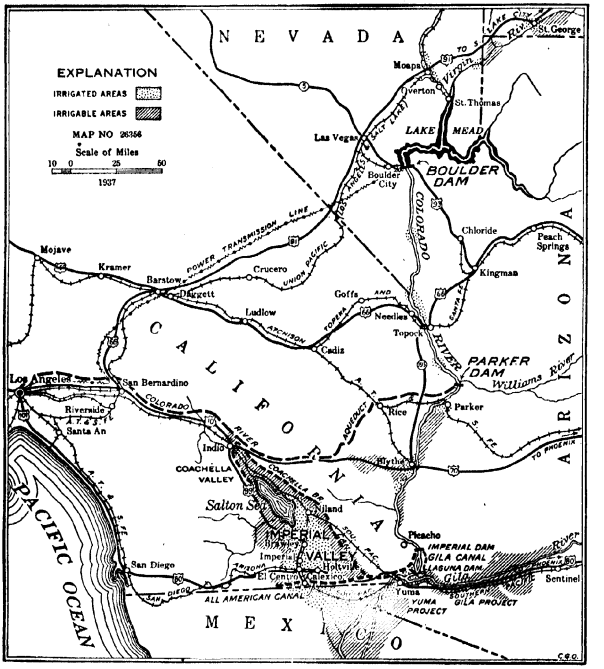


FIG. 293.—A section of country where water is the all-important element of environment. The electrical transmission line from Boulder Dam to Los Angeles, the aqueduct from Parker Dam to Los Angeles, the All-American Canal in Imperial Valley, and the Laguna Dam from which canals carry irrigation water to land around Yuma are shown. Just north of Salton Sea are the San Bernardino Mountains; and north of them, in the vicinity of Barstow, is the Mohave Desert. (*Courtesy of U.S. Department of the Interior.*)

of crops is great. Alfalfa, valuable as hay, is generally cut four or five times per year. Cotton is a major crop. Others include winter vegetables, lettuce, melons, small grains, grapefruit, grapes, and figs. It should be remembered that this is a region where shade temperatures may range from 20° to 120°F. during the year and where annual rainfall is about 3 or 4 inches. It is also that part of the United States which experiences the highest percentage of possible sunshine.

Salt River Project. In south central Arizona, in the vicinity of Phoenix, are the extensive and highly productive irrigated lands of the Salt River project. The irrigable land totals some 240,000 acres. Water is impounded by several dams on the Salt River. The oldest of these is the Roosevelt Dam, completed in



FIG. 294.—A large irrigated field of winter lettuce, not far from Phoenix, Ariz. Lettuce and vegetables, grown during the winter months, find a ready market in the northern cities of the United States. (*Courtesy of U.S. Bureau of Reclamation.*)

1911. To conserve the floodwaters of the Verde River, the Bartlett Dam has been built about 25 miles above the point where it joins the Salt River. In this region the crops produced are similar to those of the Yuma-Imperial Valley area (Figs. 294, 295). The dams provide an abundance of hydroelectric power.

Grand Coulee and Bonneville Dams. These dams are located on the Columbia River (Fig. 296). Grand Coulee is in central Washington, and Bonneville is a short distance upstream



FIG. 295.—A herd of Hereford cattle pasturing on irrigated lands near Phoenix, Ariz. Feeding beef cattle in winter is an important industry in the Salt River Valley, Arizona. Alfalfa is the principal hay crop. (*Courtesy of U.S. Bureau of Reclamation.*)



FIG. 296.—A map of the state of Washington. Ultimately most of the area inside the dotted line will be irrigated by water impounded by the Grand Coulee Dam. Much of the Yakima Valley is irrigated. The waters of the Snake River are used for irrigation in Idaho. Note the location of Bonneville Dam. Mts. Baker, Rainier, and Adams are three high peaks of the Cascade Range. It is through this mountain range that the Cascade railway tunnel, east of Seattle, has been drilled.

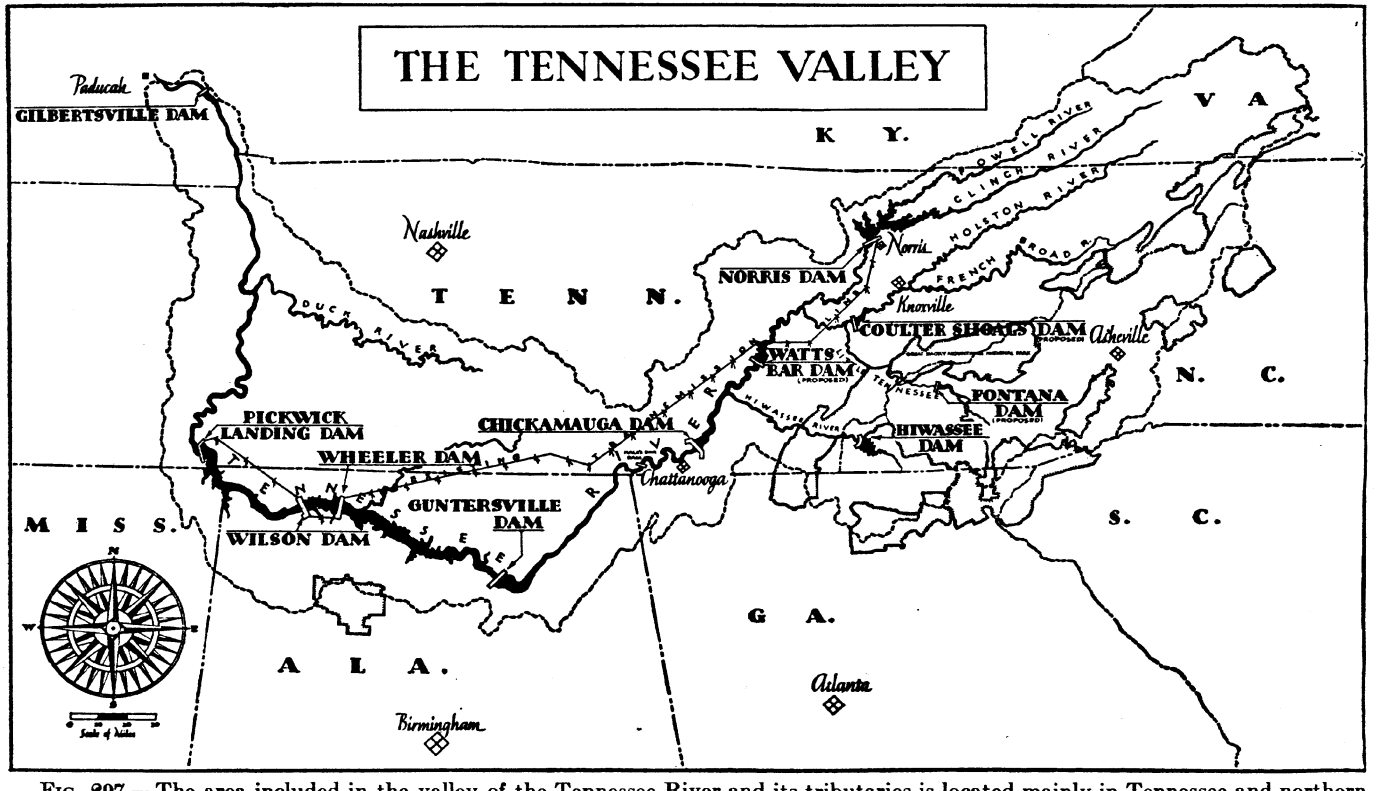


FIG. 297.—The area included in the valley of the Tennessee River and its tributaries is located mainly in Tennessee and northern Alabama. Note the names and locations of the several dams. Make a list of the largest cities shown on this map. The Wilson Dam indicates the location of Muscle Shoals, Alabama. (*Courtesy of Tennessee Valley Authority.*)

from Portland, Ore. The Grand Coulee Dam is the largest man-made structure in the world. It contains enough concrete to make two 16-foot highways from the Pacific to the Atlantic Ocean. It is not so high as Boulder Dam, yet it is two and one-half times greater in volume. The waters impounded will be used to generate electricity and to irrigate a large area lying south of the reservoir. In this region the frost-free period is about 160 days. During the irrigation season from April to October the days are hot and nights cool. Annual rainfall is about 8 inches. This region is adapted to general farming. Important crops are hay, grain, fruits, and vegetables. Bonneville Dam, unlike the Grand Coulee, was built mainly to improve navigation on the lower Columbia River and to provide hydroelectric power. Since great numbers of salmon spawn in the upper reaches of the Columbia River, provision had to be made whereby the fish could get around the dam. This is accomplished by a "ladder," or steplike series of concrete basins.

Tennessee Valley. The Tennessee Valley Authority, or TVA, is chiefly a federal project (Figs. 297, 298). The authority was created by Congress in 1933 and later amended in 1935. The work is administered by a board of directors consisting of three men appointed by the President of the United States.

The Tennessee River is much larger than any other tributary of the Ohio River. It is located in a region that has an annual average rainfall of 45 to 50 inches and where the maximum has reached 70 to 80 inches. In past years heavy downpours of rain in the Tennessee Valley have resulted in disastrous floods and excessive soil erosion. The high waters of the Tennessee River also have contributed to floods in the Ohio and Mississippi valleys.

Because of lower latitude, the growing season in this area is considerably longer than in such corn-belt states as Iowa and Nebraska. Climatically, this is a much favored region from the standpoint of agricultural production.

The chief purpose of the Tennessee Valley Authority is to develop the water resources of the valley. This work includes the building of eight dams, together with necessary locks and hydroelectric plants. These projects serve the following purposes:

1. Flood control
2. Improvement of river navigation
3. Development of electrical energy
4. Control of erosion along river banks

In addition to these, the Tennessee Valley Authority has in its program other types of work, which include

1. Control of soil erosion (On badly-eroded hill slopes this is accomplished by the planting of trees, shrubs, and grasses.)

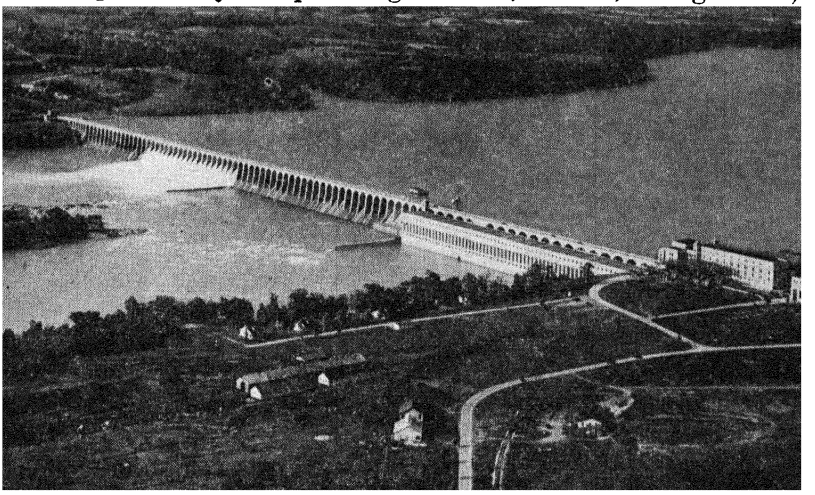


FIG. 298.—Wilson Dam from the air. Wilson Dam in northern Alabama aids navigation by eliminating 15½ miles of shoals, converts the power of falling water into electricity, and serves the nation's defense plans. Started during the First World War and completed in 1925, it is 137 feet high and 4,860 feet long, with a reservoir area of about 16,100 acres extending 15½ miles up the Tennessee River to Wheeler Dam. This project, now under the supervision of the Tennessee Valley Authority, has generating equipment with a capacity of 184,000 kw. (*Courtesy of Tennessee Valley Authority.*)

2. Improvement of soil fertility by proper rotation of crops and by employing better methods of general farming
3. Manufacture and sale of commercial fertilizers
4. Manufacture of chemicals needed in the munitions industry

The Tennessee Valley Authority has been a controversial enterprise. Some argue that it is "government in business." They say that taxes collected from the entire country should not be used to develop a small region. Also, that the sale of cheap electricity from government-owned projects is unfair to private utility companies engaged in the generation and distribution

of electrical energy. Their opponents say that government money is used to develop many sections of the country, not just one. They point out that these great projects reduce unemployment. And they quote statistics to prove that lower rates have greatly increased the consumption of electrical energy, which in turn makes for a higher standard of living.

Keokuk and Bagnell Projects. The Keokuk Dam is one of several that have been built across the upper Mississippi River.

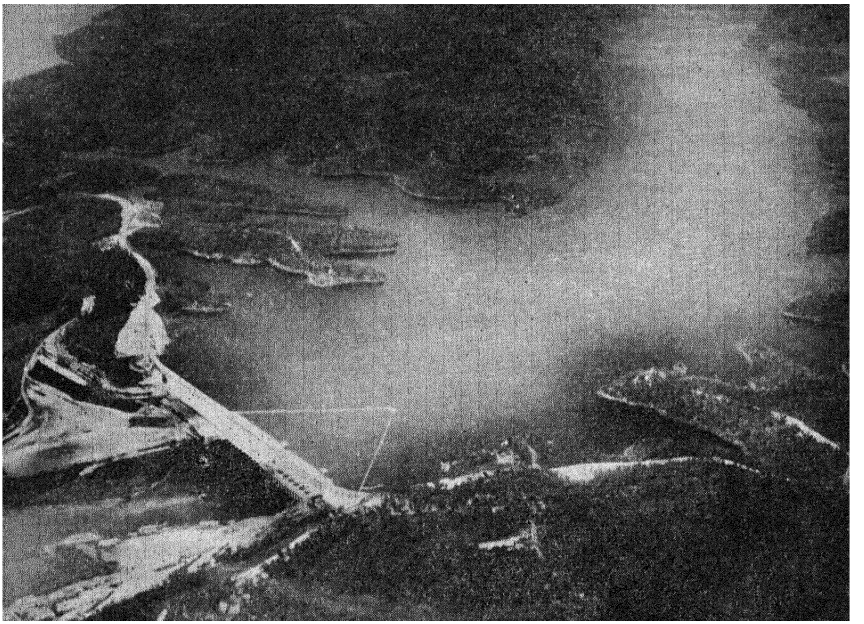


FIG. 299.—Aerial photograph of Bagnell Dam and the Lake of the Ozarks on the Osage River in southern Missouri. (*Courtesy of Union Electric Co.*)

Located at Keokuk, in southeastern Iowa, it serves three purposes: (1) generation of electrical energy, (2) flood control, and (3) improvement of river navigation. Electricity from the Koekuk project is used in much of the surrounding region. It is carried by transmission lines as far south as St. Louis.

The Bagnell Dam is located on the Osage River, about 40 miles southwest of Jefferson City, Mo. The lake formed by this dam, called *The Lake of the Ozarks*, is one of the largest artificial lakes in the world (Fig. 299). It is over 100 miles long and has a shoreline of some 1,200 miles. This extensive shoreline, much greater than that of Lake Mead, is due (1) to the sharp

meanders of the Osage River and (2) to the numerous tributary valleys (Fig. 300). Located in the wooded Ozark hills, this beautiful lake has become a prominent pleasure resort and represents a commendable use of water resources. Transmission lines carry electrical current from Bagnell Dam to St. Louis. Keokuk and Bagnell are controlled by a private utility company.

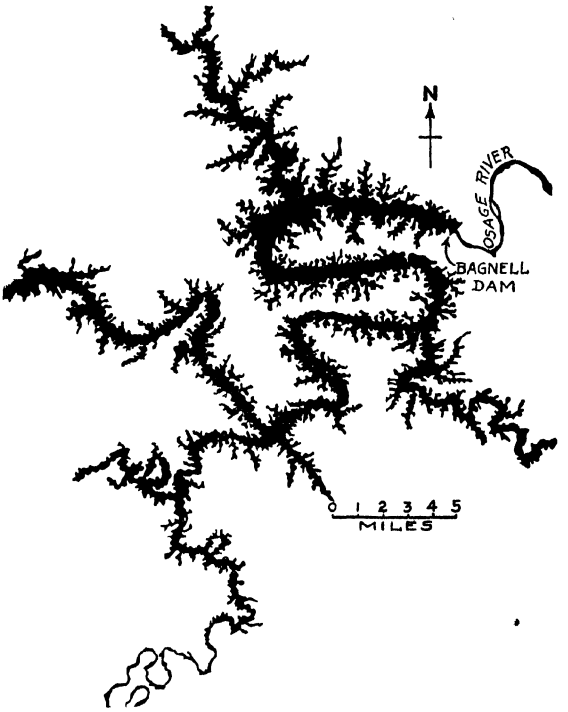


FIG. 300.—The Lake of the Ozarks, southern Missouri. The 1,200-mile shoreline of this lake is due largely to the flooding of numerous tributary valleys.

Niagara Falls. Niagara Falls provide an example of one of the most valuable water resources in the world (Fig. 301). The Niagara River has great volume and uniform flow. The water is relatively free from sediment, because it is the overflow of great settling basins, Lake Erie and the other Great Lakes. The drop at the falls is about 160 feet. Hydroelectric plants have been built on both the Canadian and the American side of the river. Some are below the falls; others, above. The total amount of electrical energy generated is enormous.

Other Uses of Surface Waters

Value of Streams for Inland Navigation. In nearly all parts of the world, except in deserts and on mountains, streams are used as avenues of interior transportation (Fig. 302). The great advantage of river transportation is its low cost. This is

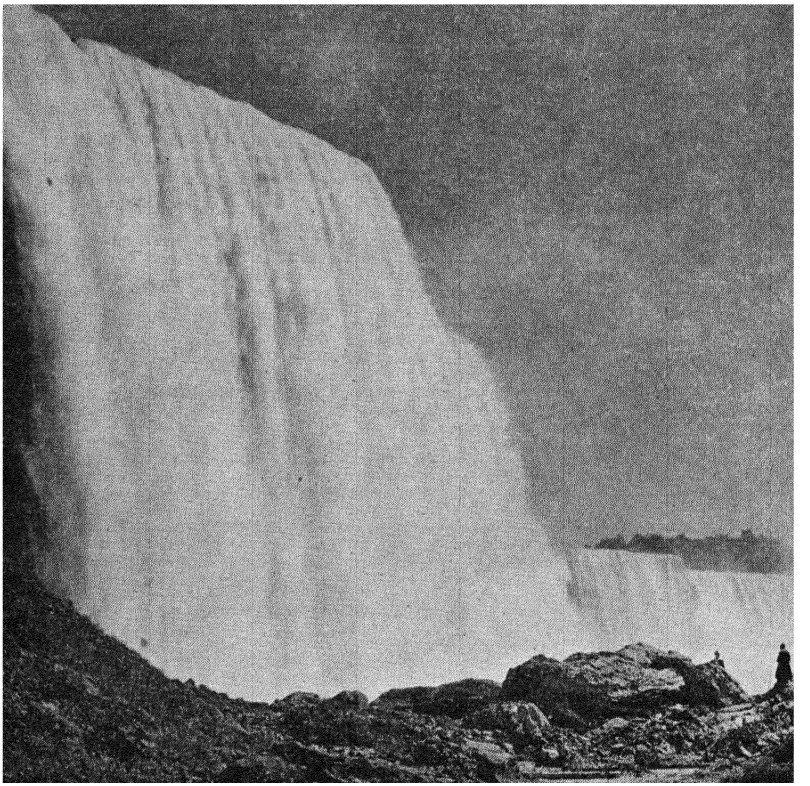


Fig. 301.—Niagara Falls, in western New York, is an important source of hydroelectric power. (*Courtesy of Buffalo, Niagara, and Eastern Power Corp.*)

due to the relatively small amount of power needed and the great quantity of freight that can be moved in one shipment. A single tugboat moves upstream or downstream with several modern steel barges loaded with various commodities (Fig. 303). These commodities consist largely of bulky materials, such as coal, lumber, grain, or building materials, that do not necessarily demand the fast shipment provided by railroad or truck.

Huge sums of money have been spent on certain rivers, such as the Rhine, Mississippi, and Missouri, to develop straighter and deeper channels. The Amazon, on the other hand, is so deep that fair-sized ships ascend its waters for some 2,000 miles. An important river from the standpoint of commerce is the

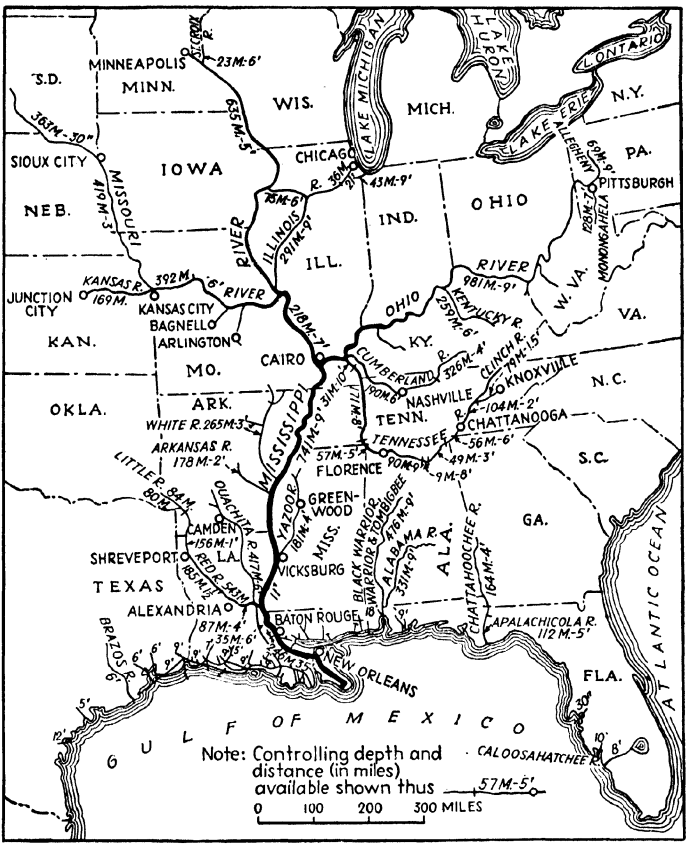


FIG. 302.—Navigable waters of the Mississippi Valley and Gulf of Mexico. (*Courtesy of Mississippi Valley Assn., St. Louis, Mo.*)

Yangtze, which is the principal means of shipping goods to and from the far interior of China.

River transportation suffers, however, from the following defects: (1) The depth of water may fluctuate considerably during the year; (2) the channel may shift from time to time or be obstructed by sandbars; (3) where winters are severe, ice may cause navigation to cease for several months; (4) it is

sometimes difficult to build the necessary facilities for handling freight on the banks of a shifting river; and (5) the movement of river craft is comparatively slow.

Two newspapers in Kansas City, Mo., have devoted space to arguments on the river-transportation question. One has favored river development because of cheap water transportation and because some railroads that parallel waterways have been forced to lower their freight rates. The other paper has

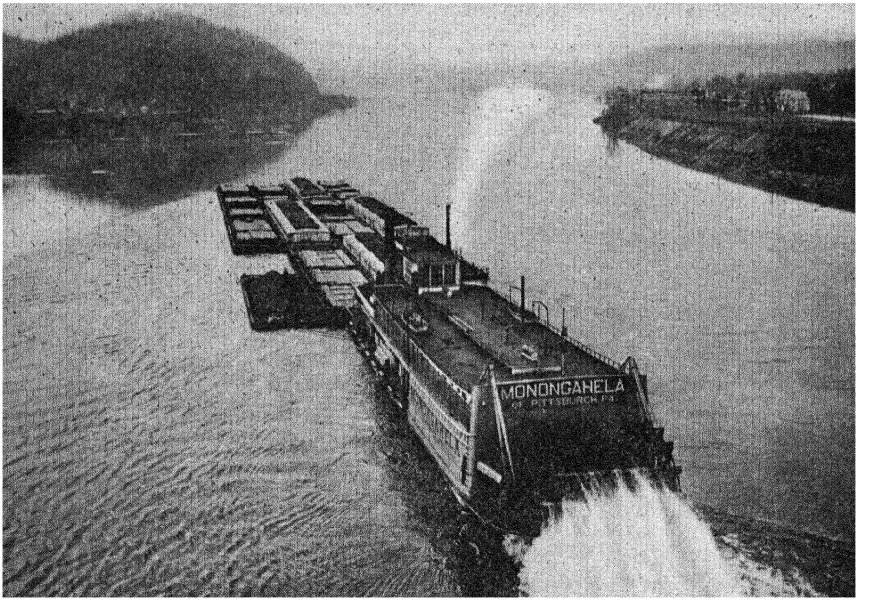


FIG. 303.—Modern river transportation on the Ohio River. A single tugboat is shown moving several barges loaded mainly with steel products. (*Courtesy of U.S. Army Engineers.*)

called the whole procedure a farce. It claims (1) that river transportation has not benefited the farmer as it was supposed to do and (2) that the enormous sums sunk in river development could have been spent for better purposes. This paper calculated and published the astounding cost per mile of improving the Missouri River between Kansas City and St. Louis and then said, "Catfish never swam in costlier surroundings."

Value of Lakes for Inland Navigation. The use of the large lakes or inland seas of the world for navigation presents less difficult problems than does the use of rivers. Some are

closed by ice part of the time, but not many are troubled by variable depths or obstructed channels. Owing to their fortunate position between the principal iron-ore and coal regions of the continent, the Great Lakes of North America have been developed into one of the most effective routes of transportation in the world. They have played a large part in the historical and industrial development of the region in which they lie. Although there is not the same opportunity for special service in other regions, some of the lakes of other continents serve the transportational needs of their regions well. Among the most used of them are the three great lakes Victoria, Tanganyika, and Nyasa in eastern Africa; the Caspian Sea and Lake Baikal in Asia; and others of smaller size.

Value of Lakes and Streams as Centers of Recreation. To most persons a visit to a lake or stream affords a pleasant diversion from the daily routine. The exhilarating sports found in swimming, fishing, and various forms of boating serve as an attraction so strong that large numbers of people make at least a brief annual trip to some body of inland water for purposes of recreation. In recent years the building of good roads and the conveniences afforded by the automobile have permitted a widespread gratification of this desire. As a result, large amounts of money are spent by vacationists, and the lakes and streams that attract them have become physical assets of great value to the regions in which they lie.

The greatest number of attractive lakes is found in regions of glaciation. Some of them are the morainic lakes of regions of glacial deposition, but the larger number is found in regions of ice scour or of ice scour with associated morainic damming. It often happens also that the conditions of ice scour that are responsible for the lakes have conspired with climate to render the surrounding land of low agricultural value. This in turn has tended to keep the region in a forested or wild condition which increases the attractiveness of the lakes and their recreational value. Lake-dotted areas are found in mountain, hill, and plain lands alike. The glacial lakes of the Alpine countries, Rocky Mountain region, high Sierras, or southern Andes add mountain scenery to their attractiveness. More accessible are the lakes of the hill lands of New England and the Adirondack

Mountains of New York. Thousands of lakes in the plains of the Great Lakes region, eastern Canada, Scandinavia, Finland, and Germany draw ever larger numbers of people to their shores. They constitute a resource worthy of studied conservation and development.

Summary

Nature has endowed the earth with many natural resources of tremendous value to man. The conservation of these resources demands our serious and constant attention.

The ground-water supply is endangered by overusage and by pollution. Surface waters, especially in rivers and lakes, furnish many cities with ample supplies of water. Such waters in some places are being contaminated by sewage disposal and by the waste products of industrial establishments and mines. Surface and ground waters both are used for irrigation. Hundreds of millions of dollars have been spent in the construction of great dams that create huge reservoirs of water to be used for irrigation and hydroelectric power.

Enormous sums of money have been spent in improving the rivers of the United States for navigation. Whether or not these expenditures are justified is a debatable question.

The Great Lakes of North America constitute the greatest inland waterway in the world.

The growth of native plants in the various regions of the world is much influenced by the amount and seasonal distribution of rain. Our next chapter deals with the natural vegetation resources of the earth and with associated animal life.

Questions

1. Write a definition of natural resources.
2. What are the classes of natural resources? Give examples of each.
3. How are natural resources classified according to their permanency? Give examples of each.
4. What do you think is meant by the conservation of natural resources?
5. Mention five important uses of water.
6. What is the daily per capita consumption of water in Chicago? What is it in your community?

7. From what sources may large supplies of water be secured?

8. What are the principal sources of water supply for large cities? What is the principal source in your city?

9. Define water table.

10. How does the depth of the water table below the earth's surface vary during wet and dry weather?

11. What three factors largely determine the supply of ground water in any given locality?

12. What rock is notable for its ability to carry ground water? Why?

13. Why do sulphur and iron sometimes make ground water unfit for use?

14. What are the most abundant soluble salts found in ground water?

15. What causes alkali water?

16. What is hard water? What are some of its objectionable qualities?

17. What underground conditions may result in the formation of a spring? A hot spring?

18. Locate the regions where unusually large springs occur.

19. Locate several health resorts that make use of either mineral or hot springs or both.

20. Why do some dug wells have only temporary supplies of water?

21. What care should be exercised in selecting a location for the drilling of a deep well?

22. What is an artesian well? What five conditions are favorable to the occurrence of artesian wells?

23. Explain the underground rock formations responsible for the many artesian wells of South Dakota.

24. Locate several noted artesian regions.

25. Mention several conservation measures that pertain to ground water.

26. Mention six or seven ways in which surface waters are important to man.

27. In general, which is harder, ground water or surface? Why?

28. Surface water, such as river water, usually must be given what treatment before it can be used?

29. What are several objections to the dumping of city sewage into rivers?

30. How is the water of the Great Lakes being contaminated?

31. In what two ways is much irrigation water lost before it can be used?

32. Only a small part of the dry lands of the earth ever can be irrigated. Why?

33. What are two or three objections to using the ground water supply for irrigation?

34. What conditions contribute to an ideal situation for water-power production?

35. What are the two essential machines in a hydroelectric plant?

36. Why can hydroelectric plants be built many miles from the locality where the electricity is to be used?

37. What determines the location of most water-power sites?

38. State several facts concerning the world distribution of water-power resources.

39. Name and locate the three principal dams on the Colorado River.

40. Boulder Dam and Lake Mead serve what five purposes?

41. Why are the irrigated lands of the Yuma district and Imperial Valley extremely productive? Mention several important crops.

42. Locate the Grand Coulee and Bonneville dams. What are the purposes of these projects?

43. What are the four principal purposes for which the Tennessee Valley Authority was created?

44. Mention two or three arguments for and against the Tennessee Valley Authority project.

45. Locate Keokuk and Bagnell dams. Account for the extensive shoreline of the Lake of the Ozarks.

46. What are some advantages of Niagara Falls from the standpoint of developing hydroelectric power?

47. What are two advantages of river transportation? What commodities especially are shipped via rivers? Why?

48. For how many miles is the Amazon River navigable?

49. What river is an important transportation artery of China?

50. Mention several objections to river development.

51. How have the Great Lakes of North America contributed to commercial and industrial development in that region?

52. Locate the following lakes: (1) Victoria, (2) Tanganyika, (3) Nyasa, (4) Baikal.

53. Mention five regions where attractive lakes suitable for recreational purposes are found. Why are they found mainly in glaciated regions?

Suggested Activities

1. If possible, make field trips to observe and study wells, springs, artesian wells, or water-supply methods of the local community. On

such trips make inquiry about the position or depth of the water table.

2. Find out about the water used in your city. What is its source? How is it treated before being delivered to the people for consumption? Is it hard or soft? If it is hard, make inquiry as to the cost of equipment necessary to change it to soft water. How much water is consumed daily by the city? How does daily consumption vary with the seasons?

3. Using a small sand table, arrange layers of sand and clay in such a manner that the occurrence of hillside springs and artesian wells will be illustrated.

4. On a large wall outline map of the United States use different colors or symbols to show major regions of big springs, artesian wells, hot springs, and the location of a few major irrigation and hydroelectric projects.

5. If possible, secure, perhaps from the physics department, a small water turbine and dynamo so that you may see the two principal machines used in hydroelectric projects.

6. Make a trip of several miles around the local community, and note the location of deep wells. Do you find any whose waters might be polluted by underground seepage?

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. The Water Supply of the Local Community
2. Health Resorts in the United States Dependent upon Hot Springs and Mineral Springs
3. Artesian Waters of the Atlantic Coastal Plain
4. Artesian Wells in North and South Dakota
5. The Water Supply for New York City
6. Pollution of Inland Waters
7. Irrigation in the Vicinity of Yuma, Ariz.
8. The Boulder Dam Project
9. The Grand Coulee Project
10. Modern River Transportation in the United States

REFERENCES

NEWELL, F. H.: *Water Resources: Present and Future Uses*, Yale University Press, New Haven, 1920.

PERSON, H. S., *et al.*: *Little Waters: Their Use and Relation to the Land*, Government Printing Office, Washington, D.C., 1936.

PIGMAN, AUGUSTUS: *A Story of Water*, D. Appleton-Century Company, Inc., New York, 1938.

The following list of references is useful in relation not only to this chapter but also to the following chapters which deal with the subject of natural resources.

Atlas of American Agriculture, U.S. Department of Agriculture, Government Printing Office, Washington, D.C., 1936.

Commerce Yearbook, Vol. 1, "United States"; Vol. 2, "Foreign Countries," U.S. Department of Commerce, Washington, D.C.

COLBY, C. C., and A. FOSTER: *Economic Geography*, Ginn and Company, Boston, 1940.

JONES, CLARENCE F.: *Economic Geography*, Henry Holt & Company, Inc., New York, 1935.

PACKARD, L. O., C. P. SINNOTT, and B. OVERTON: *The Nations at Work*, The Macmillan Company, New York, 1933.

———: *Nations Today*, The Macmillan Company, New York, 1939.

PARKINS, A. E., J. R. WHITAKER, *et al.*: *Our Natural Resources and Their Conservation*, John Wiley & Sons, Inc., New York, 1936.

Report on National Planning and Public Works in Relation to Natural Resources, National Resources Board, Government Printing Office, Washington, D.C., 1934.

RIDGLEY, D. C., and SIDNEY E. EKBLAW: *Influence of Geography on Our Economic Life*, Gregg Publishing Company, New York, 1938.

SMITH, J. RUSSELL: *Men and Resources*, Harcourt, Brace & Company, Inc., New York, 1937.

STAPLES, Z. C., and G. M. YORK: *Economic Geography*, Southwestern Publishing Company, New York, 1934.

Statistical Abstract of the United States, Government Printing Office, Washington, D.C.

WHITBECK, R. H., LOYAL DURAND, JR., and J. R. WHITAKER: *The Working World*, American Book Company, New York, 1937.

WHITBECK, R. H., and V. C. FINCH: *Economic Geography*, McGraw-Hill Book Company, Inc., New York, 1941.

Yearbook of the U.S. Department of Agriculture, Government Printing Office, Washington, D.C. (published annually).

ZIMMERMAN, F. W.: *World Resources and Industries*, Harper & Brothers, New York, 1933.

Chapter XVI. Native Vegetation and Animal Life

Among the natural resources of the earth, few are more important than native vegetation and associated animal life. To be sure, certain native plants and animals have been modified and improved by man's scientific methods. Nevertheless, remaining natural forests are our principal source of lumber; natural grass-covered areas are valuable grazing lands; and native animals of land and sea are sources of food, skins, and fur.

More and more must we give our attention to the conservation of these natural resources. Such conservation may involve one or all of the following points:

1. The sensible and economic consumption of resources now existing
2. The protection of certain animals and plants almost exterminated by man
3. The replenishing of supplies of natural resources wherever possible for the use of future generations

One needs only to think of the enormous daily consumption of lumber to realize the terrific drain on natural forests and the necessity of reforestation. The plowing of native grasslands in certain sections of semiarid United States has had a twofold detrimental effect: (1) The natural grazing land has been ruined, temporarily if not permanently, and (2) the loose soil has been whipped up by the wind and carried away in dust storms. Wise governmental supervision or regulation of man's use of natural resources is an absolute necessity, because man's desire for individual profit too often completely destroys any thought of the needs of future generations.

Plant and Animal Life

Plant Life Reflects the Conditions of Environment. Native vegetation is mainly a reflection of climatic conditions, both past and present. Other environmental elements, such as soils, landforms, and drainage, are likewise important modifiers of the plant cover. We associate certain types of vegetation with certain climates. An example is the short grass of the middle-latitude steppes.

Native vegetation often has been helpful in determining the value of a region for human use. The suitability of virgin soil for certain types of land use and crops is often clearly indicated by the vegetation cover. In the present chapter we shall give our attention to (1) the principal plant groups, (2) their relationships to environmental conditions, and (3) their world distribution.

Animal Life. It is impossible to classify animals in terms of environment, as one classifies plants. Plants cannot move about as animals do. They therefore must adapt themselves to their environment by their forms and structures. Animals, on the other hand, can, within certain limits, change their environment by migrating or burrowing. The plant is a captive of its environment and is compelled to wear the evidences of its captivity by exhibiting certain structural forms where everyone may see them. Animals, on the other hand, adjust themselves to their physical surroundings by what they *do*, rather than through their structures and forms. As a consequence no attempt is here made to classify animals into great groups, as is done for plants. Since, however, the type of animal is sometimes closely related to the native vegetation cover, brief comments occasionally are made concerning the representative animal life associated with certain vegetation groups.

Conditions of Environment That Affect Plant Life

Plant Associations, or Groups. Most of us have observed that the plant life in swamps differs markedly from the vegetation cover of higher and drier ground. This example, of course, involves small areas. However, similar environments over great areas in widely separated parts of the earth are likely to have plant covers that are much alike in general aspect. This is true

even though the plants are not composed of identical species. Thus the tropical rainforest of the Amazon Basin and the Congo, separated by wide expanses of ocean, are, nevertheless, relatively similar in general appearance and type of plants. So are the prairie lands of Argentina, the United States, and Hungary. It is with these plant associations over relatively extensive areas that the present chapter is chiefly concerned.

Temperature and Water. Unlike many animals, plants do not generate heat. As a consequence their very existence and their characteristics are greatly influenced by the temperature of the air and soil. For every species of plant there appear to be three critical temperatures: (1) the lower and (2) upper limits, beyond which it cannot exist, and (3) the best temperature, the one in which it grows most vigorously.

Different species resist cold in different ways. Some make the adjustment by retarding growth. Such may be shown by the falling of leaves from middle-latitude deciduous trees, such as the oak, elm, and maple. Certain other plants, represented by coniferous trees, such as pine and spruce, relapse into a dormant, or inactive, period without any apparent outward change. In some species the plant completes its entire life cycle during the warm season, reproducing itself by means of seeds. These are called *annuals* and are represented by many vegetables and cereals. They stand in contrast to *perennials*, such as trees, grass, and alfalfa, the vegetative parts of which live on year after year.

No plants can live entirely without water. It is taken in at the roots and is used by the plant in the formation of sap. Mineral matter in solution in sap is carried to all parts of the plant.

Certain *water-loving* plants live in water or in very damp and humid regions. Their stems are generally long and relatively fragile; leaves are large and usually thin; roots are likely to be shallow. The banana tree, characteristic of the wet tropics, is an example of such plants.

At the opposite extreme are *drought-resistant* plants. Such plants have deep or widespread root systems, shorter stems, with smaller and thicker leaves sometimes covered with wax to check the loss of water into the air. In some species a thick, corky bark may develop; in others leaves may be replaced by thorns.

The desert sagebrush is a good example of a drought-resistant plant.

In some climates certain plants are adapted to the use of considerable water during a wet season but develop drought-resistant characteristics during a dry season. Bunch grass, scrub oak, sumac, and the wild lilac of the California chaparral are examples.

Soils. Temperature and water are the two principal physical elements determining the character of the earth's vegetation. Some modifications, however, may be caused by soils of different types. Sandy or stony soils, which are very porous, are likely to develop drought-resistant plants. Excessive salt in a soil may entirely prevent plant growth. A proportion of over 3 per cent of lime in soil is likewise injurious to most vegetation. Alkali soils are barren or at best produce a very scanty vegetation.

The Great Plant Associations

Three Principal Classes of Vegetation. In our study of plant life we shall give our attention to three principal classes of natural vegetation: (1) forests, (2) grasslands, and (3) desert shrub, including tundra. In general, forests occupy the regions of wettest climate; and desert shrub, the driest; whereas grasses are intermediate in their requirements.

Forests. In the woodland or forest the tree is the essential plant (Fig. 304). Other woody plants, such as bushes and shrubs, together with grasses, may be present as well. The tree is not only the most powerful but also the most exacting creature of the vegetable kingdom. When trees grow in a closed formation and are so close together that their crowns touch, the result is a genuine forest.

Three ways of classifying trees should be kept in mind:

1. (*a*) Softwood or (*b*) hardwood
2. (*a*) Needle leaf or (*b*) broadleaf
3. (*a*) Deciduous or (*b*) evergreen

Most broadleaf trees are hardwoods; the needle trees, such as pines, are softwoods. Evergreens are those which retain some foliage throughout the year, whereas deciduous trees periodically lose their leaves and are therefore bare for a portion of the year.

Hardwoods are both evergreen and deciduous, although the conifers are rarely deciduous.

Forests demand more water than the other great vegetation types. Strong, dry winds which cause excessive evaporation are harmful to tree growth. A good forest climate is one with a warm

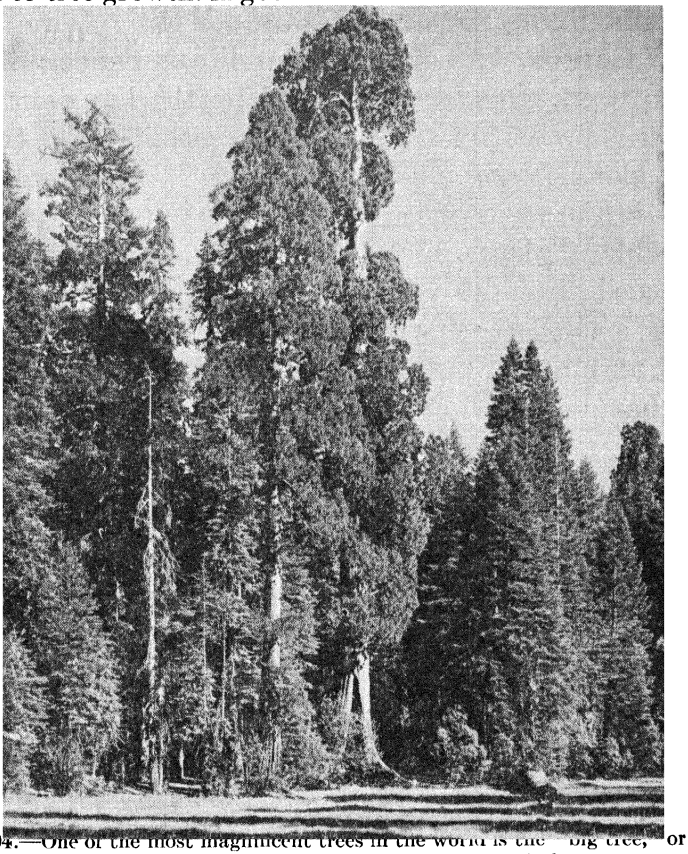


FIG. 304.—One of the most magnificent trees in the world is the "big tree," or giant sequoia, found in Sequoia National Park, California. Some of these trees are over 3,000 years old. They attain diameters of 30 to 40 feet and reach heights of 250 feet or more. (*Courtesy of U.S. Department of the Interior.*)

vegetative season, a continuously moist subsoil, and low wind velocity, especially in winter.

Grasslands. The vegetation cover of grasslands consists principally of *perennial* grasses, although other plants may be present in considerable numbers. In the low latitudes, grasslands often are called *savannas;* in the middle latitudes they go by the names of *prairies* and *steppes.* Grasslands in wet and poorly

drained areas are designated as *meadows*. Since most grasses are relatively shallow rooted, they suffer from prolonged drought if it coincides with the warm period or growing season. During the resting period, which is winter in middle latitudes, grasses can endure great drought with little injury. Climatically, then, grasslands are typical mainly of semiarid regions where most of the rain falls during the warm season.

Desert Shrubs. As far as plant life is concerned, deserts are of two types. One is represented by the hot Sahara, where little water is present in any form. The second is the cold desert of polar regions, frozen much of the year. Here the water that is present is in the form of snow and ice for many months and is not accessible to plants. In both types of desert, however, lowly, widely spaced, drought-resistant plants predominate.

Rarely are there sharp boundaries separating woodland, grassland, and desert, but almost always we find gradual transitions, or changes, from one to the other.

Types of Forests and Their Distribution

Low-latitude Forests

Tropical Rainforest. This type of woodland occupies mainly the warm tropical lowlands where rainfall is heavy and well distributed throughout the year, there being no marked dry season. The Amazon Basin, in northern South America, and west central Africa are the two largest areas of tropical rainforest. It is found also along many rainy coasts and islands in the tropics.

Luxuriant and complex! Such is the character of the tropical rainforest (Fig. 305). In external appearance it presents a richly varied combination of many colors. Gray, olive, brown, and yellow tints are more common than the fresh green of middle-latitude woodlands. The skyline, too, is different. The crown of the tropical forest is irregular and jagged with many crests and furrows. This comes from the great variety of trees of varying heights. No other forest equals it in richness of species. These are intricately intermingled. Seldom is there a large stand of a single kind of tree, as is usually the case in forests of middle latitudes. Tropical rainforest is evergreen broadleaf in character. There is

no general dormant period, each tree shedding its foliage as the new leaves grow (Fig. 306). Just as the climate is without seasonal change, the vegetation is likewise. As a result of the continuousness of the addition and fall of leaves, the forest is never bare and without foliage. Needle trees are largely absent, leaves usually being broad and thin.

An internal view shows the tropical rainforest to be composed of tall trees, often over 100 feet high, with large diameters,

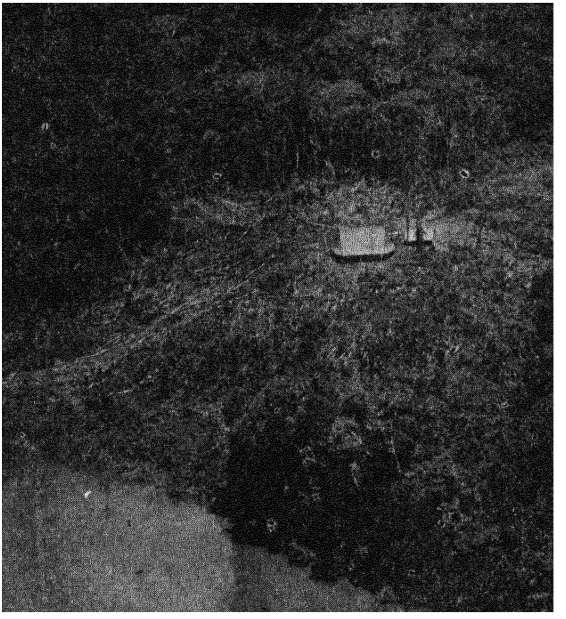


FIG. 305.—Aerial view of tropical rainforest, with clearing, in the Amazon Basin. (*Courtesy of Hamilton Rice Expedition.*)

growing close together. It is not a "single-storied" forest, because there is usually an "understory" of smaller trees. The result is a dense shade with very subdued light underneath (Fig. 307). In the Congo forest, Shantz found that the time required for a photograph was twenty thousand times the normal exposure in the open. The trees have few lower branches, their trunks being smooth, resembling a conifer more than an oak. Lianas, climbing plants, epiphytes, and parasites are relatively abundant.[1] This mass of vines and creepers appears almost to

[1] *Lianas* are ropelike plants which entwine themselves around trunks and branches. *Epiphytes*, of which orchids are a common example, characteristically grow on the

suffocate the trees that are its supports. Within the forest the tall, branchless trunks resemble gigantic dark columns supporting an almost impenetrable cover composed of the interlocking crowns of the trees, vines, and creepers. In the virgin

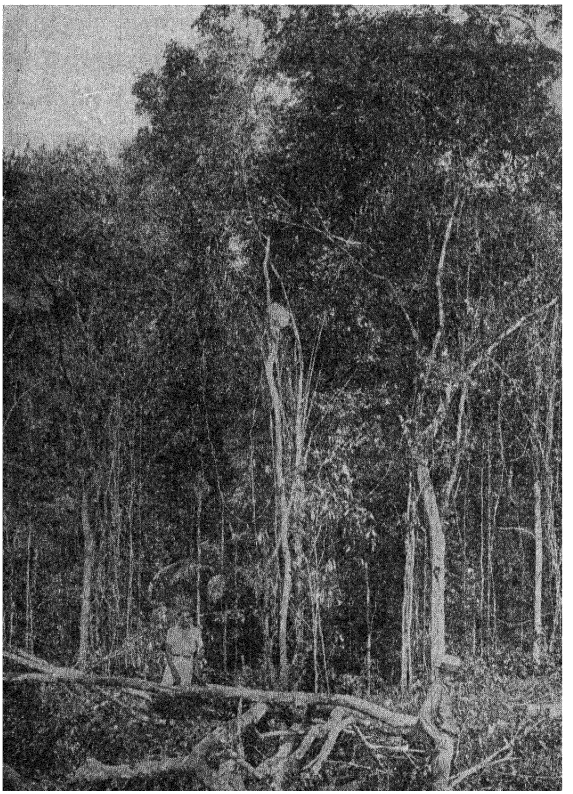


FIG. 306.—The abundance of lianas and the dense, almost impenetrable forest crown are clearly shown in this side view of a tropical rainforest in Brazil. Undergrowth is not unusually conspicuous. (*Courtesy of Field Museum of Natural History.*)

forest, because of deep shade, undergrowth is not extremely dense. However, it is often sufficient to obstruct distant views. In regions of deepest shade, only a thick mat of herbs or ferns covers the floor, so that one can proceed in all directions without following paths or even chopping new ones. Typical *jungle* conditions, with a thick and impenetrable undergrowth, chiefly

branches of tropical trees and spread their roots among the cracks in the bark. They frequently have hanging roots. *Parasites* are plants that feed from the sap of the tree on which they grow.

are characteristic of sections where light reaches the forest floor. Such, for example, may be observed along rivers and coasts, on steep wet slopes, and in abandoned agricultural clearings (Fig. 305). Largely because of the abundant moisture in the surface soil, tropical rainforest trees are shallow rooted, their great trunks commonly being held upright by giant supporting roots.

Animal life of the tropical rainforest varies in kind and abundance from one region to another. In the crown of the forest,



FIG. 307.—Interior view of the tropical rainforest in the Belgian Congo. The time required for this photograph was twenty thousand times the normal exposure in the open. Undergrowth appears to be more dense than in Fig. 306. (*Courtesy of American Geographical Society.*)

where there is an abundance of food, a great variety of birds and some climbing animals, such as monkeys and apes, exist. On the darkened floor below, large animals usually are not numerous. However, in Africa, the hippopotamus inhabits the river margins, and elephants, giraffes, and the big catlike animals may penetrate the forest for some distance. Snakes and other amphibians are relatively abundant.

It is chiefly in insect life that the tropical forest abounds. The hum and sing of insects are ever present. Ants are numbered in billions. Termites, a kind of destructive woodworm, are likewise abundant. Not only in the tropical forest but throughout

most poorly drained areas in the low latitudes are to be found parasitic disease-carrying insects. Some of them are dangerous alike to man and animals. Yellow fever, sleeping sickness, and malaria, dreaded diseases of the tropics, are all transmitted to man through the bites of insects.

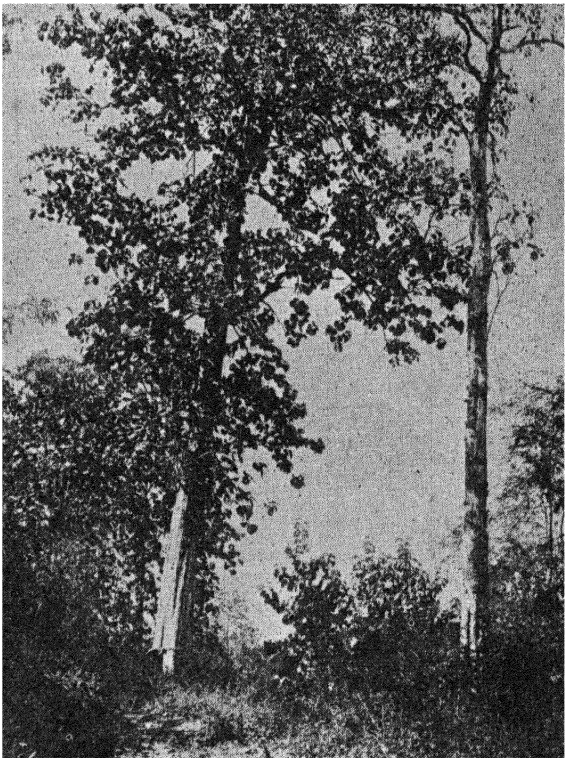


FIG. 308.—Teak trees, like the large Burmese tree to the left in this picture, grow in tropical forest regions. (*Courtesy of U.S. Forest Service.*)

Lighter Tropical Forest. This forest has temperature requirements similar to those of the tropical rainforest. It occupies, however, regions of less rainfall or, more typically, regions where there is a distinct, but short, dry season. Relatively large areas of this forest type are found in southeastern Asia and often are designated as *monsoon forests* (Fig. 308). A somewhat similar type, the *savanna forest*, occupies transitional belts between tropical rainforest and the drier, true savannas (Fig. 309). Trees are more widely spaced and are mainly broad-

leaf deciduous in character. Tall bamboo thickets are common in the monsoon forests.

Valuable Tropical Trees. Brief mention is here made of a few valuable tropical trees. The wild *rubber* tree was first discovered in the rainforest of Amazonia. It has since been planted in a number of localities in the humid tropics. Extensive areas devoted to rubber-tree plantations are found especially in the Malay Peninsula and East Indies and to a lesser extent in parts of Brazil and west central Africa.

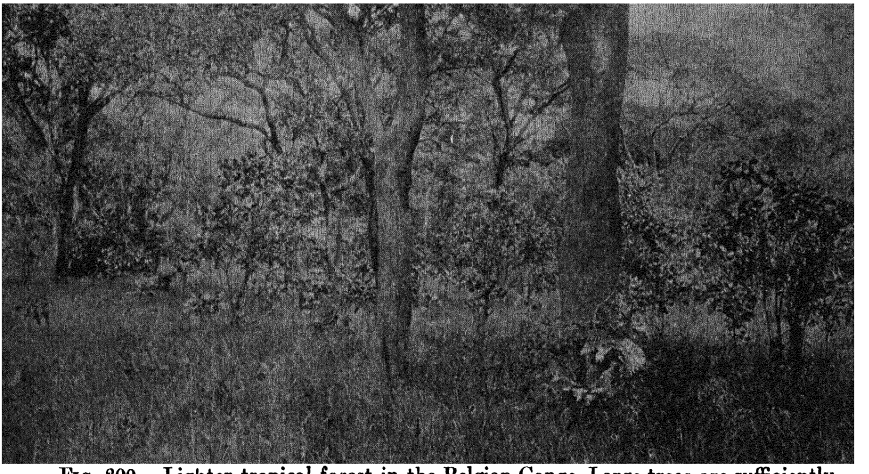


FIG. 309.—Lighter tropical forest in the Belgian Congo. Large trees are sufficiently far apart so that they do not cast a dense shade. Grass mantles the forest floor. (*Courtesy of American Geographical Society.*)

The *banana* tree is produced on a large scale especially in hot, humid coastal lowlands of the tropics. Honduras and Jamaica are leading exporters of bananas.

Chicle is a gummy substance made from the juice of a tropical tree found in Central and South America. It is an important export from Guatemala. It is treated, flavored, and put on the market as the familiar chewing gum.

The bark of the *cinchona* tree is the source of *quinine*, a valuable drug. Java, Colombia, and Ecuador are leading producers of cinchona bark.

Mahogany trees are found in certain parts of the American tropics. Much mahogany is exported from British Honduras. The trees characteristically are widely scattered in the forest. Great difficulty often is encountered in getting the trees to water,

where they can be floated to concentration points. This partially accounts for the relatively high price of mahogany lumber.

Near the southern edge of the tropics in South America, in the Gran Chaco of Paraguay and northern Argentina, is found the *quebracho* tree. This is a most important source of *tannin*, a substance needed in the treatment of hides of animals in the making of high-grade leather. Tannin is a principal export from Paraguay, much of it coming to the United States.

Teakwood (Fig. 308) is well known for its durability, especially in the building of ships. It is an important export from Burma and Siam. There are many other tropical woods and products of tropical trees besides those which we have mentioned.



FIG. 310.—This picture of Mediterranean woodland in California shows an open stand of dwarf oak merging with California grassland. (*Courtesy of U.S. Forest Service.*)

MIDDLE-LATITUDE FORESTS

Mediterranean Type. This is a relatively rare type of forest because it consists of broadleaf evergreens in a climate that has a summer drought. The trees have developed protective devices against rapid loss of water so that they retain their foliage even during the dry season. This unique Mediterranean woodland is found in subtropical regions with mild, rainy winters and long, dry, warm-to-hot summers. The largest representative area is the Mediterranean Sea borderlands, with smaller areas in California, middle Chile, southern Australia, and the Cape Town region of Africa.

Mediterranean woodland is mainly a mixed forest of low, or even stunted, trees and woody shrubs (Fig. 310). Tall trees are

rare. The virgin forest under the more favorable conditions of climate and soil is composed of low, widely spaced trees. The ground is completely or partially covered with a pale, dusty bush vegetation. As a protection against evaporation, the tree trunks are encased in a thick bark. The cork oak of Spain and Portugal has an unusually thick bark which is peeled from the tree, moistened, and flattened out. It is then cut into many forms of cork and sold throughout the world. In addition to a thick bark,

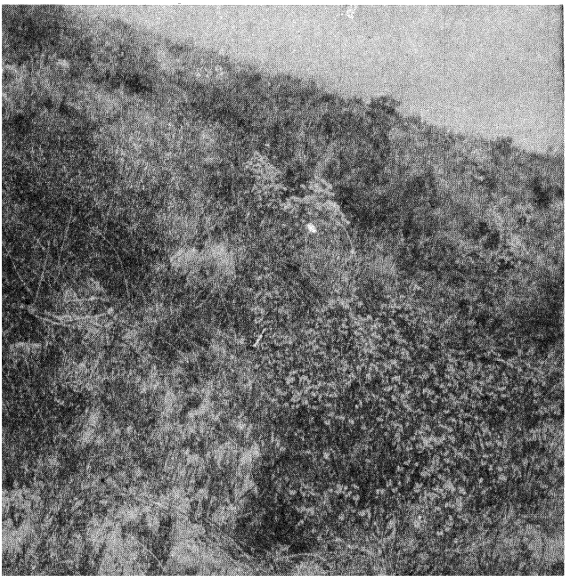


FIG. 311.—Mediterranean chaparral in Cape Province, South Africa. (*Courtesy of American Geographical Society.*)

the trees of Mediterranean woodlands develop leaves that are small, thick, and leathery, with hard surfaces. The olive tree, with its massive trunk, gnarled branches, thick bark, and small, stiff, leathery leaves is very representative of the Mediterranean type of tree.

Even more common than the woodland composed of low trees and shrubs described above is a vegetation mantle consisting principally of shrubs and bushes in which there may be some stunted trees (Fig. 311). In California this bush thicket is known as *chaparral.*

Broadleaf, or Hardwood, Forests. Within the more humid parts of the middle latitudes are found two great forest groups:

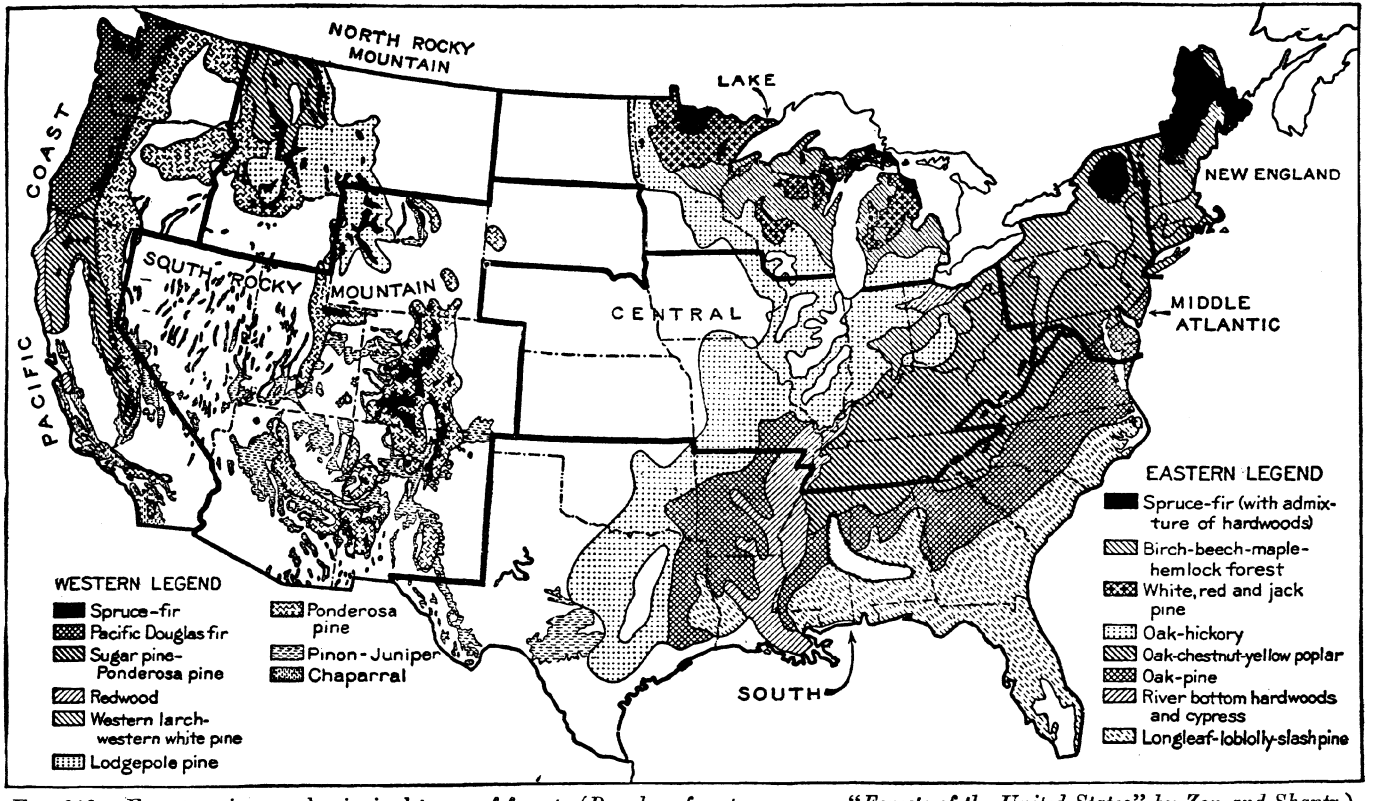


FIG. 312.—Forest regions and principal types of forest. (*Based on forest cover map "Forests of the United States" by Zon and Shantz.*)

(1) the broadleaf trees, or hardwoods, and (2) the needle-leaf conifers, or softwoods. Over large areas they exist as mixed conifer-broadleaf forests.

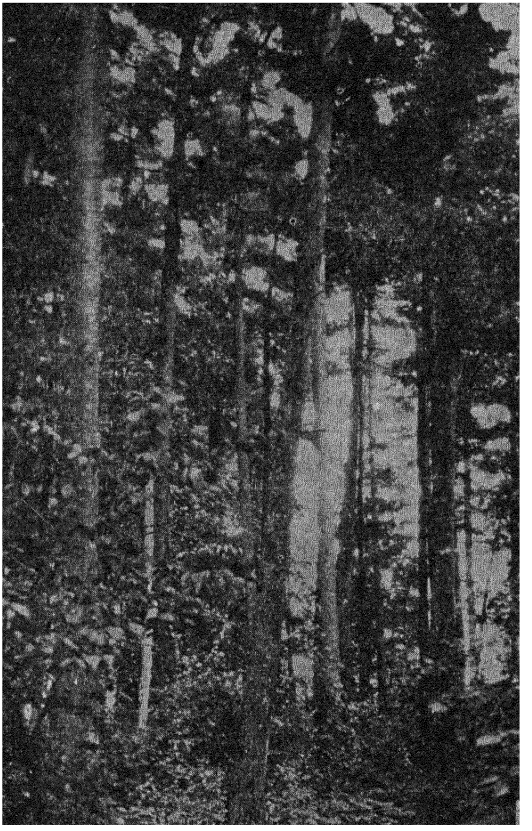


FIG. 313.—Mixed hardwood-conifer forest (birch, beech, maple, and hemlock) in Michigan. Much of this type of forest occupied lands not well suited to agriculture, so that its removal has resulted in extensive areas of relatively barren, desolate, cut-over land. (*Courtesy of U.S. Forest Service.*)

Temperate hardwood forests vary widely in composition. In the eastern half of the United States two general hardwood-forest areas are distinguished (Fig. 312), as follows:

1. *The northeast area* in northern Wisconsin and Michigan, New York, and southern New England. Principal trees—birch, beech, and maple, but with a large number of hemlock and other conifers (Fig. 313).

2. *The central and southern area* extending from Pennsylvania to Missouri and Arkansas. Principal trees—oak, hickory, chestnut, and poplar (Fig. 314). This was originally the finest and most extensive area of hardwoods anywhere in the world. Much of the forest was removed years ago when land was being cleared for agricultural use. The remaining stand of trees, however, continues to provide a good supply of lumber for



FIG. 314.—A mixed hardwood forest (oak, hickory) in northern Indiana. Much of this type of forest occupied good agricultural land and as a consequence was destroyed in the process of settlement. (*Courtesy of U.S. Department of Agriculture.*)

furniture manufacturing. Some of the more beautiful woods are becoming scarce, therefore more expensive. Such, for example, is the walnut. As a result, much furniture is constructed of cheaper wood which has a thin veneer, or covering, of walnut glued on the outside. In this great region, fairly extensive areas of virgin forest still remain, particularly in the rougher Appalachian country and in Tennessee, Kentucky, Missouri, and Arkansas. Much of this timberland has been set aside as national forests. By far the greater part of the

forest is deciduous in character, the trees dropping their leaves during the winter season.

Outside the United States, other relatively large areas of temperate hardwoods or mixed forests are to be found in Japan, Chosen, southeastern China, central Russia, southwestern Siberia, western Europe, southern Chile, southeastern Australia, and New Zealand.

Coniferous, or Softwood, Forests. Coniferous trees are almost exclusively evergreen. The addition and fall of needles

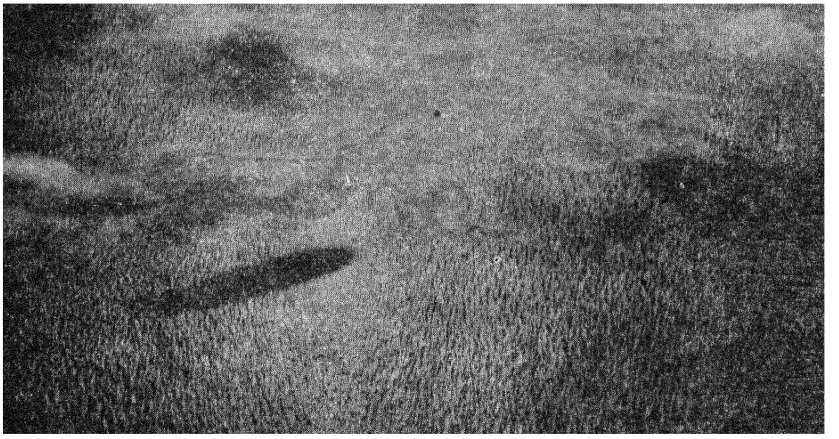


FIG. 315.—Air view of the swamp taiga of western Siberia. This region did not suffer glaciation. (*Courtesy of American Geographical Society of New York, photograph by Luftschiffbau Zeppelin.*)

is a continuous process and not confined to any particular period or season. Unlike broad leaves, however, the needles of conifers are drought resistant, so that shedding is not necessary to protect against a cold or dry season. In general, soils that develop under coniferous forests are not so fertile as those of the broadleaf hardwoods.

The subarctic belt of conifers is noted for its great area. It extends across northern Canada and northern Eurasia. The name *taiga* (*tī'-ga*) has been given to this region (Fig. 315). The northern edge of the taiga, in the neighborhood of the Arctic Circle, blends into the treeless tundra, a region thoroughly hostile to tree growth. The Eurasian taiga forms the single largest continuous forest area on earth. Conifers such as larch,

spruce, fir, and pine predominate, although there is a scattering of deciduous trees. In these regions of long, cold, dry winters and short, cool summers trees are relatively small in size, usually not over $1\frac{1}{4}$ feet in diameter, and growth is slow (Fig. 316). On the shaded forest floor, vegetation is meager, mosses and lichens being the most common plant forms. Little humus, which is decayed vegetation, is made available to the soil, because

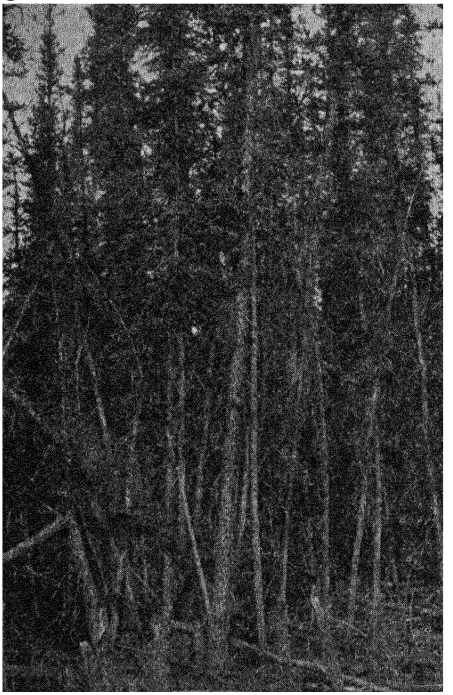


FIG. 316.—Side view of the taiga in Yukon, Canada. Note the relative smallness of the trees. (*Courtesy of U.S. Forest Service.*)

needle leaves are a poor source of humus. In addition, the low temperatures and deep shade act to retard decomposition and to discourage the activity of soil fauna, especially earthworms.

Animal life is not so abundant as in the middle-latitude forests farther south. However, many fur-bearing animals inhabit the taiga, and trapping is an important occupation. The long-continued cold tends to make for heavy pelts. Wolf, bear, fox, otter, mink, ermine, squirrel, lynx, and sable are representative animals.

In the lower middle latitudes are other areas of needle trees which are more valuable as a timber resource than the taiga. This is because the trees are larger, produce a better quality of wood,

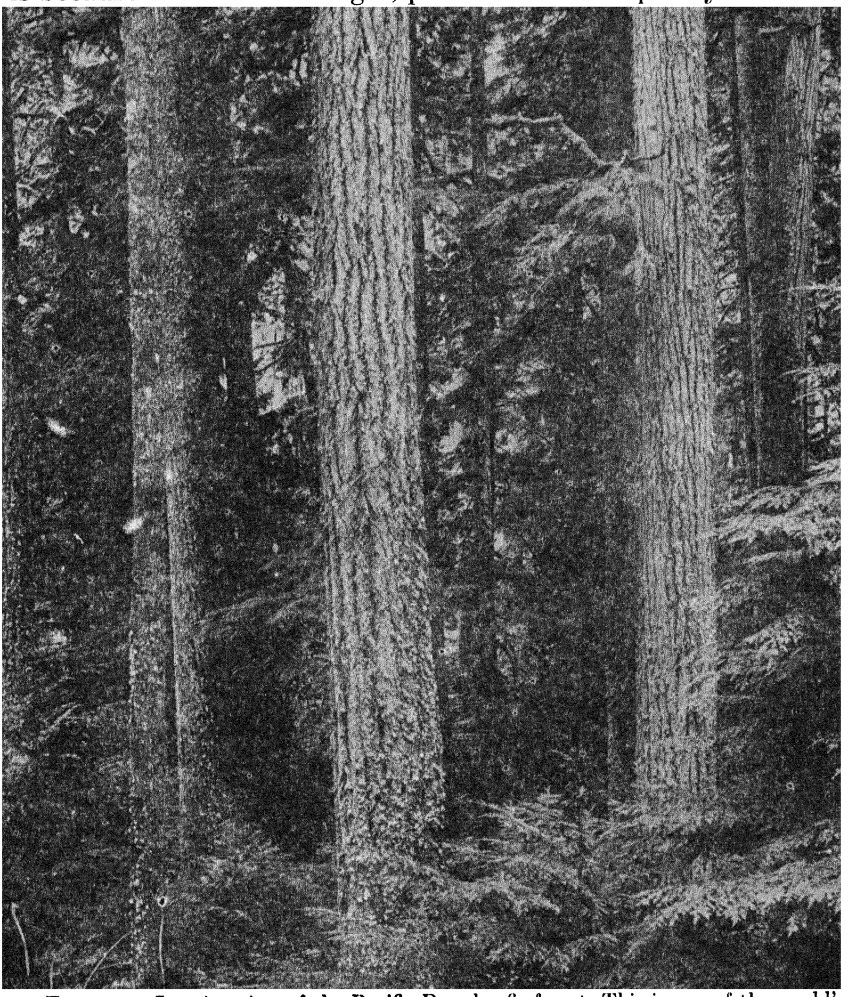
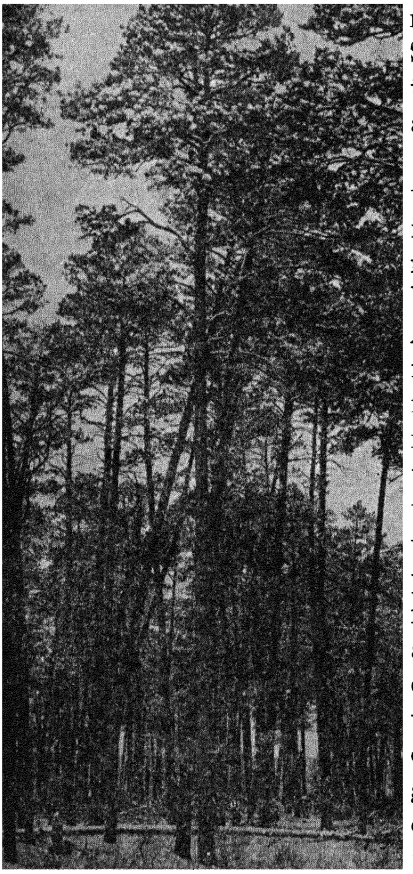


FIG. 317.—Interior view of the Pacific Douglas fir forest. This is one of the world's finest softwood forests. Trees are of large size, and the stand is dense. (*Courtesy of U.S. Forest Service.*)

and are more accessible. In western North America, broken belts of conifers extend southward from the taiga. They follow the rainier highland chains of the Pacific Coast mountains and the Rocky Mountains to beyond the Mexican border. The rainy slopes of the Coastal Ranges, Cascades, and Sierras support

magnificent forests. At present the state of Washington ranks first in lumber production. Among the finer timber trees in Washington and Oregon is the Douglas fir (Fig. 317). Farther south in the Coastal Ranges of northern California are the great redwood forests, and in the Sierras of central California is the giant sequoia, the largest of all trees (Fig. 304).



Norway and jack pines in northern Minnesota is representative of the northeastern pine forest of jack, red, and white pines. (*Courtesy of U.S. Department of Agriculture.*)

Another area of conifers extends southward from the taiga into southeastern Canada; the northern portions of Minnesota, Wisconsin, and Michigan; the Adirondacks in New York; and much of Maine (Fig. 318). This region is outstanding at present for its tremendous production of woodpulp used in the manufacture of paper. The most valuable timber trees, especially white pine, have been cut from this forest, leaving behind extensive areas of waste and cut-over land of little value. Many writers cite this region as a glaring example of the ruthless destruction of a great natural resource, with little effort being made in the way of replenishing the supply.

South of the taiga, in Eurasia, valuable coniferous forests occupy the slopes of the Alps, Carpathians, and other highland regions as well as certain sandy areas of coastal plains.

Separated from this northern belt of conifers by extensive broadleaf forests is the southern pine forest of the United States. It occupies the Atlantic and Gulf Coastal Plain. It is composed of 10 different species of pine of which the longleaf is most abundant (Fig. 319). Climatically this needle-tree forest seems

somewhat out of place, for rainfall is abundant, and the growing season long. However, the poor, sandy soil and high evaporation are offsetting factors, creating an environment that is generally hostile to broadleaf varieties. Open parklike character, with the ground covered by a mantle of coarse grasses or low shrubs, is typical. The southern pine forest has, during the last few decades, been one of the principal sources of American lumber, although the peak of its production has been passed. Extensive areas of nearly worthless cut-over land are now one of the most con-



FIG. 319.—The southern pine forest (longleaf, loblolly, and slash pines) of the United States is typical of the Atlantic and Gulf Coastal Plain. (*Courtesy of U.S. Forest Service.*)

spicuous features of the southern-pine region. In recent years, however, considerable areas have been planted to a fast-growing pine which can be utilized in the manufacture of paper.

On the poorly drained floodplains of rivers, pines give way to a contrasting forest type composed of such trees as tupelo, red gum, and cypress. As a source of lumber the Southern states rank high in the production of yellow pine, cypress, and gum. An important industry is the distilling of resin to obtain turpentine and rosin, which together are called *naval stores* (Fig. 320). The resin is secured by tapping certain of the pine trees, much as rubber trees are tapped for the valuable latex. On storage docks at Mobile, Pensacola, Savannah, and Charleston one may

observe thousands of barrels of naval stores awaiting shipment on ocean freighters.

Conservation of Forests. It is to be regretted that the early lumbermen ruthlessly destroyed great forests of fine timber and gave little thought to replenishing the supply. In their haste to



FIG. 320. –This pine tree has been cut so that the resin from which turpentine is distilled will exude. The gum collects in the smaller cup and is then poured into the hand barrel. (*Courtesy of U.S. Forest Service.*)

cut the big trees they ruined many of the smaller ones. In the past, and even in recent years, people have been too careless about putting out campfires and cigarettes, with the result that disastrous forest fires have ruined thousands of square miles of fine trees (Fig. 321). Today, however, much attention is being given to our forest lands. Federal and state governments regard conservation as of vital importance. With respect to forests, work is being done along the following lines:

1. Reforestation, involving the actual planting of trees where it seems advisable (Figs. 322, 323).
2. Protection against forest fires
3. Improved logging operations (Fig. 324)
4. Improved milling operations

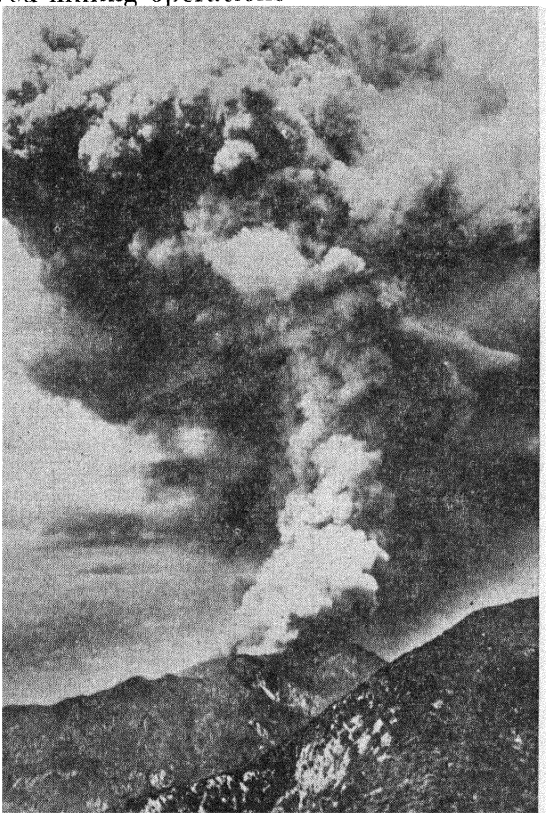


FIG. 321.—Forest fire on Echo Mountain, California. This picture was taken 10 minutes after the fire started. (*Courtesy of U.S. Forest Service.*)

5. Study of methods of controlling tree diseases
6. Establishing of state and national forests under the supervision of trained men

Types of Grasslands and Their Distribution

Tropical Grasslands: Savanna and Steppe. Savannas dominantly are composed of tall and unusually coarse grasses growing in tufts, the latter separated by intervals of bare soil. They spring up rapidly at the beginning of the rainy season and may,



FIG. 322.—Reforestation in Coeur d'Alene National Forest, northern Idaho. Civilian Conservation Corps workers are planting small trees on the slopes near the Coeur d'Alene River. This part of the forest suffered from a bad fire in 1931. (*Courtesy of U.S. Forest Service.*)



FIG. 323.—Reforestation in Lolo National Forest, Montana. The yellow pine seedlings, 15 years old, stand among the blackened trunks of larger trees ruined by a forest fire. (*Courtesy of U.S. Forest Service.*)

within a few months, reach heights of 4 to 12 feet (Figs. 325, 326). Seldom do savannas have the refreshing tints of humid meadows but instead are dull green in color with yellowish and brownish tints. Blades are stiff and harsh, especially when dry. In the drought season the grasses become dry and brown so that they burn readily. Among the natives it is a common practice to burn off the old grasses in order to make way for new growth

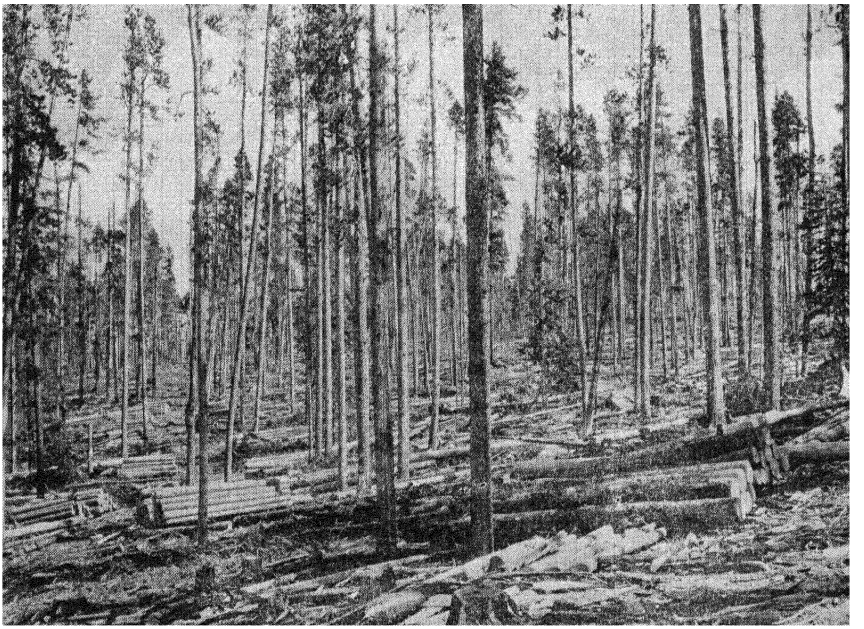


FIG. 324.—This picture, taken in the Medicine Bow National Forest, Wyoming, illustrates proper methods of cutting timber. (*Courtesy of U.S. Forest Service.*)

at the beginning of the rains. Shrubs and low trees usually are present in the wetter parts of the savanna.

Tropical grasslands were originally inhabited by a great variety of grazing animals such as antelope, zebra, gazelle, and giraffe, together with many carnivorous animals, including the lion, hyena, leopard, and cheetah. All these have suffered greatly, however, at the hands of hunters.

Middle-latitude Grasslands: Prairie and Steppe. Middle-latitude grasslands are composed of finer and usually shorter grasses than those of tropical savannas. Two principal sub-



FIG. 325.—The tall, coarse grasses of the African savanna north of the equator grow about 8 feet tall, which brings them well into the lower branches of the small trees. (*Courtesy of American Geographical Society.*)



FIG. 326.—Tall-grass savanna [illegible] Colony, Africa. Flat-topped acacia trees dot the grassland. (*Courtesy of American Geographical Society.*)

divisions are recognized: (1) the tall-grass prairies and (2) the short-grass and bunch-grass steppes.

The *prairie* is dominated by tall, luxuriant, and relatively deep-rooted grasses (Fig. 327). Usually a large variety of showy, flowering plants is intermingled with the grasses, so that in the spring the original American prairies had the appearance of a colorful flower garden. Over most prairie regions the annual rainfall varies between 20 and 40 inches, the principal supply coming during the summer season. Where rainfall is less than



FIG. 327.—Tall-grass prairie in the region of the sand hills of western Nebraska. (*Courtesy of U.S. Forest Service.*)

about 20 inches, so that the depth of moist soil is under 2 feet, short grasses of the steppe type replace the prairie grass. Where the depth of moist soil is greater than about 30 inches, the tall grasses flourish. The earth's principal regions of original tall grasses are: (1) parts of central United States and the prairie provinces of Canada; (2) the Argentine Pampa, Uruguay, and southeastern Brazil; (3) parts of southern Russia; (4) the plains of the Danube in Hungary and Rumania; and (5) possibly parts of North China and Manchuria. In most of the prairie regions the original vegetation has been destroyed through bringing the land under cultivation.

The *steppe*, composed of shorter, shallow-rooted grasses is typical of semiarid regions where, as indicated above, the depth of moist soil is usually less than 2 feet. In dry years

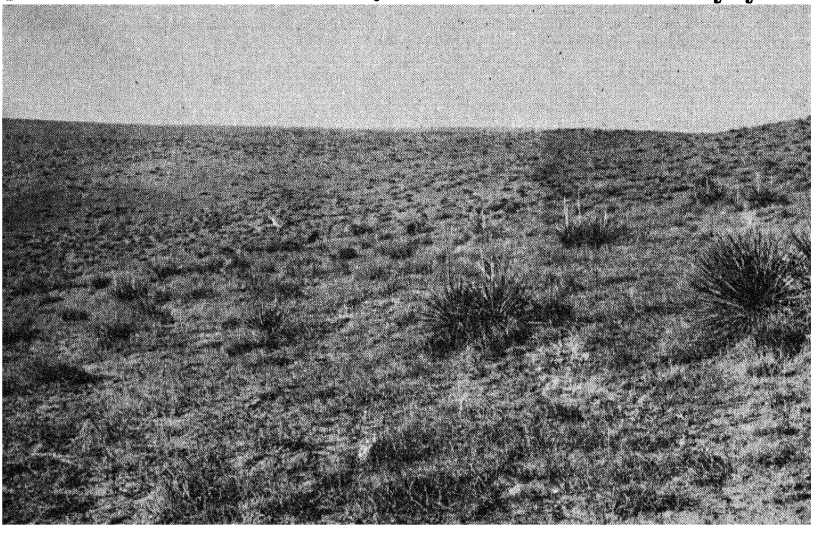


FIG. 328.—Short-grass steppe in Colorado. (*Courtesy of U.S. Forest Service.*)

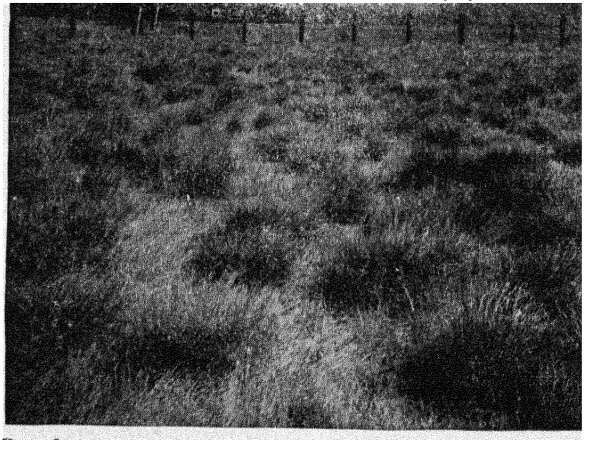


FIG. 329.—Bunch grass, Oregon. (*Courtesy of U.S. Department of Agriculture.*)

the steppe has the uniform appearance of an endless carpet. In wetter years there is greater variation, owing to the growth of taller plants on the short-grass sod. Within the United States two subdivisions of steppe are recognized: (1) short grass and (2) bunch grass. Short grass is characteristic of the Great Plains which lie east of the Rocky Mountains and, for the most

part, west of the 100th meridian. There the meager rainfall is concentrated in late spring and early summer or just preceding and during the growing season (Fig. 328). Bunch grass occupies regions with about the same amount of precipitation as does the short grass but where it is not so much confined to the warm season (Fig. 329). It is characteristic of regions west of the Rocky Mountains, particularly in California, Washington, Oregon, Idaho, and western Montana. Large parts of the middle latitude's short-grass and bunch-grass regions, although unplowed, have been overgrazed to the extent that weedy plants have taken the place of the original vegetation. Great herds of bison once inhabited the American grasslands, but ruthless slaughter has almost exterminated them.

Conservation of Grasslands. In the United States, measures are being taken to conserve and improve the short-grass regions of the Western states. Such conservation involves

1. Prevention of overgrazing
2. Reseeding and protection of areas already overgrazed
3. Restrictions on the plowing of virgin sod
4. Community cooperation in fighting grass fires
5. Irrigation

Once the sod of grasslands in semiarid regions is broken by the plow, then the dry topsoil is whipped up by the wind and carried away. Thus in recent years thousands of people have witnessed great dust storms in the Western and Midwestern states. Disastrous soil erosion or removal results not only from high winds but also from occasional rains which wash away some of the topsoil. It seems, therefore, that a wise course of procedure would be to preserve the native grasslands for the grazing of livestock and to be careful not to overgraze.

Desert Shrub and Tundra

"Dry" Deserts. Some few deserts or parts of deserts are extensive areas of rocky plain or sand and almost wholly without plant life. This is the exception rather than the rule. Most arid regions of both low and middle latitudes have *some* vegetation even though it is sparse. It may be low bunch grass, widely spaced and with bushes, or in places fleshy water-storing plants, such as cacti. Much more commonly it is perennial drought-

resistant shrub. In the United States this latter type of vegetation predominates over a large part of the area west of the Rockies, interrupted here and there by bunch grass or by forests at higher elevations. Annual rainfall over much of this region is under 12 inches.

The perennial shrubs of desert areas grow far apart, with much bare soil showing between (Fig. 330). This wide spacing is a response to low rainfall. Growth is very slow. Desert shrubs,

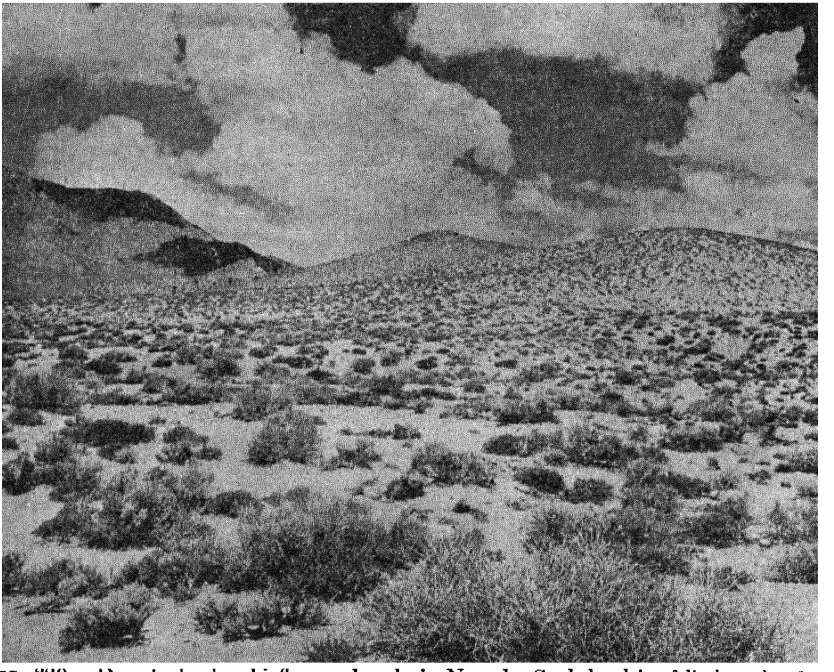


FIG. 330.—Desert shrub, chiefly sagebrush, in Nevada. Such land is of little value for grazing. (*Photograph by John C. Weaver.*)

such as the American sagebrush and creosote bush, are equipped through special forms of roots, stems, and leaves to withstand drought. Some are deciduous; others, evergreen in character. Certain desert plants bear flowers of brilliant color. In contrast to the scanty, low, pale-green vegetation of the desert proper is the verdant color of luxuriant vegetation around oases where water is abundant. Almost knife-edge boundaries frequently separate the two.

Desert vegetation is of importance in several ways, two of which may be mentioned. (1) It tends to retard the shifting

about by winds of desert soils and sand. (2) It provides a source of food, especially for such animals as sheep, goats, and camels. However, the food supply in any one place usually is so scanty that some desert peoples are nomadic; *i.e.*, they move from place to place. Such conditions contribute to the sparse populations of deserts. The large state of Nevada, for example, has less than one person per square mile, whereas Massachusetts has over 500.

Tundra, or Cold Deserts. Genuine tundra is composed largely of such lowly forms as mosses, lichens, and sedges, the whole incompletely covering the ground. In places there is much

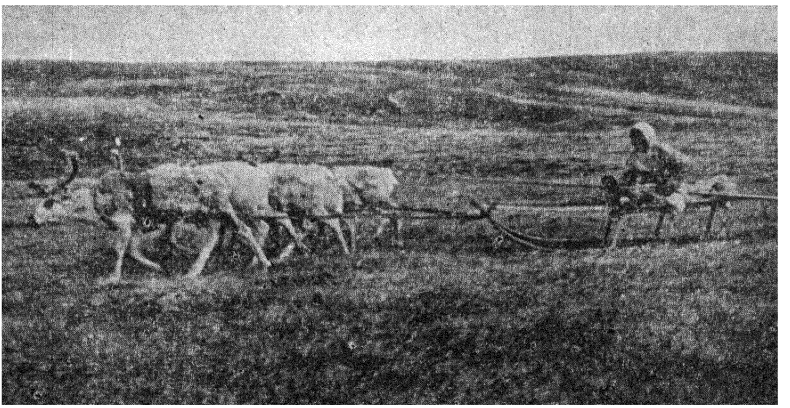


FIG. 331.—Moss tundra in summer along the lower Yenisei River in western Siberia. (*Courtesy of Geographical Review, published by the American Geographical Society of New York, photograph by H. U. Hall.*)

bare, stony soil with only the most meager plant life. On the southern margins of the tundra, where it merges into the taiga, or coniferous forest, vegetation cover is more complete. Most tundra plants appear drought resistant, having stiff, hard, leathery leaves. As a result of the short period between frosts, the vegetative period in the tundra is reduced to 2 months or less. For this reason plants are compelled to hurry through their vegetative cycle, and even then many of them are frozen while still in flower or fruit.

To animals as well as to plants, tundra is inhospitable. Bird life is largely migratory, inhabiting these regions principally in summer and wintering farther south. Large, predatory,

carnivorous animals, such as bears, wolves, and foxes, fare badly in winter, being usually in the extremity of famine and reaching spring in an emaciated condition. Reindeer, or caribou, and musk ox are the two largest and most valuable of the herbivorous tundra animals (Fig. 331). Siberian tribes never feed their reindeer but compel them to forage for their food even in winter. Mosquitoes and stinging flies are thick in summer, these being among the principal torments of man and animals, forcing them to seek higher and drier sites. Animals of the tundra do not hibernate. The smaller forms, such as hares, foxes, and wolves, make their winter quarters underneath the snow where temperatures are not severe. Seal, walrus, and polar bears inhabit the coastal margins or the drift ice, where they feed chiefly on marine life.

It should be noted that vegetation of the tundra is of *some* value in that it provides a source of food especially for such animals as reindeer and musk ox. These animals in turn are of great value to Eskimos who inhabit the coastal regions in some parts of the tundra. One should not get the idea that tundra is characteristic of all polar regions. Over most of Greenland and much of Antarctica, for example, there exist the great icecaps which are practically devoid of both plant and animal life.

Resources of the Sea

Plant Life. Plant life in the seas is largely confined to those parts where light is relatively abundant. Such are (1) the shallow coastal waters and (2) the surface waters in general. Fixed or rooted plants are practically restricted to shallow waters close to land. Microscopic plant life, on the other hand, makes up a considerable part of the mass of floating organic substance called *plankton*. These microscopic plants at the surface of the ocean are the principal basis of sea life. Upon them myriads of small sea animals, such as Crustacea, feed, and they in turn are the most important source of food for fish. Thus the plankton mass, composed of tiny plant and animal forms, is the principal reservoir of fish food. On the whole it is most abundant in coastal waters.

Edible Fish. The greatest resource of the oceans is edible fish, and yet the world's annual catch, amounting roughly to

700 million dollars, ordinarily does not equal the value of the American corn, cotton, hay, or wheat crop. Most of the world's fishing is done along the margins of continents in waters whose depths are less than 200 fathoms, or 1,200 feet.[1] This concentration of fish in shallow coastal waters is due largely to an abundant food supply furnished by (1) floating plankton, (2) rivers entering the sea, and (3) rooted algae in the shoal waters near shore. Commercial fishing grounds of importance are, in general, outside the tropics and in the Northern Hemisphere. There are more species of fish in tropical waters than in higher latitudes, yet there is a lack of concentration of vast numbers of desirable food fish within relatively small areas.

Organized commercial fishing on a large scale is concentrated in four regions: (1) the coastal lands of Japan, Sakhalin, and eastern Siberia; (2) those of New England, eastern Canada, and Newfoundland; (3) the coasts of northwestern Europe; and (4) the Pacific Coast of northwestern United States, Canada, and Alaska.

The coastal waters from Cape Cod to Newfoundland are the world's greatest cod fisheries. Herring, mackerel, haddock, and halibut are a few of the other commercially valuable fish of this region. The most valuable of all canned fish is the salmon, caught in coastal waters and streams from Washington to Alaska. Huge quantities of fish are taken from the banks of the North Sea by skilled fishermen from Norway and the British Isles. Stavanger, Norway, for example, is noted for its exports of sardines.

Sea Mammals. In addition to edible fish, other sea animals, such as seal, walrus, and whale, are valuable for their skins, oil, bone, ivory, or flesh. Without exception, each of these animals has been the object of ruthless slaughter. This has led to serious reduction in numbers. In some instances the animals have been almost exterminated. Especially were fur seals killed by the thousands. Today they are protected by international agreement. For example, seal herds that inhabit the Pribilof Islands in the Bering Sea are under the protection of the United States government.

[1] The term *banks* is applied to the shallow water of coastal margins. In some banks of the North Sea the water is less than 100 feet deep.

A native of shallow coastal arctic waters and sought for its ivory and tough hide, the walrus has suffered the same fate as the seal. Whales inhabit the North Atlantic, North Pacific, Arctic, and Antarctic seas. Their particular value is for oil and whalebone, but the significance of these products has declined as cheaper substitutes have been made available. In the arctic seas, whales have been so greatly reduced in numbers that the whaling industry has all but disappeared. Formerly, all these animals furnished one of the principal sources of food for the natives who occupied the arctic coasts.

Summary

Three principal classes of natural vegetation are (1) forests, (2) grasslands, and (3) desert shrub, including tundra. In general, forests are found in humid lands; grasslands, in subhumid or semiarid; and desert shrub, in the dry lands. The tropical rainforest contains many kinds of trees, but it seldom has a large stand of one species.

In the intermediate zones the softwood evergreens are represented by such trees as the pine, cedar, fir, and spruce; the hardwood deciduous trees, by the oak, maple, walnut, and hickory.

Forest conservation involves especially reforestation and the prevention of forest fires. Forests check soil erosion and retard the immediate runoff of rain water.

Grasslands consist mainly of two types: the savanna and the steppe. In the middle latitudes the prairies consist of tall grasses; the steppes, of short grasses. Grassland conservation is necessary to preserve permanent grazing lands and to check soil erosion.

Desert shrub provides meager food for goats, sheep, and camels. The tundra is valuable as a food resource for reindeer and musk ox.

Fish constitute the most valuable food resource of the sea. The principal fishing grounds are the North Sea region, the Newfoundland banks, and the Sakhalin waters.

Questions

1. Mention three important phases in a planned program of conservation.

2. What elements of environment affect native vegetation?

3. Define annual and perennial plants. Give examples.

4. Mention several characteristics of water plants and drought, resistant plants. Give examples.

5. Name the three principal classes of natural vegetation.

6. Explain what is meant by a genuine forest.

7. How are trees classified?

8. Briefly describe a good forest climate.

9. Climatically, grasslands are typical of what regions?

10. Explain the two types of deserts as far as plant life is concerned. Give examples.

11. Locate the largest areas of tropical rainforest.

12. What is true of the rainforest with respect to number of species of plants? Large areas occupied almost exclusively by one species of tree?

13. Mention a few characteristics of the rainforest.

14. Describe the typical jungle. Where is it found?

15. What animal life is most abundant in the rainforest?

16. Why are certain tropical insects dangerous to man? Give examples.

17. Mention several valuable tropical trees.

18. What is one factor that accounts for the relatively high price of mahogany wood?

19. With regard to quebracho and teak, where are they found? Why is each valuable?

20. Describe the climate of Mediterranean woodlands.

21. Why is the Mediterranean said to be "a relatively rare type of forest"?

22. Locate the largest areas of Mediterranean woodland.

23. What characteristics of trees enable them to withstand the summer drought in Mediterranean regions?

24. Where is the cork oak found? Of what use is it?

25. What is chaparral?

26. Locate the two general hardwood areas in eastern United States.

27. Why is walnut and mahogany veneering an economical procedure?

28. Do evergreens shed their leaves? If so, is the shedding characteristic of any particular season?

29. Why are the needles of conifers drought resistant?

30. Locate the two greatest areas of taiga.

31. Where is the largest continuous forest area on earth? What are two handicaps of this forest as a source of lumber?

32. Why is little humus made available in most coniferous forests?

33. Name several fur-bearing animals of the taiga.

34. Which slopes of mountains in western United States are especially tree-covered? Why?

35. Which state ranks first in lumber production? What is the most valuable kind of tree in this region?

36. Note the United States map showing forest regions. In what states is the oak-hickory belt? The white, red, and jack pine? Douglas fir? Chaparral?

37. Mention several facts concerning the coniferous forest of northeastern United States and adjacent parts of Canada.

38. Locate the southern pine forest. Why is this forest said to be "climatically somewhat out of place"?

39. What lumber comes from the Southern states?

40. What are naval stores? How are they secured?

41. What steps are being taken to promote forest conservation?

42. Describe the savanna grassland. Why is the grass sometimes burned off during the dry season?

43. What animals are characteristic of the savanna?

44. What is the difference between prairie and steppe?

45. What is the average annual rainfall over prairie regions? Over steppes?

46. Name the two subdivisions of steppe lands in the United States. Where is each located?

47. What measures are being taken toward conservation of grasslands?

48. Mention two common American desert shrubs.

49. Locate and describe the tundra.

50. Why are plants in the tundra compelled to "hurry through their vegetative cycle"?

51. What animals inhabit the tundra?

52. What insects present a powerful blockade to human settlement in the tundra?

53. Of what does plankton consist? Its value?

54. Explain what is meant by fishing banks. What are some reasons why fish concentrate in such areas?

55. Why are commercial fishing grounds for the most part not located in the tropics?

56. Locate the four principal areas where commercial fishing is concentrated. Which is noted for cod?

57. Locate the Pribilof Islands. Why are they important?

58. The governments of the United States and Canada have given considerable aid to the natives of Alaska and northern Canada in the raising of large herds of caribou. Why has this been a wise policy?

Suggested Activities

1. Review the location of all places mentioned in this chapter.
2. Seek the cooperation of lumber companies in preparing an attractive display of the principal kinds of hardwoods and softwoods.
3. The *Journal of Forestry*, published by the Society of American Foresters, Washington, D.C., is an excellent source for interesting class reports on many of the topics covered in this chapter.
4. Write to the U.S. Forest Service and the U.S. Bureau of Fisheries for lists of publications for sale. Many of these publications can be secured at small cost and offer additional sources of information for class reports.
5. On a large wall outline map of North America, outline and color the principal forest regions.
6. If you live in a state where there are national or state forests, draw a large wall map of the state showing the location of these forests.
7. Make a list of common trees found in your community.
8. Review the location of savanna grasslands in Africa and South America. Discuss their relative values from the standpoint of agricultural usage.
9. Collect recent material on the conservation of natural resources from books and magazine articles. Individual reports on this subject may be put together in the form of a booklet, with illustrations.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Forest Conservation in the United States
2. World Distribution of Tropical Rainforest
3. The Rainforest of the Amazon Basin
4. The Rainforest of the Congo Basin
5. Animal Life in the Rainforest
6. Woodpulp and Paper Manufacturing in North America
7. The Cork Oak and Olive, Typical Mediterranean Trees
8. Lumbering in the Pacific States
9. Hardwoods and Their Uses
10. The Beneficial Effects of Forests with Regard to Soil Erosion and Floods
11. The Savannas as Grazing Lands
12. The Limitations of Agriculture in Steppe Regions

References

BRUERE, M. B.: *Taming Our Forests*, Forest Service, U.S. Department of Agriculture, Washington, D.C., 1938.

———: *What Forests Give*, Forest Service, U.S. Department of Agriculture, Washington, D. C., 1938.

CHASE, STUART: *Rich Land, Poor Land*, McGraw-Hill Book Company, Inc., New York, 1938.

GLOVER, KATHERINE: *America Begins Again*, McGraw-Hill Book Company, Inc., New York, 1939.

HAVILAND, MAUD D.: *Forest, Steppe, and Tundra*, Cambridge University Press, Cambridge, 1936.

Report on National Planning and Public Works in Relation to Natural Resources, National Resources Board, Government Printing Office, Washington, D.C., 1934.

WHITBECK, R. H., and V. C. FINCH: *Economic Geography*, McGraw-Hill Book Company, Inc., New York, 1941.

Chapter XVII. Soils

Of all the natural resources of the earth, soil and water are two of the most necessary to man's existence. Types of soil and the available water supply vary greatly in different geographical regions. Unlike air, soil may be exhausted by careless cropping methods or seriously damaged by the erosion of running water. Since animal life is dependent upon plant life, and plant life upon the soil, it is obvious that the welfare of mankind is closely associated with the maintenance of soil fertility.

Soil is composed of *inorganic* (mineral) and *organic* substances. A given soil was not created in the beginning exactly as it is now but is the product of development, or evolution. It evolved from the parent material, or mantle rock, by the slow processes of weathering, accompanied by the growth and influence of living organisms. The organisms concerned include higher animals, earthworms, abundant forms of microscopic life, and many kinds of natural vegetation. The remains of vegetation have been deposited upon and within the surface soils for thousands of years. For this reason, soil is considered to extend downward only so far as abundant organic life penetrates, generally not more than 5 to 8 feet. Below the soil, whatever its thickness, is the parent material of the soil, and below that is solid rock.

Parent Material. Soils differ in the processes by which their parent material was accumulated. This is shown by the following outline:

1. *Transported soils*

a. Alluvial soils (These are the soils whose parent material, *alluvium*, has been transported and deposited by water. They are found in regions such as floodplains, deltas, and alluvial fans.)

b. Glacial soils (These have been transported and deposited by moving ice. Such are abundant, for example, in certain regions covered by glacial moraines.)

c. Eolian soils (These are transported and deposited by the wind. During a single dust storm, winds carry thousands of tons of soil from one place to another. The deposits of *loess* along the Missouri and Mississippi rivers and in eastern Nebraska are examples of eolian soils.) (Fig. 332.)

2. *Residual soils* (These soils have *not* been moved about but are derived from parent material formed by the weathering of bedrock immediately beneath. Two examples are the heavy



FIG. 332.—A recent road-cut through a loess hill in the prairie region of eastern Nebraska. Loess has a brownish-yellow or buff color and stands in almost vertical walls.

clay soils formed from shale and the soils high in sand content formed from the weathering of sandstone.)

Composition of the Soil. The principal ingredients of a soil are (1) mineral substances, (2) organic compounds, (3) living organisms, (4) water, and (5) air. The bulk of most soils is made up of earth minerals. These minerals supply many of the chemical elements (about 15) required for the proper growth of plants. The more abundant elements in most soils are oxygen, silicon, aluminum, and iron. Some elements are secured by plants directly from the atmosphere. The larger number, however, are taken in solution through the root system. A soil that is deficient in soluble, or easily dissolved, mineral matter is a poor soil. Some elements are plentiful in most soils; others

are likely to be less abundant. Especially is this true of calcium, nitrogen, phosphorus, and potassium. These four are most necessary to the growth of plants and constitute the principal mineral elements in most commercial fertilizers.

Calcium is present in the earth's crust especially in the form of limestone. It is necessary, however, for the calcium carbonate of limestone to be dissolved before it can be used by plants. Nitrogen is essential to the growth of most plants,

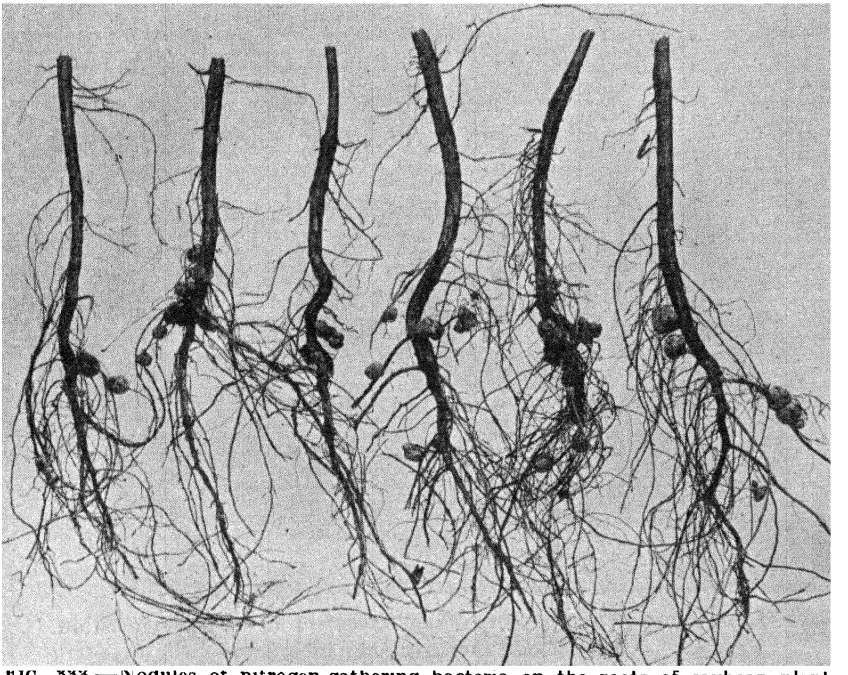


FIG. 333.—Nodules of nitrogen-gathering bacteria on the roots of soybean plants. (*Courtesy of Missouri College of Agriculture.*)

and they quickly show a deficiency of it by poor growth. There is an inexhaustible supply of nitrogen in the air, but that is not directly available to plants, which must take it from the soil in solution. It is made available in the soil in the form of soluble nitrates largely through the work of microscopic organisms. In this connection the legumes, such as clovers, alfalfa, soybeans, and peas, are of tremendous value. On the roots of these plants are colonies, or nodules, of bacteria (Fig. 333). These bacteria have the power of absorbing nitrogen from the air. The nitrogen is transformed in such a way that it is passed on

to the plant on which the bacteria are growing. Therefore, when a legume is plowed under, it adds not only vegetable matter to the soil but also considerable nitrogen. Even though the top part of the plant is not plowed under, the root system adds some nitrogen to the soil.

Phosphorus and potassium occur in certain rocks and minerals but not always in a soluble form. Valuable deposits of phosphate rock, used in commercial fertilizers, are found in Florida and Tennessee. For many years the potash deposits of



FIG. 334.—Lime is spread over a plowed field to correct an acid soil condition. (*Courtesy of Soil Conservation Service.*)

Germany have furnished the principal supply of potassium. In the United States, considerable potash is being mined in the vicinity of Carlsbad, N.M.

The maintenance of soil fertility is an ever present and vitally important problem. The use of commercial fertilizers is expensive. Fertility can be maintained by (1) the conservation and frequent application of animal manures and (2) the use of a proper system of crop rotation. A 4-year rotation of crops is frequently worked out. In following such a plan, corn might be planted the first and second years, oats the third year, and clover the fourth. It will be noted that a legume, clover, is included in this series of crops. Sometimes the legume is plowed

under. This greatly enriches the soil by the addition of organic matter. Decomposed and partly decomposed organic matter is called *humus*. It is largely responsible for the dark color of soils due to the presence of carbon. As it dissolves, it furnishes certain elements for plant growth and yields organic acids that aid in the solution of soil minerals. Humus is necessary for the growth of certain beneficial microorganisms. It also helps the soil absorb and hold moisture and improves its quality from the standpoint of cultivation.

Acid Soils and Alkaline Soils. Soil water, through the solution of carbon dioxide from the air and the addition of the products of organic decay, tends to become a weak acid. Certain alkaline substances in the soil, especially lime, neutralize the acids. A soil with an excess of acid is called an *acid,* or *sour,* soil. Strongly acid soils generally are unfavorable to the existence of earthworms and various soil bacteria, especially those which transform atmospheric nitrogen. Many economic crops will not grow on such a soil. The acid condition may be reduced or corrected by the addition of an alkaline substance, such as pulverized limestone (Fig. 334).

Alkaline soils are more common in arid and semiarid regions. Here the growth of plants and the accumulation of organic acids are deficient. Excessive evaporation of soil water leaves the alkaline substances especially in the top layers. In some places strongly alkaline soils may be recognized by their white color and scarcity of vegetation. Such soils are practically worthless. The condition may be remedied by the application of abundant irrigation water which dissolves and, with proper drainage, carries away the excess of alkali.

Size and Arrangement of Soil Particles. The size of soil particles is referred to as soil *texture.* From coarse to fine, soil particles are graded as coarse sand, fine sand, silt, and clay. Most soils consist of a mixture of these different-sized particles, with one predominating. Sand and silt consist of mineral particles, largely insoluble. They furnish, therefore, little available plant food. Clay, on the other hand, is a most valuable source of soluble mineral matter.

The term *loam* is applied to the better soils which contain desirable proportions of clay, silt, fine sand, and humus. The

finer the soil particles the more surface area they expose. Thus a clay soil offers a much greater "feeding area" for the roots of plants than does a sandy soil. Because clay soils have more pore space, they hold more water and retain it longer than do sandy soils. As a result, certain clay soils sometimes become very sticky and hard to cultivate. In some regions they are best adapted to pasture land, although many clay soils are excellent for wheat production. Sandy soils, on the other hand, dry rather quickly. Such soils have large pore spaces, but the total pore space is less than in clay. The large pore spaces readily permit air to penetrate the soil. Sandy soils usually are easily cultivated. In many places they are used for vegetable gardening and fruit raising, because in early spring the penetration of warm air causes the soil to warm rapidly.

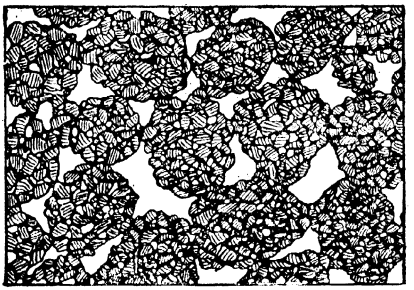


FIG. 335.—This diagram illustrates structure and pore space in soil.

In many clays and silty soils, it is found that the soil particles are arranged in groups. This grouping is called *soil structure*. The grouping of the tiny particles is extremely beneficial, because larger pore spaces are created which more easily permit the penetration of air and the roots of growing plants (Fig. 335). In addition the cultivating qualities of the soil are greatly improved. A good soil structure is promoted by the presence of lime and by the growth and decay of plant roots or the addition of organic fertilizers.

Soil Color. In many regions the color of the soil is a conspicuous feature of the landscape. Soils range in color through a wide variation of shades or tints from white to black. Among the commonest colors are dull shades of red, rust brown, and yellow. These are due to the presence of the various oxides of iron. Black and dark-brown colors in soils usually, but not always, denote a considerable content of organic matter. Dark soils are better absorbers of solar radiation than are those of light color, and therefore they tend to be warmer. Many dark surface soils are underlain by subsoils of a much lighter color, often caused by the decrease of humus with depth and the greater abundance

of clay. Loess usually is easily identified, because, in addition to standing in vertical walls like solid rock, it has a uniform buff color from top to bottom (Fig. 332). In general, dark soils are considered to be more productive than light-colored ones, although this is not always true.

Water and Air in the Soil. Plants absorb their food from the soil in solutions, but only a few crop plants are able to thrive in soils in which the pore space between the soil particles is completely filled with water all the time. Most of them require soils containing both air and water. The penetration of the soil by air permits the oxygen, nitrogen, carbon dioxide, and other constituents of the atmosphere to do their part in soil formation. Soils that are moistened frequently have films of water about their particles. This is called *capillary water*. With its dissolved minerals, it passes into the tiny root hairs of growing plants. When the supply of capillary water is abundant, it moves slowly downward under the pull of gravity. When the supply is diminished by plant use or surface evaporation, it may move horizontally or even creep upward. The upward movement, known as *capillary action*, or *capillarity*, is much more effective in fine clay soils than in sandy soils. Thus grasses growing on clay soils suffer less during dry weather than those on coarser soils. The water that moves downward into the zone of ground water may be called *gravitational* water. It and the position of the water table depend upon the frequency and amount of water received by the soil. In dry regions, of course, the water table usually is lower than in humid regions. That is one reason why alfalfa is the most important crop grown on irrigated lands. Alfalfa, unlike clover, develops a root system that penetrates deep into the soil. Roots 10 to 20 feet in length are not uncommon. Thus this valuable hay crop will survive in regions of light rainfall, because it goes deep after water, whereas a shallow-rooted crop would perish.

Drainage and Irrigation. The drainage of some soils is necessary to remove excess water so that air may fill a part of the pore space. Many plants are killed by too frequent watering, especially in soils that have poor subsurface drainage. Soil drainage is accomplished mainly by two methods: (1) Large ditches carry the excess water to streams or rivers (Fig. 336). (2) Lines

of tile, placed about 2 to 4 feet beneath the surface, carry water to the ditches. The size of ditch and tile is determined by the amount of water to be removed. In the United States, soil drainage has been necessary, especially in the swampy areas of the coastal plains, in the floodplains of large rivers, and in the marshy parts of the glacial plains of the North Central states (Fig. 337).

Irrigation is any artificial method by which water is applied to soil for the purpose of aiding plant growth. It takes various

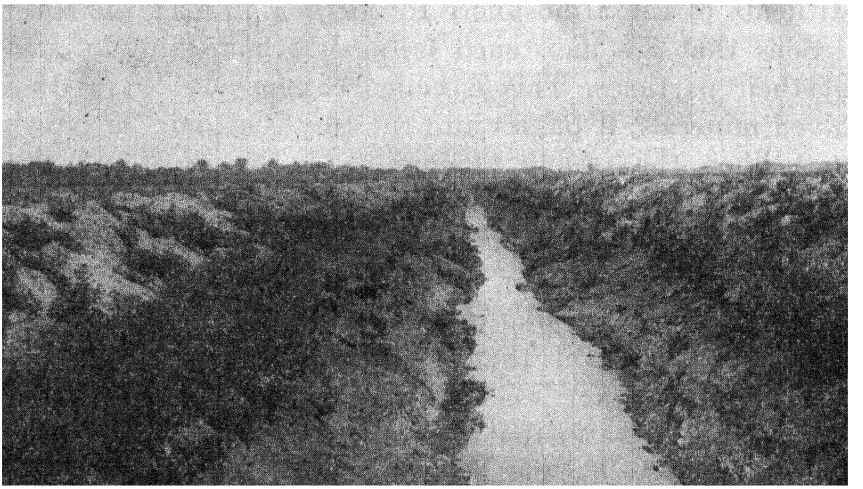


FIG. 336.—Drainage ditch in the Grand River bottom in northern Missouri. (*Courtesy of Missouri College of Agriculture.*)

forms, such as pouring water on a potted plant, sprinkling the lawn, or turning fine streams of water on a garden provided with a system of overhead water pipes. However, the large irrigation projects in arid and semiarid lands make use of canals and small ditches which distribute water over the fields. In such regions the principal sources of water are the many reservoirs formed by dams built across streams. In the United States the large irrigation projects are located in the Western states.

Mature and Immature Soils. As previously stated, a well-developed soil is the result of slow evolution caused by the physical and chemical processes of soil formation which operate under a given set of environmental conditions. Since environ-

mental conditions differ greatly over the earth's surface, it follows that many different types of soil must result. However, soils tend to be much alike in certain geographical regions where the parent material, climate, and natural vegetation are fairly uniform. Thus a soil type that is characteristic of much of the Great Plains of the United States differs greatly from one developed, for example, under the conditions that prevail in the Amazon Basin of Brazil, but it may be very much like one developed in the plains of southern Russia. In some places the

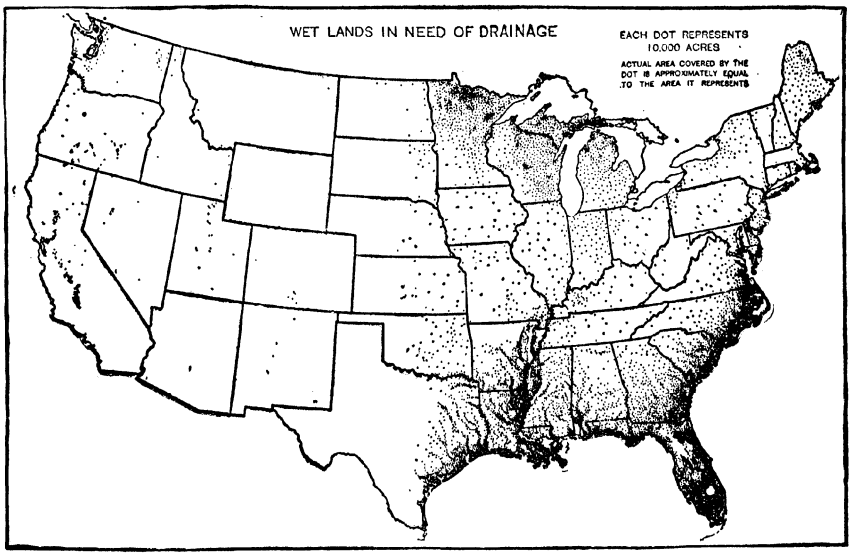


FIG. 337.—The largest total area needing drainage is the swampy region of the Atlantic and Gulf coasts. A second area is the newer glacial drift in Minnesota, Wisconsin, and Michigan. (*Courtesy of U.S. Department of Agriculture.*)

processes of soil formation have been permitted to operate without interruption for long periods of time. The resulting soil in such areas is called a *mature soil.* Such soils best develop on gently rolling lands, where drainage is good but the rate of erosion slow, and where the parent material is fairly deep. *Immature* soils are those wherein the processes of soil formation have been interrupted or hindered by natural conditions. On steep slopes, for example, the topsoil is removed so continuously that a mature soil cannot develop. In areas that are frequently flooded and new deposits of alluvium laid down, immature soils are to be found. Agricultural practices such as deforestation,

plowing, and heavy grazing tend to increase the rate of erosion and otherwise to destroy mature soils. Yet, when mature soils are present, they show significant similarities over large areas.

Soils and Climate

Importance of Climate. Among the various factors that combine to transform mantle rock, or regolith, into soil, no other is so important as the condition of climate. Quantity of soil moisture and prevalent conditions of soil temperature affect the soil directly. They also condition the growth of natural vegetation and the activity of microorganisms. These likewise are concerned with soil development. It is possible, therefore, to distinguish between (1) the soils of humid forest regions and those of semiarid grasslands and (2) the soils of the tropics and those of middle or high latitudes.

Soils of Humid Forest Lands. The mature soils of humid regions generally have developed under natural vegetations of forest or woodland which do not add large amounts of organic matter to them. As a whole, these soils are (1) much leached, meaning that frequent rains dissolve and remove soluble mineral matter; (2) prevailingly light in color; and (3) characterized by a comparatively low content of both organic matter and mineral plant foods. They may be divided into two principal groups:

Tropical Red Soils. These are the most widespread soils of the humid tropics, particularly of the regions of tropical rainforest climate. Red soils of various kinds cover large areas in the Amazon Basin, in central and west central Africa, and in other tropical regions. As a result of leaching, the tropical red soils are low in most of the mineral elements needed by plants. Their nitrogen content is only moderate also. Some plant remains are carried down into them by ants and other earth-dwelling organisms, but high temperatures promote the rapid oxidation of such materials, and heavy rainfall leaches the products of oxidation out quickly. For these reasons the tropical red soils are only moderately good for ordinary field crops. They are benefited by the use of certain kinds of fertilizers but not by others that are quickly removed in solution. The primitive inhabitants of tropical red soil regions till small clearings in the

forests; and as the soil becomes unproductive, they move and make new clearings.

Some tropical red soils have been so much leached under special conditions that they are porous and extremely infertile. These are called *laterites*, and the term *laterite* is sometimes mistakenly applied to any red soil of the rainy tropics. However, the true laterites are believed to be of limited extent.

Modified Tropical Red Soils. It should not be inferred that all soils of the humid tropics are infertile. In many parts of the tropics and subtropics are types of soil that may be called *modified tropical red soils.* Some of them are rich alluvial silts in river floodplains; others are found on slopes where erosion has removed the leached upper soil layers, exposing fresh young earth minerals from beneath. In general the agricultural productivity of these soils is superior to that of the common types of mature red soils.

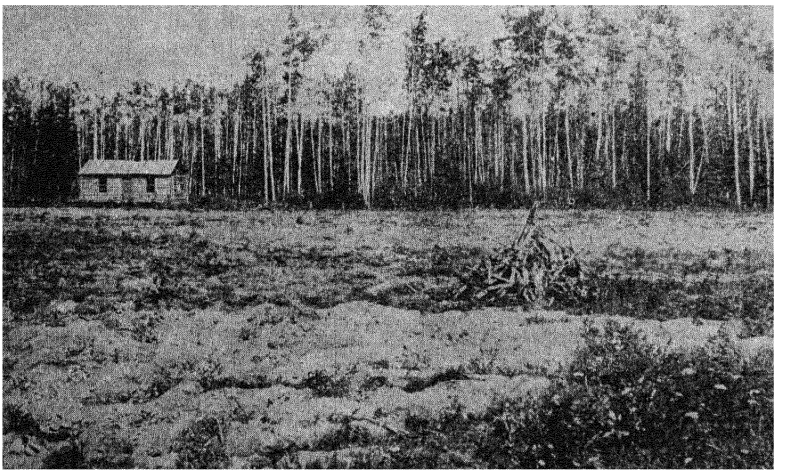


FIG. 338.—A forest podzol, newly cleared, east of Peace River, Alberta. The plow has turned under the surface layers and has exposed the fluffy whitish-gray sand.

Podzols. These are the typical mature soils of regions having subarctic climate (Fig. 338). They are developed under a natural vegetation of coniferous forests. True podzols cover vast areas in northern Canada and northern Russia and smaller areas in other localities. The long, cold winter and moderate summer temperatures and a forest litter of resinous pine needles retard

bacterial action. Formed on the surface is a brown layer of raw humus or half-decomposed organic remains. This spongy material retains water that becomes highly acid and is unfavorable to the existence of earthworms. The customary and valuable work of earthworms in mingling the decayed vegetation with other parts of the soil is not accomplished. Beneath the top layer of organic remains is a layer of grayish-white soil, low in fertility. The podzols, as a whole, are poor agricultural soils.

Modified Podzolic Soils. These soils, developed under deciduous forests with an admixture of shrubs and grasses, are superior to the subarctic type. They cover considerable areas in a belt extending from southern Missouri to New York and across Europe from France through central Russia. That these soils are superior to the true podzols is evidenced by the fact that thousands of square miles of deciduous forests have been cleared of trees in order to make the soil available for agricultural production. The humus formed by the broad leaves of deciduous trees is superior to that formed by the needles of the conifers. The organic matter contains some lime, so that the modified podzols are less acid than the true podzols. This condition promotes the beneficial soil-building activities of earthworms and other soil organisms.

Grassland Soils. In regions where the moisture supply is almost, but not quite, sufficient to support a forest vegetation, it normally is sufficient to support a dense and luxuriant growth of grasses. The growth and annual death of a part of the thick grass sod and its fibrous roots add organic matter *in* the soil where it decomposes slowly and gives rise to a large supply of humus. This humus is not confined to the surface but extends to depths of from several inches to 3 or 4 feet. Slow leaching, a result of less rain, leaves sufficient lime in the soil to aid in promoting excellent structure. The abundant and deep organic material produces dark soils and contributes much to the agricultural strength for which these soils are famous.

Among the grassland soils, the *chernozem* (a Russian word meaning "black earth") is considered to be the finest type developed (Fig. 339). In North America this soil forms a belt through Saskatchewan southward across eastern North Dakota, South Dakota, Nebraska, and central Kansas, Oklahoma, and

Texas. Another belt is found in southern Russia, just north of the Black Sea. Smaller areas occur in eastern Argentina, near Buenos Aires; in Manchukuo; and in eastern Australia. Considerable areas are found in the African grasslands bordering the tropical rainforest. The surface material of the chernozem is black or dark brown in color. When cultivated, this soil, because of its excellent structure, crumbles into a fine seedbed having a large capacity for holding water. The reserves of both organic and mineral plant foods are so abundant that the soils will stand cropping for long periods without fertilization. In general there

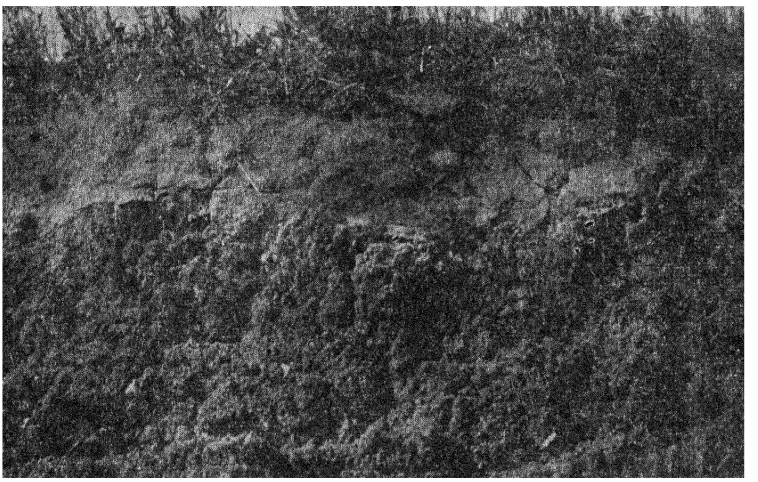


FIG. 339.—A vertical section in a mellow grassland soil of the chernozen type, near Hythe, Alberta. The deep penetration of grass roots is shown clearly. (*Photograph by Mary McRae Colby.*)

are no better soils for producing cereals, cotton, and other crops that draw heavily upon soil fertility. The two outstanding belts of chernozem soils in North America and Russia suffer, however, from their location in the interiors of continents where droughts often hinder crop production.

East of the chernozem belt in North America are the so-called *prairie soils*. They form the rich corn-belt soils of Illinois, Iowa, and northern Missouri and have been developed mainly in regions of older glacial drift. Prairie soils resemble chernozems in being dark in color, but they are not so rich in lime content. However, they rank among the most productive soils of the world. From the chernozem belt to the Rocky Mountains are

brown soils that have resulted mainly from the growth of short grasses.

Desert Soils. The typical soils of arid lands develop under sparse vegetations composed largely of widely spaced desert shrubs. They therefore lack the abundant organic matter of grassland soils. Light-colored soils predominate. This is due in part to (1) the low humus content and (2) the predominance of weathered rock minerals, often including much lime or other alkaline materials. Desert soils tend to be low in nitrogen but may contain large supplies of soluble minerals. Some of these soils, when irrigated and given proper care, may be made highly productive.

Soil Conservation

Causes of Soil Erosion. A grass sod serves as an excellent binding material for a soil. When that sod is broken by the plow, the danger of soil removal by running water and high winds is greatly increased. Likewise, deforestation exposes soils to the heavy downpours of occasional storms, and, especially on hill slopes or in mountains, the amount and rapidity of the resulting soil erosion present a most serious problem. Truly it can be said that man's use of soil and forest has played into the hands of the processes of degradation.

Destructiveness of Soil Erosion. Some idea of the destructiveness of soil erosion in the United States may be had from a government report that states that the annual losses of plant nutrients from the cropped lands and pastures of the country through leaching and erosion are almost six times greater than the quantity of those elements removed from the same lands in crops or forage. We learn from the same report that

> . . . already the utility of approximately 35,000,000 acres of formerly good farm land has been essentially destroyed, in so far as the production of cultivated crops is concerned, chiefly by gully erosion. This represents an area about the size of Pennsylvania, Massachusetts, and Connecticut combined, or 218,000 farms of 160 acres each. From about 125 million additional acres—land still largely in cultivation—the topsoil, representing the most productive part of the land, has been washed off or largely washed off by the erosive action of unrestrained runoff of storm waters. In addition, approximately 100 million acres

of cultivated land are starting in the direction of the 125 million acres of impoverished soil-stripped land. These prodigious losses do not take into account the wide-spread erosional wastage that is speeding up over the vast domain of the western grazing areas [Fig. 340].[1]

Kinds of Soil Erosion. One of the most widespread and least noticed kinds of erosion on tilled land is *sheet wash.* This may be accomplished by the removal of a uniform thin layer of soil, but more commonly it results from the formation of myriads of tiny gullies (Fig. 341). These gullies are so small that they

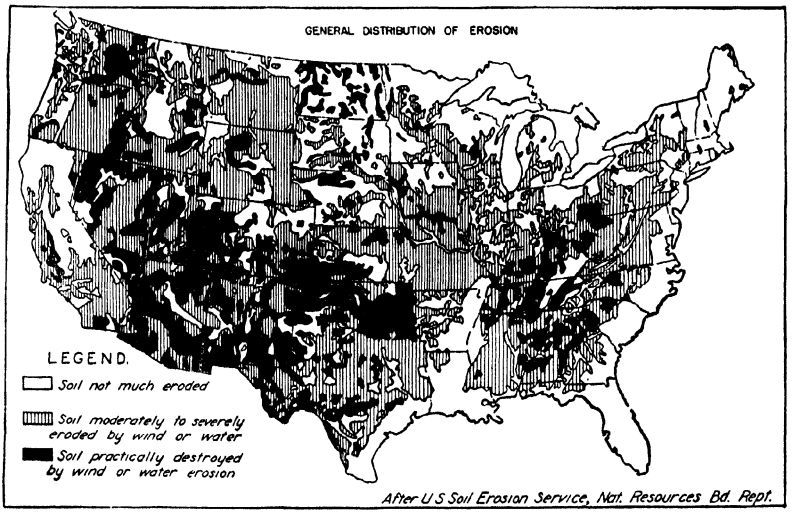


FIG. 340.—A large part of the United States has already suffered severe loss through soil erosion.

may be erased by the next cultivation of the field; but others soon form, and the stripping process continues. This phase of soil erosion is the more harmful because it removes the finer and more fertile of the soil particles first.

A second type of soil erosion is that of *gullying.* Successive downpours of rain will cause a gully to become rapidly wider and deeper. At the same time it becomes longer by headwater erosion. In some soils a single thunderstorm will produce new gullies a foot or two in depth. If the gullies are allowed to become larger,

[1] *Report on National Planning and Public Works in Relation to Natural Resources,* p. 161, National Resources Board, Government Printing Office, Washington, D.C., 1934.

they soon interfere with the processes of planting and cultivation (Figs. 342, 343).

A third type of soil erosion is that caused by the wind. From all plowed fields, especially those which are dry, some soil is removed by high winds. In the United States, however, more serious wind erosion has occurred in the semiarid lands of western Kansas and Oklahoma and eastern Colorado. As more land in this region is cultivated, dust storms seem to increase in number and severity. During the prolonged drought of 1934, millions of

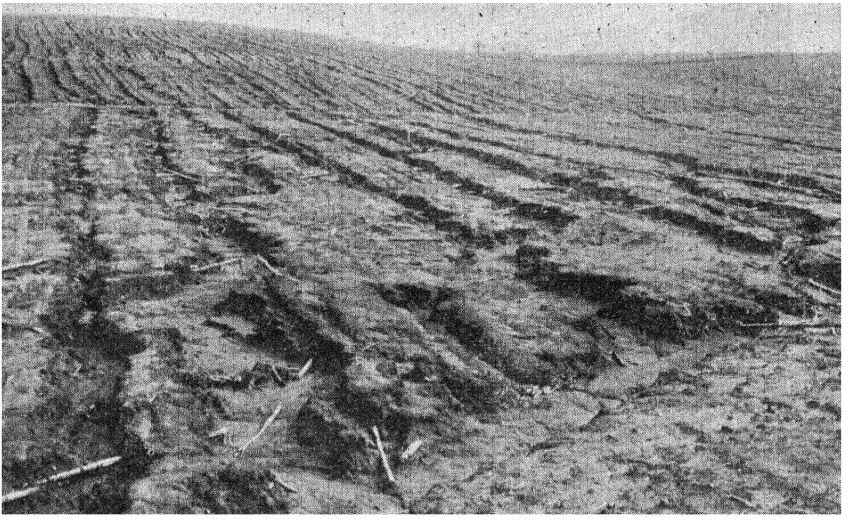


FIG. 341.—Small gullies in a tilled field may lead to serious soil erosion. (*Courtesy of Soil Conservation Service.*)

tons of fertile topsoil were drifted about like snow by storms or were lifted so high into the air that quantities settled far to the eastward. The huge dust clouds that may be seen in New Mexico strongly resemble the black clouds of an approaching thunderstorm. In such dust clouds the total weight of soil being transported probably runs into the hundreds of tons.

Reduction of Destructive Soil Erosion. The seriousness of the soil-erosion menace is barely beginning to be realized in America, and too little is being done to reduce the loss. Certain preventive methods may be used to reduce the rate of destructive erosion. A program of planned soil conservation should be supported. Such a program must include a slow return to per-

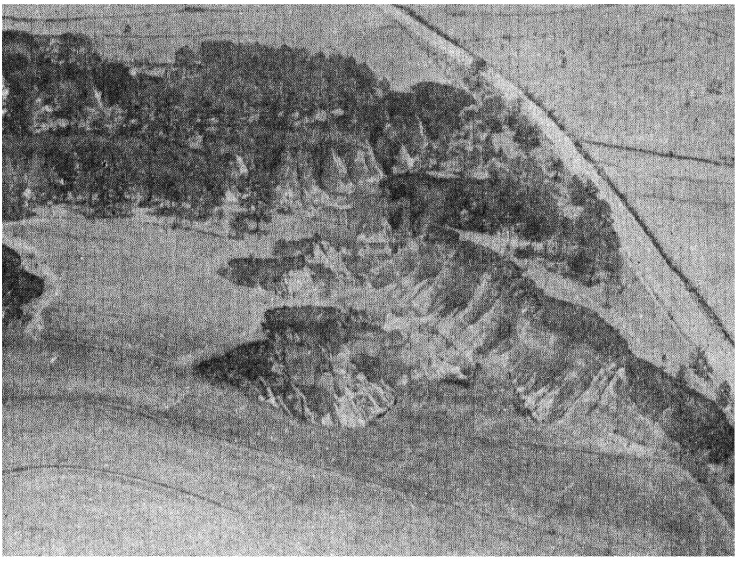


FIG. 342.—This cultivated slope has been badly damaged by gullying. (*Courtesy of Soil Conservation Service.*)

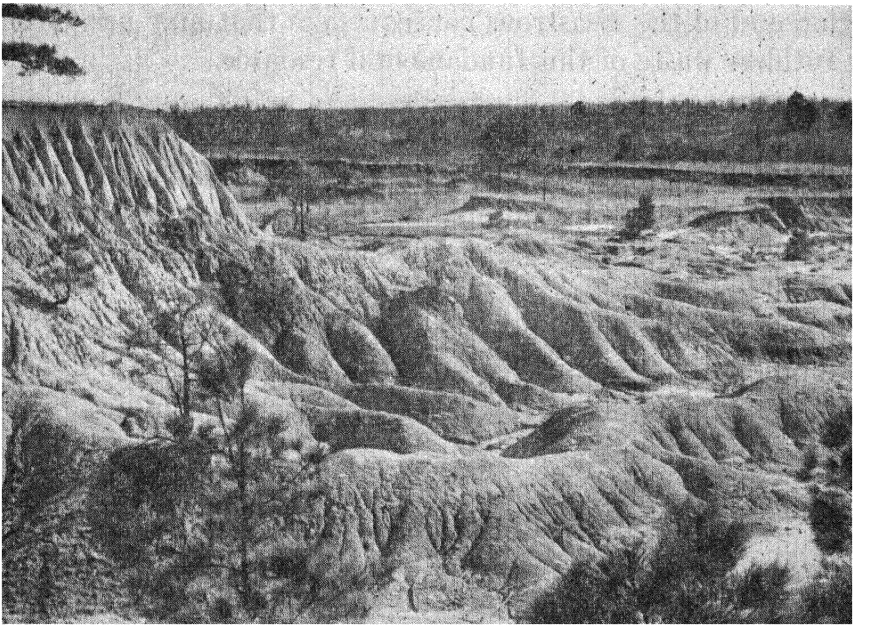


FIG. 343.—**Unchecked gullying** has completely destroyed this land for agricultural use. (*Courtesy of Farm Security Administration, photograph by Evans.*)

manent forest or permanent grass on those lands where erosion has progressed so far as to destroy the value of the land for tillage. It must include also means of protecting, by conservative methods of tillage and management, those areas which are best suited to and are required for crop production, so that they may continue to be productive for hundreds or thousands of years to come.

Among the methods having this latter end in view, the specialists in erosion control recommend (1) the construction of dams or obstructions to erosion in gullies already formed; (2) the plowing and tilling of land along contour levels in order to cause furrows to run across the land slope and thus reduce the rate of sheet wash; and (3) the construction of contour terraces with embankments of sod, brush, or other soil-retaining vegetation at intervals to deflect surface drainage and prevent the formation of gullies. The method last named is much employed now in the South and should have wider application. Above all is required an awakened consciousness of the need for soil protection and of the disastrous consequences that may arise from the ruthless waste of this fundamental resource.

Summary

Transported soils include alluvial soils, glacial drift, and loess. Residual soils are formed by the decay of bedrock just beneath them. The necessary constituents of a good soil should be maintained by crop rotation and fertilization. In general, mature are richer than immature soils. Also, grassland soils are more productive than are forest soils.

Methods of soil conservation include the following:

1. Crop rotation
2. Contour plowing
3. The terracing of hill slopes
4. Use of grasses to bind soil and thus to check erosion
5. Protection of woodlands and grasslands against fire
6. Systematic pasture management
7. Control of gullying
8. Restoring badly eroded soils to grasses, legumes, or tree crops

9. Construction of farm ponds and reservoirs to impound surplus water

10. The use of commercial fertilizers

Questions

1. In what ways may soil fertility be reduced?
2. Why is it necessary that soil fertility be maintained?
3. What are the principal processes involved in the evolution of a soil?
4. What organisms aid in soil formation?
5. Explain the formation of the three kinds of transported soils.
6. What is a residual soil? Give two examples.
7. Name the five principal ingredients of a soil.
8. Why must a soil contain soluble mineral matter?
9. Most commercial fertilizers contain what four mineral elements?
10. What rock furnishes a supply of calcium for many soils?
11. What is a legume? Why are such plants of great value in maintaining soil fertility?
12. Mention two regions that produce phosphate rock. Potash.
13. What are two relatively inexpensive methods of maintaining soil fertility?
14. What is meant by crop rotation? What rotations (if any) are used in your locality?
15. Explain what is meant by the humus content of a soil. In what three ways is humus of value to a soil?
16. What is an acid soil? How may acidity be reduced?
17. Where are alkaline soils most common? Why?
18. What color are some alkali soils? How may the excess of alkali be removed?
19. Define soil texture. Give examples.
20. How do silt and clay differ as to soluble mineral content?
21. What is meant by the term *loam* as applied to soils?
22. Contrast clay and sand as to water-holding capacity.
23. For what uses are clay soils best adapted? Sandy soils?
24. Define soil structure. Give two reasons why good soil structure is very desirable.
25. Explain the cause of certain soil colors.
26. Why do some soils grade from black to yellow with depth?
27. How can loess be identified?
28. How does soil color influence absorption of solar energy?
29. Why is air necessary in soil?

30. What is capillary water? Capillary action? Gravitational water?

31. Why is alfalfa well adapted to irrigated lands?

32. Why must some soils be drained? What two methods are used?

33. In what parts of the United States is soil drainage necessary?

34. Define irrigation. What methods are used?

35. Explain mature and immature soils.

36. Mention three characteristics of mature soils of humid forest lands.

37. What are laterites? Where are they found? In general are they highly productive soils or not? Why?

38. What are podzols? Where are they found? In general are they highly productive soils or not? Why?

39. Where is the belt of modified podzolic soils in the United States?

40. Why are grassland soils likely to be more fertile than forest soils?

41. What is meant by chernozems? Where are they found? What is the disadvantage of their location in Russia and North America?

42. Where are prairie soils found in the United States?

43. Mention two characteristics of typical desert soils.

44. How is soil erosion checked by forests? By grass sod?

45. Discuss the destructiveness of soil erosion.

46. Explain what is meant by sheet wash.

47. Small areas of light-colored soil may be noticed in the higher parts of freshly plowed fields. Explain.

48. What damage is done by gullying? How may this type of soil erosion be checked?

49. Where in the United States have dust storms been especially destructive? What would help to check such erosion?

50. What procedures does a permanent soil conservation policy involve?

51. What methods of controlling soil erosion are suggested by soil specialists?

Suggested Activities

1. Secure samples of several different kinds of local soils. Compare the soils as to color, texture, structure, and humus content. Which soil is superior from the standpoint of cultivation? Do any local soils have a so-called hardpan? (Look up the meaning of this expression.)

2. Using litmus paper, test several soils for acidity.

3. If possible, secure samples of loess, alkali, prairie, and forest soils. Examine them carefully.

4. Make field trips to study methods of soil drainage or irrigation, if such are to be observed in your community. Notice also any places where destructive soil erosion is evident. Are any methods being employed to check the erosion?

5. While driving across country, watch for places where sheet erosion has removed much of the black topsoil, exposing a considerable area of lighter colored clay soil.

6. Bring to the laboratory the root system of some legume (clover or alfalfa). Note the nodules formed by the nitrogen-gathering bacteria.

7. If possible, secure soil maps of your county and state. Study these carefully.

8. Secure a glass tube 2 or 3 feet long, with an inside diameter of 1 or 2 inches. Along the roadside or at the edge of a gully find a place where the soil layers from the surface downward are exposed. Fill the glass tube to correspond with the layers observed. Such a collection is called a soil profile.

9. Write to your state college of agriculture for a list of bulletins dealing with the subject of soils. Some colleges sell samples of soil from various parts of the state at small cost.

NOTE: Other activities may be found in the laboratory manual

TOPICS FOR CLASS REPORTS

1. The Soils of the Local Community
2. Relation of Local Soils to Farm Value
3. Productivity of Local Soil Types
4. Methods Used to Check Soil Erosion
5. Crop Rotation as a Means of Soil Conservation
6. Legumes Used in Crop Rotations
7. Texture of Different Local Soils
8. Drainage, or Irrigation, of Local Soils
9. The Chernozem Belt of North America
10. The Loess Region of Northern China
11. Forest Soils versus Prairie Soils
12. Commercial Fertilizers

REFERENCES

Atlas of American Agriculture: Part 3, "Soils of the United States," U.S. Department of Agriculture, Government Printing Office, Washington, D.C., 1936.

BENNETT, HUGH HAMMOND: *Soil Conservation*, McGraw-Hill Book Company, Inc., New York, 1939.

CHASE, STUART: *Rich Land, Poor Land*, McGraw-Hill Book Company, Inc., New York, 1938.

GLOVER, KATHERINE: *America Begins Again*, McGraw-Hill Book Company, Inc., New York, 1939.

Report on National Planning and Public Works in Relation to Natural Resources, National Resources Board, Government Printing Office, Washington, D.C., 1934.

Soil Conservation Service, Bulletins on soil conservation: "Erosion Control in the Northeast," "Erosion on Roads and Adjacent Lands," "Legumes in Soil Conservation Practices," "Our Soil: Its Wastage and Preservation," "Soil Defense in the South," "Soil-depleting, Soil-conserving, and Soil-building Crops," "Soil Erosion in the Karst Lands of Kentucky," "Topsoil: Its Preservation," U.S. Department of Agriculture, Washington, D.C.

WOLFANGER, L. A.: *The Major Soil Divisions of the United States*, John Wiley & Sons, Inc., New York, 1930.

Chapter XVIII. Mineral Fuels, Ores, and Other Economic Minerals

Industrial civilization of the modern type is based to a large extent upon the mineral fuels, principally coal and petroleum. Some knowledge of these fundamental, nonrenewable earth resources is necessary to an understanding of the industrial development and economic problems of certain regions and countries. The United States not only ranks first in coal and petroleum resources but has available also great quantities of natural gas and much undeveloped water power. Outside those natural resources necessary to life itself, it is probable that coal would be missed more than any other, and without doubt iron would be next in order. Electrical power is generated by the use of coal, petroleum, and water power. Here, again, coal is the most important *source* of power, although certain hydroelectric developments, such as Niagara Falls, the Tennessee Valley Authority, and others, distribute tremendous quantities of electrical energy over considerable areas. Even the widespread use of electrical power in the United States, however, is far behind that of certain European countries.

Coal

Formation of Coal. Coal is a form of *sedimentary* rock. It consists of materials derived largely from the *carbon* of plant tissues. In the geological column (Appendix G) the *coal age* is called the *carboniferous age*. Even thin beds of coal represent long periods of accumulation during which plant remains were preserved from the ordinary processes of complete decay. They were buried underneath swamp waters and later beneath layers of mud, sand, or lime. Such deposits of plant remains accumulated mainly in ancient swamps. The original position

of all swamp deposits is nearly horizontal. When such deposits are buried beneath other sediments, they become members of a series of horizontal sedimentary rocks. The coal beds of some of the greatest coal fields of the world have still an essentially horizontal position, a condition that simplifies the problems of coal mining. In some fields the beds are not horizontal but are considerably warped, or folded. This has caused metamorphism of the coal in a few localities.

Most individual coal beds are relatively small in area. Such, however, is not necessarily true of coal fields. In the regions now occupied by some of the greater fields, swamp evidently existed over wide areas and for long periods of time. In such regions it is probable that individual swamps flourished, disappeared, and were buried beneath earthy sediments. In later years another swamp formed above the old one but was separated from it by layers of sediment. In certain localities a half-dozen or more coal beds are known to lie one above another, separated by various thicknesses of sedimentary rock. By drilling test holes, geologists learn the depths and thicknesses of coal layers and their approximate area. In this way estimates of coal reserves available for future use are made.

Varieties of Coal. Several varieties of coal are recognized, each representing a stage in the evolution of swamp deposits into high-grade coal. Only four of them will be mentioned here.

It may be assumed that all coal began as *peat.* This substance consists of preserved but crumbled and blackened organic remains. It is similar to that which may be seen underlying present swamps and bogs. The higher forms of coal are a result of the transformation of peat. This is brought about largely by the weight of overlying rock and crustal disturbances, such as folding of rock layers.

Lignite, a crumbly brown coal, is a somewhat older and more compact substance than peat.

Bituminous, or soft, coal is next in order. There are many grades of bituminous coal. Of great importance is *coking* coal, suitable for the manufacture of coke of the type required in iron-smelting furnaces. Other grades are called *noncoking,* but they may be well suited to use as fuel for the production of power or for heating.

Anthracite, or hard, coal probably resulted from metamorphism of bituminous coal through further compression of the coal beds, especially when accompanied by warping and faulting. This transformation produced a coal that is low in gas and high in carbon. Anthracite, therefore, is nearly a smokeless fuel.

Accessibility of Coal. The accessibility of coal deposits has two meanings: (1) nearness of the coal field to markets and

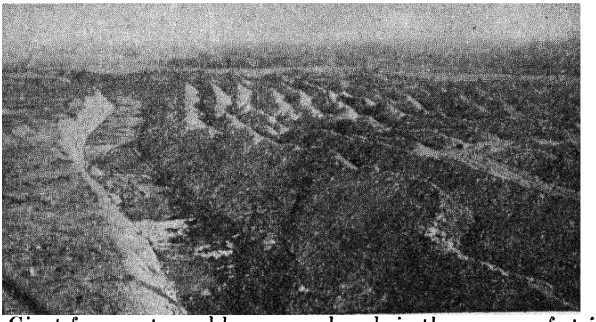


FIG. 344.—Giant furrows turned by power shovels in the process of strip mining in southern Illinois. The 4-foot bed of coal exposed in the bottom of the trench is mined out before the next furrow is turned.

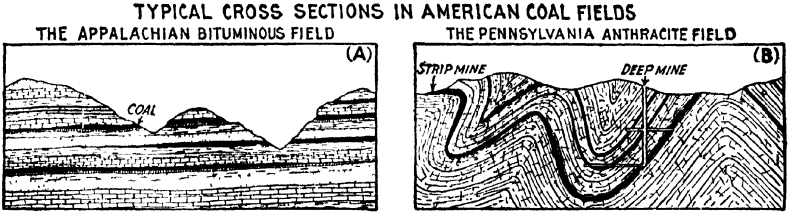


FIG. 345.—These diagrams show in contrast the common relationships of surface and structure in the bituminous and anthracite fields of the Appalachian coal regions.

(2) depth of the coal layers, nature of intervening rocks, and other factors affecting the ease with which it may be mined. Consider for a time the second meaning. In some localities of little-disturbed sedimentary rocks, coal beds are found so close to the surface that they may be mined in open pits after the removal of only a few feet of overlying earth or rock (Fig. 344). In others they are so far underground as to be reached only by mine shafts of great depth. In still others, although originally they were deeply buried, the coal beds are now made readily accessible by deep valleys which expose outcrops of coal among the rocks of the valley walls (Figs. 345, 346). In regions of

complicated rock structure, coal beds, once horizontal but now greatly folded, present various degrees of accessibility. In some such localities erosion exposes parts of the coal beds at the surface. In others the beds are bent downward to great depths or are displaced or shattered by faulting. In such structures the difficulties of mining are greatly increased (Fig. 345).



FIG. 346.—A stratum of bituminous coal outcropping, along with other sedimentary strata, in a road-cut on a West Virginia hillside.

COAL REGIONS OF NORTH AMERICA

North America not only is the continent of greatest coal production but also is credited with the greatest of all coal reserves. These have been estimated at 5 trillions of tons. This is more than two-thirds of the total estimated supply of the world. The coals include representatives of every class from high-grade anthracite to the lowest grades of lignite. They are contained in several fields the location and extent of which are shown in Fig. 347.

Appalachian Coal Field. This is the most important coal field of the continent. It is composed of two principal subdivisions:

1. *The anthracite region* is a small, highly folded section in the ridge-and-valley region of northeastern Pennsylvania. In this region are many cities dependent upon the anthracite mines. Scranton and Wilkes-Barre are two of the most important. Numerous railroad lines carry the coal to many markets. This region is the source of most of the anthracite used in America, but the supply is limited. Moreover, the coal seams are not easily accessible. These factors make anthracite an expensive fuel (Fig. 345*B*).

2. *The bituminous region* is a large area of little-folded rocks which contain numerous beds of bituminous coal, some of them thick and of high quality. This region extends from northwestern Pennsylvania to northwestern Alabama. Some of the coal beds are of the high quality required for the manufacture of coke needed in the blast furnaces of steel mills. That is particularly true of one deposit of great thickness and large extent in western Pennsylvania. It was the basis of Pittsburgh's

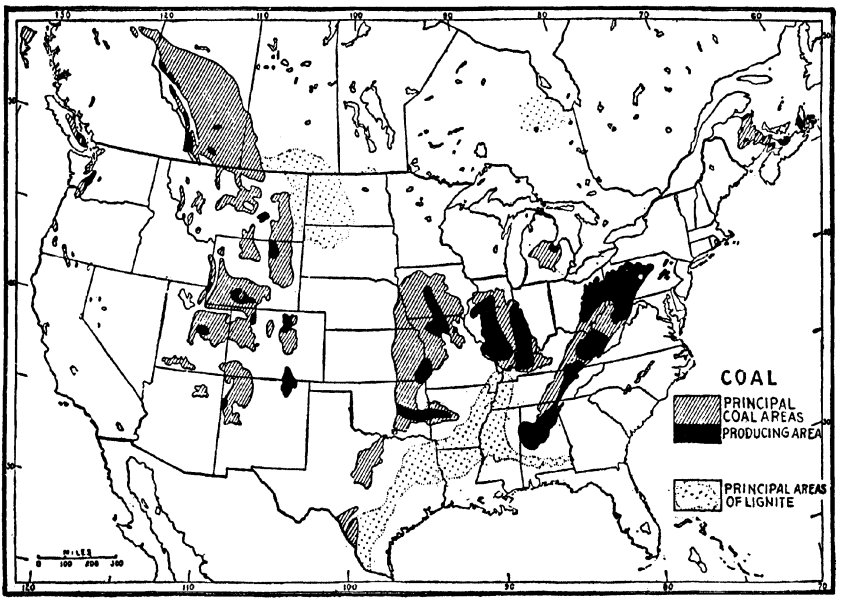


FIG. 347.—The principal coal fields of North America. The small fields in eastern Pennsylvania contain most of the anthracite.

early supremacy in iron and steel manufacture, and it still furnishes coke for that city and several others.

More than three-fourths of the high-grade coal of the continent is obtained from the Appalachian bituminous field. In many places it is easily mined. Deep valleys expose the coal beds along the valley walls, and mining is relatively simple. The abundance, accessibility, and high quality of these coal deposits give the Appalachian field first importance in America and perhaps in the world. Near the southern end of the field is Birmingham, Ala. Here are found suitable deposits of iron ore, limestone, and coal, a combination that has made Birmingham an important iron and steel center.

Other Fields. The interior region of the United States also is abundantly provided with coal fields. Next to Pennsylvania and West Virginia, Illinois is a heavy producer. Farther west, coal is mined in a region that extends from Iowa through Missouri, Kansas, and Oklahoma and into Texas. The great share of this coal is bituminous, some of it rather low grade. Throughout the Rocky Mountain region, from Alberta to New Mexico, are rather widely separated coal-producing areas. Here, again, the coal is mainly bituminous. On the Pacific Coast, two small areas are of note, one in Vancouver Island, the other in southern Alaska. Rather extensive deposits of lignite are found (1) in parts of Texas, Louisiana, and other Southern states and (2) in Montana, the Dakotas, and southern Saskatchewan.

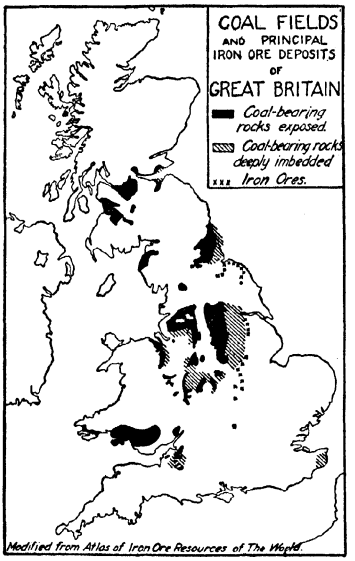


FIG. 348.

COAL IN OTHER CONTINENTS

South America. Of all the continents, South America has the misfortune to be the least well endowed with coal. There are in its entire extent very few areas of coal-bearing rocks. Only in the Andes of Peru and on the coast of central Chile are there known deposits of value. Obviously, this shortage is a serious handicap to the industrial development of South American countries.

Europe. European coal fields are more productive than any in other parts of the world, except those of North America. In total coal reserves it is estimated that Europe ranks third among the continents, North America first, and Asia second.

British coal fields occupy no less than six distinct regions in England, Scotland, and Wales (Fig. 348). The coal is mainly of bituminous quality or better. Associated with each of the major fields is an important industrial district. The region of South Wales is especially well situated for the export of coal. Some of the mines today extend far underground, greatly increasing

the cost of production. The total quantity of coal remaining in Great Britain is sufficient for many years to come.

Continental European coal fields are numerous, but none covers so much area as the larger North American fields. Little coal of importance is found in the Mediterranean Basin or in the ancient crystalline rocks of Scandinavia and Finland. The more important fields and better grades of coal lie in a centrally located belt extending from northern France through Belgium, Germany, Czechoslovakia, and Poland into Russia (Fig. 349). Germany is estimated to have the greatest coal reserves of any

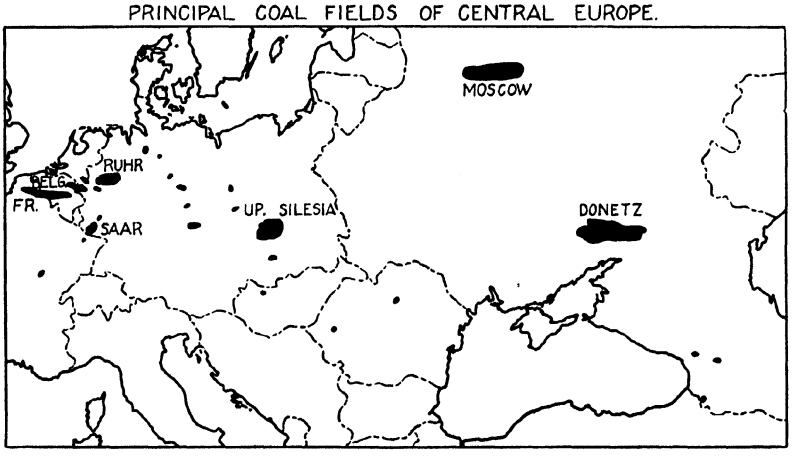


FIG. 349.

European country. A most important coal-producing region is that which lies in northern France, extending through central Belgium into Germany. The field of western Germany is of particular importance because it is the present center of the heavy iron and steel industries of Germany. Near by is the coal field of the politically famous Saar Basin. Another important field is in eastern Germany. Probably the most important field in Russia is that of the Donets Basin in the south. It is the center of heavy industry in modern Russia.

Asia. As previously stated, it is believed that Asia contains larger coal reserves than any other continent except North America. Figure 350 indicates the location of the known fields of major importance. China is thought to have more than three-fourths of the total reserves. The quantity of high-grade coal in

China is estimated to be greater than that of any other country in the world, except the United States. Other important coal reserves are in Siberia and India.

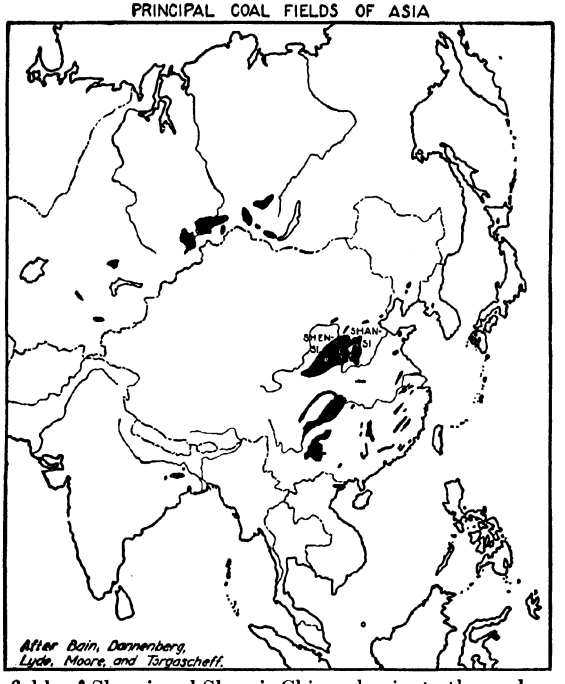


FIG. 350.—The fields of Shensi and Shansi, China, dominate the coal resources of Asia.

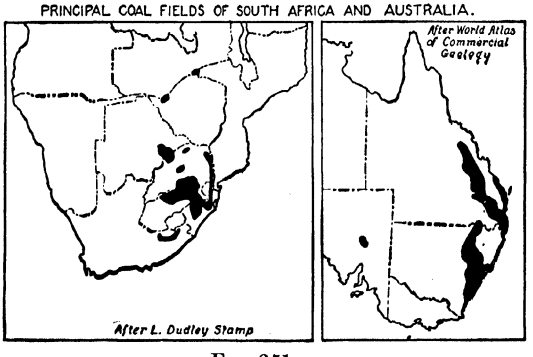


FIG. 351.

Africa and Australasia. The principal coal fields of Australia are near the eastern coast. Because of its abundance, good quality, and accessibility, Australian coal is the leading source of supply in the Southern Hemisphere. In the huge continent of

Africa, the principal coal reserves, located mainly in the extreme southeastern part, are less than those of Australia (Fig. 351).

Conservation of Coal. The known reserves of coal in the United States are much greater than those of petroleum. Long after petroleum has become scarce, coal will still be in use. Our great supply of coal, however, is no reason why we should be wasteful with it. Several conservation measures can be employed. Some of them are:

1. Reduce the waste caused by improper mining methods
2. Improve the efficiency of coal-burning furnaces
3. Improve the quality of poorer grades of coal by chemical treatment
4. Avoid waste in making coke
5. Improve the efficiency of steam engines and steam turbines

We in the United States are mining our valuable mineral fuels at an enormous rate. Annual production of coal has been in the neighborhood of 600 million tons, and of petroleum 900 million barrels. These staggering figures should make us more conscious than ever of the need of conservation.

Petroleum

Occurrence of Petroleum. Petroleum, natural gas, and asphalt are related earth materials, probably of organic origin. Crude oil as it comes from the ground is a thick, greenish-black or brown liquid. Because of its chemical nature it may be split up into a great number of products suited to many uses.

Petroleum and its related substances are found in quantity in sedimentary rocks only. Probably this is because these substances are derived from microscopic marine organisms whose remains were originally intermingled with marine deposits. Generally they are found in porous rocks, especially sandstone. The oil and gas fill the pore space in the rock. Some porous limestones have been found to contain petroleum. Oil sands sometimes occur far below the earth's surface. A few wells have been drilled to a depth of over 2 miles. Oil pools are bodies of oil trapped in some kind of pocket from which they cannot escape. Such a pool may occur in the sandstone of an anticline, especially where the sandstone is capped by an impervious rock, such as

shale (Fig. 352). The oil and gas, being lighter than water, tend to rise to the top of the sandstone "dome" and are there held in captivity by the overlying rock formation.

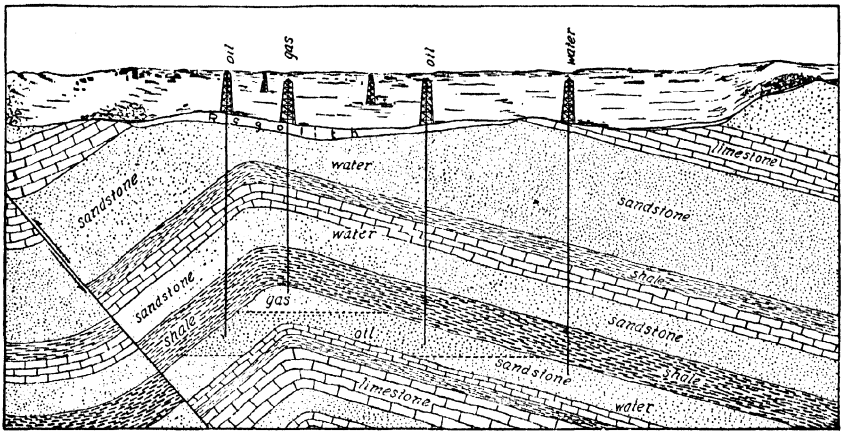


FIG. 352.—This diagram illustrates one form of structure in which petroleum is entrapped and shows the relation between the locations of several wells and the nature of their products. The existence of this anticlinal structure is not evident from the surface relief.

OIL AND GAS FIELDS

Fields in the United States. Nature has endowed the United States with several regions in which petroleum and gas are found. The production of these fuels in the United States far exceeds that of any other country. Each region includes a number of fields, which vary in production. Some produce both oil and gas; some yield oil but not much gas, and others yield gas alone. In every productive field are many wells that have been abandoned.

The principal regions of oil and gas production, indicated in Fig. 353, are as follows:

1. *Appalachian Region.* The first oil and gas field to be developed on a modern scale was in the Allegheny region of America. That region was for many years the most productive in the world. Pools occur intermittently from western New York to Tennessee. Petroleum of this region is noted for its superior quality, which involves low sulphur content; ease of refining; and the fact that, upon distillation, it leaves a residue of paraffin rather than asphalt. This region long ago reached its peak of oil

production. However, much natural gas remains. It is a valuable fuel in home and factory. Of all the fuels, natural gas probably is the most perfect.

2. *Eastern Interior Region.* Fields of importance are located in Ohio, Indiana, Illinois, and Michigan. Production in this region is small compared with that of the Mid-Continent region. In past years, however, the field in southern Indiana and Illinois was of considerable importance. New discoveries in Illinois are bringing this field back into prominence again.

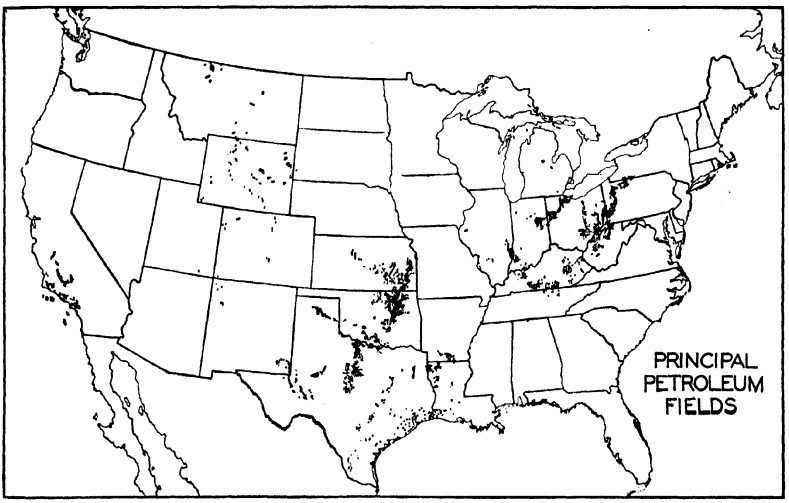


FIG. 353.—Many of the pools included in the principal petroleum fields of the United States are very small. Only the larger have been included on this map, and the areas of many of them have been enlarged or combined to make them visible at this map scale.

3. *Mid-Continent Region.* This includes several widely scattered fields and hundreds of pools in Kansas, Oklahoma, central and western Texas, southern Arkansas, and northern Louisiana (Fig. 354). Petroleum, of both paraffin and asphaltic types, is found in abundance. This region produces about two-thirds of the entire United States output. Some pools have been exhausted, but deeper drilling has reached oil in older rocks. Both oil and natural gas are transported in underground pipe lines to many parts of the United States (Fig. 355). Natural gas is so abundant that much of it is wasted. It is said that the present quantity of gas allowed to escape daily in the process of getting oil from the Texas Panhandle field

alone is the full equivalent of more than 1,000 carloads of coal. There is no reasonable defense for such ruthless waste of a non-renewable resource.

4. *Gulf Coast Region.* This includes numerous pools found in coastal Texas and Louisiana. Much of this oil is piped to Gulf Coast cities, loaded on oil tankers, and shipped to both American and foreign seaports.



FIG. 354.—A portion of the Mid-Continent oil field in southeastern Kansas, showing the many individual pools that lie within the area.

5. *Rocky Mountain Region.* This comprises many fields distributed over a large area. Wyoming is the leading producer at present. This entire region, however, is the least productive of the major oil regions.

6. *California Region.* The oil and gas fields of California are distributed over a belt that extends from the environs of Los Angeles northward toward San Francisco (Fig. 356). Some fields are located on the ocean shore; others inland, such as those in the vicinity of Bakersfield. This region ranks second to the Mid-Continent in production. Its oils mainly are heavy and of the asphaltic type. Large refineries are located in the vicinity of San Francisco and Los Angeles. Production of oil proceeds at such tremendous rate that the reserves are being used rapidly. In this connection it should be remembered that coal reserves on the Pacific Coast are of relatively small extent.

Caribbean Regions. Bordering the Caribbean Sea are two productive oil regions (Fig. 357). One of them, on the coast of Mexico, includes fields near Tampico and Tuxpam. For some years Mexico ranked second among the oil-producing countries of the world. The oil, however, was removed at such a terrific rate, largely by foreign companies, that Mexico's rank has dropped considerably.

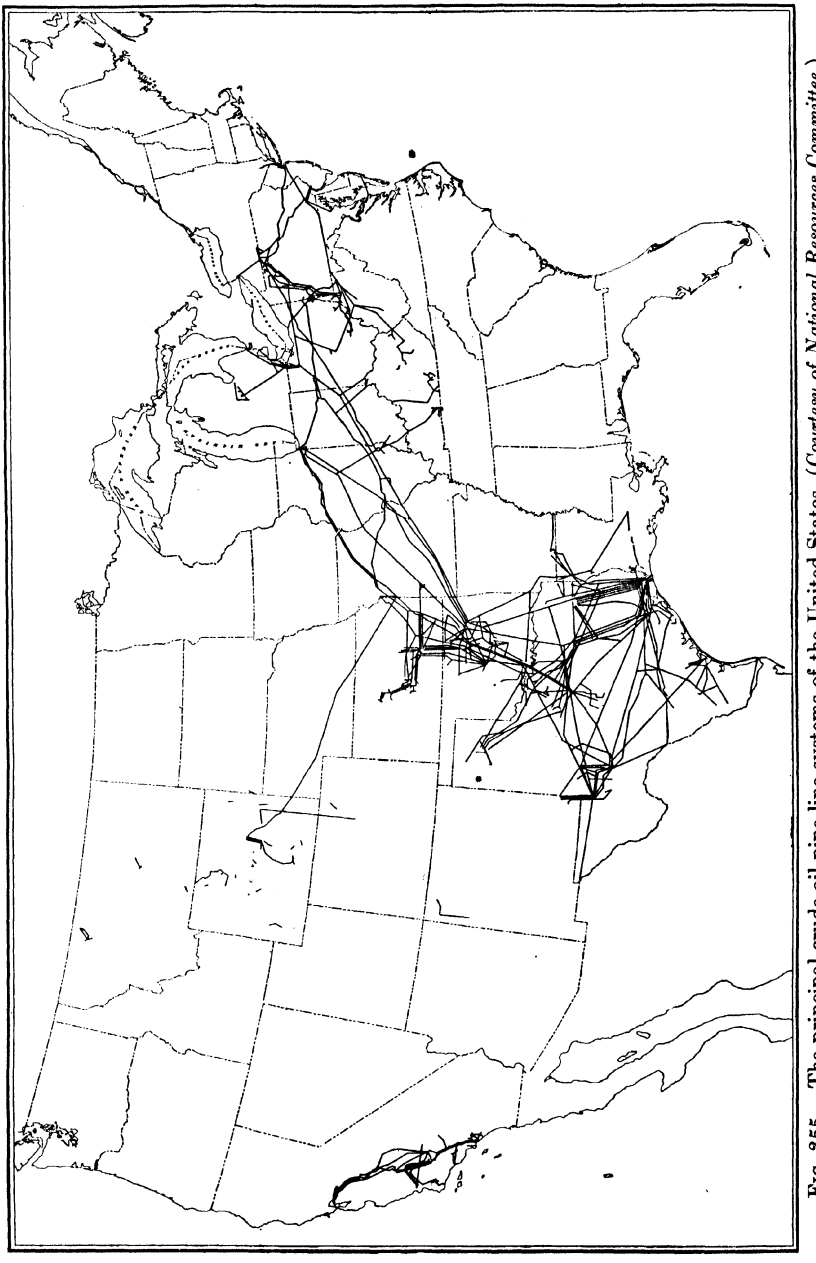


FIG. 355.—The principal crude-oil pipe-line systems of the United States. (*Courtesy of National Resources Committee.*)

A second region includes several fields distributed along the north coast of South America, mainly in Venezuela, Colombia, and the island of Trinidad. The principal field is in the vicinity of the Gulf of Maracaibo, Venezuela. Many wells are located in the gulf itself. At present, Venezuela ranks third in oil production. Much of the oil is shipped on tankers to refineries

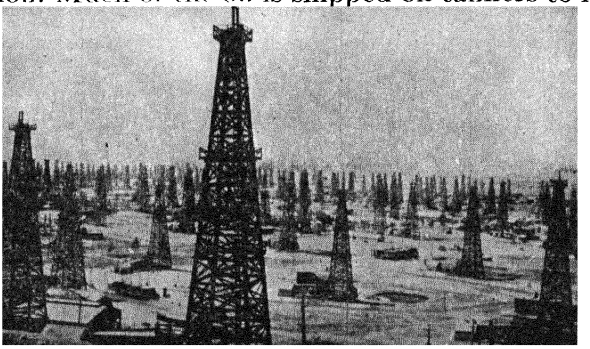


FIG. 356.—The forest of oil derricks that occupies the low arch of Signal Hill, near Long Beach, Calif.

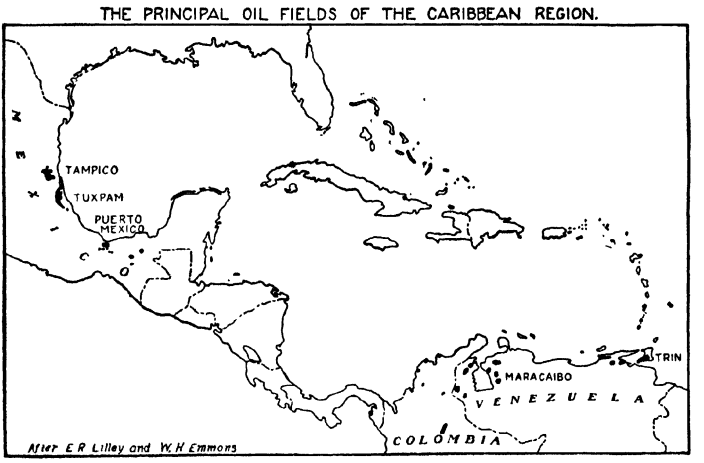


FIG. 357.

on the Atlantic Coast of the United States. Seepage and evaporation from an ancient oil pool in Trinidad gave rise to the famous asphalt lake of that island. The hardened asphalt, removed from the surface, is replaced by the slow upwelling of new supplies from beneath.

Europe. Some oil has been produced for many years in Rumania and Poland. However, the oldest, most persistent,

and most productive fields are in southeastern Russia adjacent to the Caucasus Mountains and the Caspian Sea (Fig. 358). Of several fields in this region, that near Baku on the Caspian Sea is most famous. Russia, ranking second to the United States in oil production, still has vast areas of land to be explored for possible oil fields.

Asia. About the head of the Persian Gulf are the producing fields of Iran (Persia). Known reserves of great importance are located also in Iraq. The control of these resources has been, in recent years, a matter of great concern in international politics.

Some petroleum is obtained from fields in Burma, but a much larger quantity from the East Indies, especially Sumatra

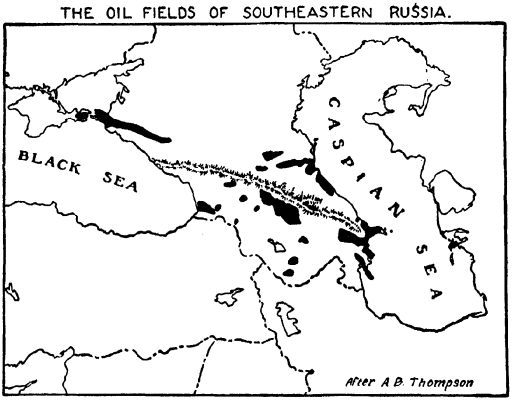


FIG. 358.

and Borneo. The reserves in these islands are believed to be considerable.

ADDITIONAL SOURCES OF PETROLEUM

Oil That the Pumps Cannot Raise. Not all the oil in an oil pool can be obtained by pumping. It is estimated that in some cases as much as half the original supply clings to the rock particles and remains in the ground. Improved methods of recovery may, in the future, make some of that oil available.

Oil Shales. In the United States and elsewhere large supplies of oil-yielding organic matter are contained in compact shales. Petroleum has been obtained from rich oil shales of that kind in Scotland, and it can be done in other localities. How-

ever, the cost of production is high, because the rock must first be quarried or mined and then treated before the crude oil, such as now flows from wells, can be obtained. In the United States considerable supplies of oil shale are known to exist, especially in Wyoming, Colorado, and Utah.

Petroleum Supply Fast Disappearing

How Long Will It Last? The active life of most oil pools is relatively short. Already some good fields have declined in production until they are but minor factors in the national output. The question of how long the United States can maintain its present enormous petroleum production of 900 million barrels per year is not capable of assured answer. It is believed that within a score of years production will be reduced much below the levels to which Americans are accustomed. Deeper drilling and further search probably will bring to light new pools. However, such discoveries become more difficult each year, and according to the National Resources Committee *Report* of 1939 the *known* reserve is sufficient to last for only 20 years at the present rate of consumption.

Ways in Which It Is Wasted. In addition to a tremendous rate of consumption, the people of the United States have been guilty of wasting both oil and natural gas and of wasting huge sums of money in drilling useless wells.

Fires have caused enormous losses in both petroleum and natural gas. In recent years, however, methods of control have been much improved.

War and war preparations place an enormous drain on petroleum resources. Such a drain robs the people of a fast-disappearing fuel. People make good use of the automobile or Diesel-engined ocean liner in traveling from place to place in a country or from one country to another. Travel is not only a pleasure. It educates us and broadens our point of view. It helps us to understand how people live in other parts of the world. Such an understanding promotes tolerance, national harmony, and the increasing demand for world peace. But war is consuming enormous quantities of the very resource that has vastly increased the amount of traveling that people do. The nations of the world are guilty of using a precious fuel for

human slaughter, a fuel that ought to be used for human pleasure and education.

Ores and Other Economic Minerals

Classes of Mineral Resources. In addition to water and the mineral fuels, the earth provides many inorganic substances for human use. In the list are the raw materials of a wide array of industries. The substances are of great diversity. Think for a moment of the vast difference between ordinary sand and the fine metals and jewels in an expensive watch. The mineral resources drawn upon to supply these needs may be grouped as follows:

1. *The Ores of the Metallic Minerals.* These ores are treated in one or more ways in order to separate and concentrate the metals in them. A list of the more important metals includes iron, copper, lead, zinc, aluminum, gold, silver, tin, nickel, platinum, and tungsten.

2. *The Solid, Nonmetallic, Nonfuel Minerals.* In this group are included building stone, sand and gravel, clays, lime, salt, fertilizers, abrasives, and gems.

The Metallic Minerals

Importance of Metals and Their Ores. Before the beginning of written history men knew the value of certain metals, and they sought the materials from which they might be obtained. Man's intelligent use of the metals is largely responsible for the material progress enjoyed by civilization today. It is convenient to think of two general groups of metals:

1. *Precious or Semiprecious Metals.* These occur in relatively small amounts. Examples are gold, silver, platinum, chromium, tungsten, and nickel. Some of these metals are very costly. Gold, for instance, is worth $35 an ounce at the present time.

2. *Nonprecious Metals.* These occur in relatively large amounts. Examples are iron, copper, lead, zinc, and aluminum. These metals are called *nonprecious*, yet as a group they are more useful to man than are the precious metals.

In the various phases of modern industry, metals are used in different ways. In some cases a single metal may be suitable

for a specific use. In others it is found that a combination of several metals, called an *alloy*, is more desirable. For example, brass is a combination of copper and zinc; bronze, of copper and tin; stainless steel, of nickel, chromium, and steel; copper coin, of copper and nickel. Very hard steel is made by adding tungsten; flexible steel, by adding vanadium. Pure aluminum and alloys of aluminum are of tremendous value in the automobile and airplane industries.

A few metals that are used in large quantities, such as iron, may be thought of as fundamental resources. This is particularly true if they occur near supplies of fuel needed to smelt them. Iron is called the most useful of all metals. The possession of a domestic supply of iron ore is considered by the great nations always, next to a supply of coal or petroleum, a matter of major economic importance.

Ore Deposits. An ore deposit is a concentration of a metallic mineral, or one of its chemical compounds, sufficiently rich in metal to make mining profitable. Some metals, for example gold and copper, are found locally in the metallic, or "native," state. More commonly the metallic elements occur in chemical combination with other elements in the form of such compounds as sulphides, sulphates, oxides, and carbonates. The process of separating the metal from the other substances in the ore is called *smelting*.

How Are Ore Deposits Formed? The formation of ore deposits of profitable quality is believed to have been brought about in several different ways. Let us consider the more important ones.

1. *By Underground Water.* Tiny amounts of metallic compounds, scattered through rocks, were taken up by circulating water and deposited at some other place in a concentrated form. This deposition could take place in a rock crevice, in which case a vein of ore was formed. Hot underground water, resulting from contact with hot igneous rocks, was more effective in the work of solution and deposition than was cold water.

2. *By Cooling of Liquid Rock.* When hot igneous rock cooled, it was possible for metallic compounds to come together and to be discovered later as separate masses within the parent rock.

3. *By Contact Metamorphism.* When hot igneous rock was intruded into other rocks, the plane of contact between hot and cold rock was likely to be one of mineralization. This was due not only to the effect of heat itself but also to the chemical work of associated hot water and gases.

Ore deposits are discovered more often in mountains than in plains for two reasons: (1) Conditions in mountains usually are more favorable to the formation of ores and (2) vigorous erosion, characteristic of mountains, exposes the rock formation which may enable the prospector to locate the ore body.

Iron Ores and Their Distribution

Nature of Iron Ores. With the exception of aluminum, iron is the most abundant of the metallic minerals in the rocks of the earth. Because it is so easily oxidized or rusted, it is seldom found in metallic form but in chemical combination. The most important of these combinations are (1) *hematite,* an oxide, mainly dark red in color; (2) *limonite,* the yellow-brown oxide; and (3) *magnetite,* which is black, magnetic iron oxide. The red and brown oxides are particularly abundant. They often give red, yellow, or brown color to soils. Pure hematite and magnetite contain as much as 70 per cent of metallic iron, but most of the ore mined runs much less than this amount.

The distribution and quality of iron ore is a matter of national concern. The deposits of largest present value are (1) high in metallic iron, (2) low in objectionable impurities, (3) capable of being inexpensively mined, and (4) situated so that they may be transported cheaply to regions where the other necessary ingredients of iron manufacture are easily assembled. In addition the manufacturing centers should be near a large market for iron and steel. Few iron-ore deposits meet all those qualifications. A few, which meet enough of them, have attained international importance.

Iron Ores of the United States. In the United States, much more iron ore is mined and used than in any other country of the world. This is in part made possible by the high quality, ease of mining, and convenient location of the ores of the Lake Superior region. Several bodies of ore are located in this region, which includes parts of northern Minnesota, Wisconsin, and

Michigan (Fig. 359). The ores mainly are hematite of a desirable grade. They have been concentrated in the ancient crystalline

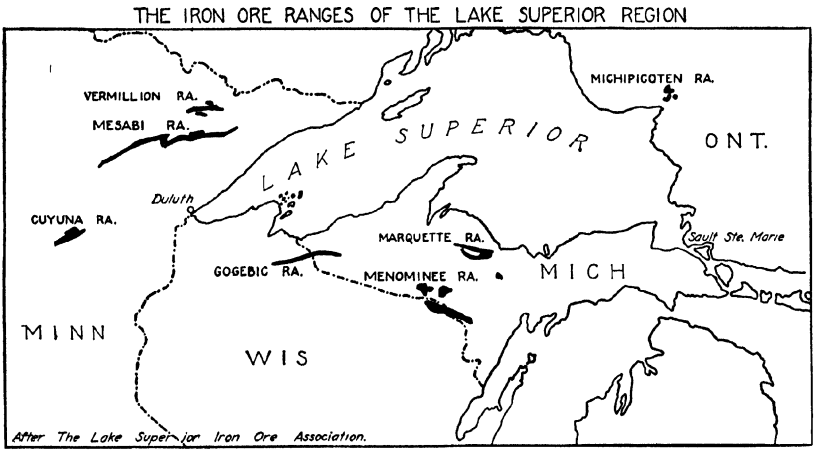


FIG. 359.

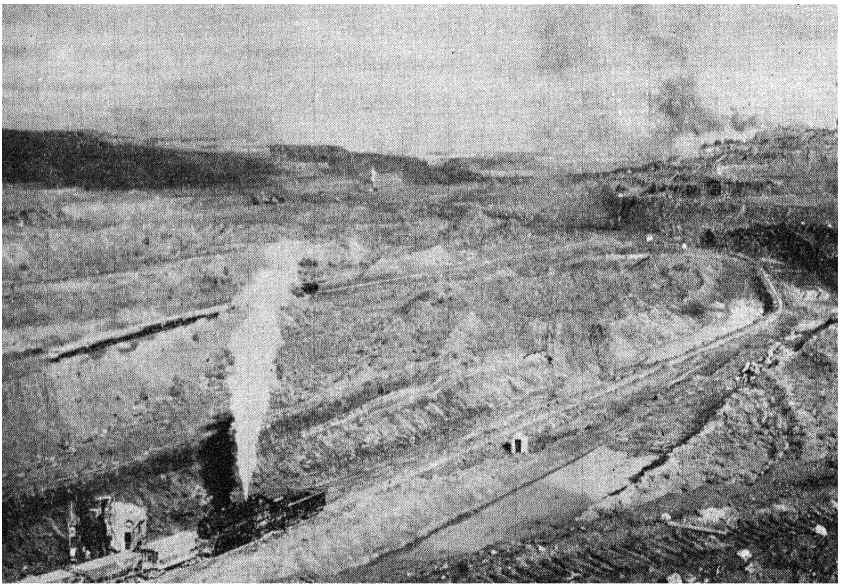


FIG. 360.—Mining iron ore from an open pit in Minnesota. (*Courtesy of U S. Steel.*)

rocks of the region by the work of ground water. They lie in pockets that, in general, are near the surface. In the Mesabi Range north of Duluth, Minn., the ores are overlain by a relatively thin covering of glacial drift. When this surface covering

is stripped away, the ore may be removed by steam shovels in open pits (Fig. 360). It is the most productive body of iron ore in the world.

The relation of the Lake Superior ores to regions of manufacture and market is fortunate also. The construction of a ship canal through the rapids of Saint Marys River, connecting Lakes Superior and Huron, provides a deep waterway for the transportation of ore. Water routes lead almost from the mine to the very margin of the Appalachian coal field and the heart of the American industrial region (Fig. 361). The cost of trans-

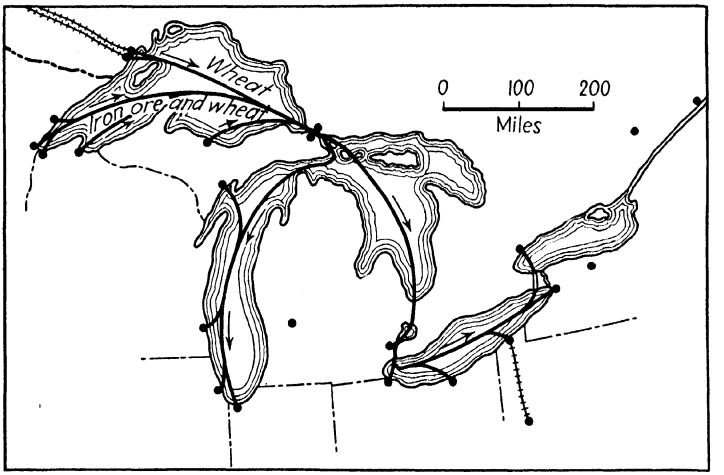


FIG. 361.—The paths of iron-ore and wheat boats from western to eastern lake ports.

portation has been reduced to a very low figure. Huge ore docks are located at Duluth, Superior, Ashland, Marquette, and Escanaba. A boat can be loaded in a very few hours. The boats move south and east to Chicago, Gary, Detroit, Toledo, Cleveland, and Buffalo and even reach Lake Ontario via the Welland Canal. Thousands of tons of ore are unloaded at ports located on the south shore of Lake Erie. From these ports the ore moves by train to the greatest iron- and steel-manufacturing region in the United States, located in western Pennsylvania and eastern Ohio. The ore boats on the return trip to the West carry huge quantities of coal.

Among the sedimentary rocks of the folded Appalachians are beds of hematite which are found in localities from New York to central Alabama. These ores are most used in Alabama, where,

in the vicinity of Birmingham, they are mined along with the necessary coal and limestone needed in smelting.

Iron Ores South of the United States. Iron ore is mined and exported from Cuba and Chile. Some of it reaches seaports on the Atlantic Coast of the United States, which again emphasizes the low cost of water transportation. One of the largest iron-ore reserves in the world is located in Brazil, about 200 miles north of Rio de Janeiro, but it is difficult to reach and is not used now.

European Iron-ore Deposits. The iron industries of Europe depend mainly upon European sources of ore. Like those of North America, the greatest centers of iron manufacture are located in, or close to, the principal coal fields. In Europe, however, much ore must cross international boundary lines.

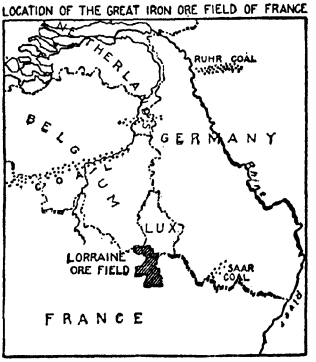


FIG. 362.

The iron ores of France include the largest single iron reserve in Europe and one of the largest ones in the world. They are found in the northeastern part of the country in the province of Lorraine and extend across the boundary into Luxembourg and slightly into Belgium (Fig. 362).

Scattered, low-grade deposits of iron ore are found in the British Isles. It has long been the practice of British smelters to import other ores, especially from Sweden, Spain, and Newfoundland. However, Britain has a sufficient supply of low-grade ores to last for many years.

In the extreme northern part of Sweden are moderately abundant supplies of iron ores, noted for their high quality. They are mainly magnetite, average 55 to 65 per cent iron, and are exported especially to Germany and Great Britain.

Significant Facts about the Iron Resource. The world regions in which abundant deposits of iron ore and of coking coal are closely associated lie on the borders of the North Atlantic Basin. These include eastern United States and the countries of northwestern Europe. In them are the present world centers of heavy iron and steel manufacture and of many other industries that depend on cheap iron and steel. There seems

good geographic basis for believing that those centers will long continue, because no others appear to have better natural endowment or more advantageous location. Perhaps the world's greatest reserves of ore are in Brazil and India. However, Brazil has not any, and India only a limited supply of, coking coal. China has large reserves of excellent coal but no known supply of ore of comparable importance. Also, it may be noted, Japan, now a progressive industrial nation, has but limited domestic supplies of coal and even less iron of usable grade. The United States is fortunate in having abundant supplies of good ore and coking coal situated so that they are practically connected by a deep waterway which provides cheap transportation. However, it is believed that the Lake Superior iron region has reached its peak in production and will show a steady decline in future years. Then other and more expensive sources of ore must be sought. Here, again, conservation demands that corporations and individuals cooperate to avoid waste. The United States exports great quantities of scrap iron. Whether this is a wise policy or not is a debatable question.

Other Metals of Economic Importance

Aluminum. This metal is more expensive per pound than iron largely because rich aluminum ores are scarce and the process of obtaining the metal from its ores is a very costly one. The few aluminum plants in the United States are located near large hydroelectric developments because of the large amount of electric current needed. In combination with oxygen, aluminum is widely distributed throughout the earth's crust. It is an important constituent of clay. The most important mineral is *bauxite* (bôks'ĭt), a name derived from Baux, France, where it occurs. In the United States, deposits of bauxite are found in Arkansas, Georgia, Alabama, and Tennessee. Aluminum has several valuable properties. It is strong, light in weight, does not corrode or rust easily, and is a good conductor of electricity. It forms valuable alloys with other metals. In a powdered form it is used to make a metallic paint.

Lead and Zinc. Deposits of the metallic minerals are characteristic of mountainous regions, yet there are notable exceptions. One such exception is found in the deposits of lead

and zinc ores associated with sedimentary rocks. Examples of these are found in southwestern Wisconsin and adjacent Illinois, the famous Joplin district in southwestern Missouri, northeastern Oklahoma, and southeastern Kansas (Fig. 363). The Joplin area, in addition to its output of lead, has long been the leading producer of zinc. Large deposits of galena in southeastern Missouri place that state first in lead production. Other regions of note are the zinc deposits of New Jersey and

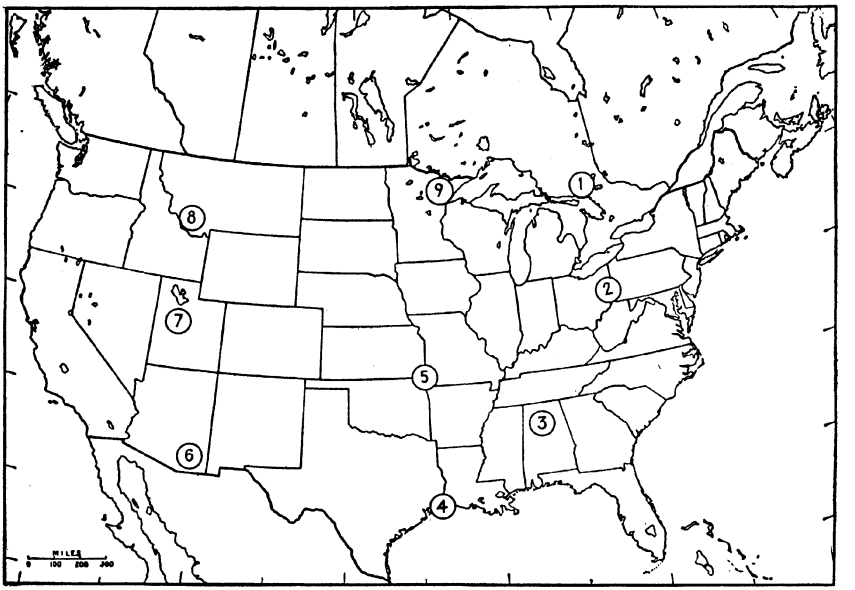


FIG. 363.—The following regions are shown by number: (1) nickel-producing region of Ontario; (2) iron- and steel-manufacturing district of Pennsylvania and Ohio; (3) Birmingham iron and steel district; (4) sulphur-producing region; (5) Tri-State lead and zinc region; (6) Arizona copper region; (7) Utah copper region; (8) Anaconda-Butte copper region; (9) Mesabi iron-ore region.

the lead deposits of Utah and Idaho. Among the nations of the world the United States ranks first in the production of both lead and zinc. These metals are useful in many ways. Lead is valuable especially in making hollow pipe, which is easily bent and very durable, and in the manufacture of batteries. Zinc is used in making brass and as a thin coating on sheets of steel forms the familiar galvanized iron. Both metals are used in the manufacture of paint and munitions.

Copper, Nickel, and Tin. As in the case of lead and zinc, the United States ranks first in the production of copper. The

mines in the high Andes Mountains of Chile, largely owned and operated by Americans, put that country in second place. Three



FIG. 364.—Looking down upon Bingham, Utah, and Bingham Canyon, where large quantities of low-grade copper ore are mined on the open mountain side. (*Courtesy of U.S. Army Air Corps, photograph by Capt. A. W. Stevens.*)

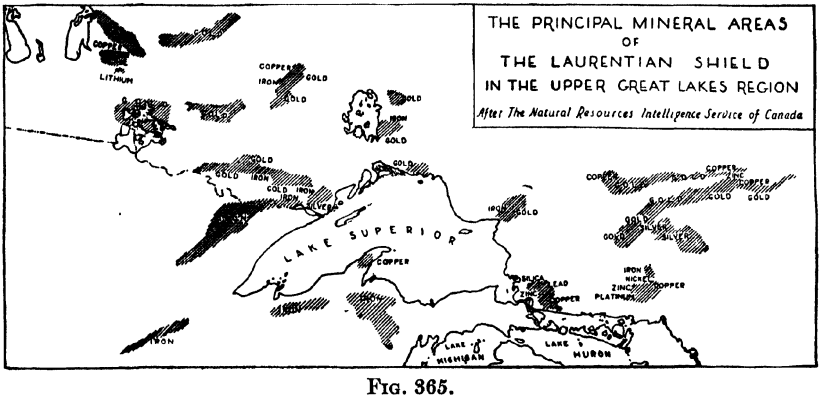


FIG. 365.

important copper-producing districts in the United States are (1) southern Arizona, (2) northern Utah, and (3) western Montana. The Utah mines produce relatively low-grade ore, yet the

yearly output is tremendous (Fig. 364). The Anaconda-Butte district in western Montana has produced copper, gold, and silver worth many millions of dollars. Since copper is an excellent conductor of electricity, huge quantities of it are used in the making of wire and electrical apparatus.

The principal known world resources of nickel and tin are outside the United States. Ninety per cent of the world's supply of nickel is produced in Ontario, north of Lake Huron. This area produces considerable quantities of other metals, including gold, silver, and copper (Fig. 365). Nickel is one of the most valuable metals in the making of alloys. Tin is produced mainly in the Malay Peninsula and near-by islands and in the high mountains of Bolivia. An important use of it is in the making of tin cans which consist of a thin sheet of steel coated with tin. The metal has many other uses.

Gold and Silver. At the present time the greatest gold- and diamond-producing region in the world is in the vicinity of Johannesburg and Kimberley, located in South Africa. About one-half the world's output of gold is produced in this district. Production of gold has recently been stimulated in Canada by new discoveries and in the United States by the increase in price from $20 to $35 an ounce. South Dakota, California, and Colorado are leading United States producers. In the production of silver, Mexico is far in the lead, with the United States and Canada next in rank. Utah, Idaho, and Montana are leading producers of the silver ores.

The Nonmetallic, Nonfuel Minerals

Quartz, Lime, Clay, and Gypsum. Quartz sand is used in large quantities and in many ways. It is an ingredient of concrete, mortar, and plaster. In the manufacture of glass, sand is the chief raw material used. Good grades of glass sand, free from iron or clay, may be sought hundreds of miles from the centers of glass manufacture. Since quartz is harder than most steel, it can be used effectively as an abrasive. The sandblast is employed to clean stone and metal surfaces. Different sizes of sand particles are used in making the various grades of sandpaper. Nature cements the sand particles together to form sandstone, which in turn may be metamorphosed into quartzite. In certain regions

sandstone and quartzite constitute valuable resources because of their use as building and industrial stones.

Lime, a combination of calcium and oxygen, is ordinarily pure white in color. Much of it is made by heating suitable grades of limestone. Lime is a most important building material. Mortar, used in laying brick and stone, is made of a mixture of lime, sand, and water. One of the most valuable of all building mate-

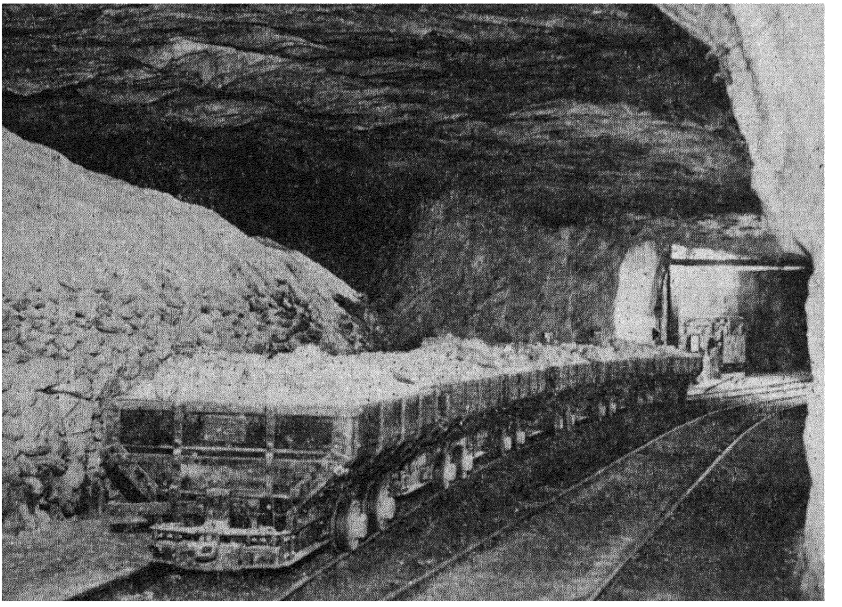


FIG. 366.—This view inside a salt mine near Hutchinson, Kans., shows cars loaded with rock salt, which is mainly white to light gray in color. Some rock salt, or halite, is as clear as glass. (*Courtesy of Carey Salt Co.*)

rials, cement, is manufactured by using a mixture of limestone and shale. The mineral calcite is the principal ingredient of limestone, which in some localities is a valuable building stone, an example being the famous Bedford limestone, quarried in southern Indiana. Under the processes of metamorphism, limestone changes to marble, excellent grades of which are quarried in Vermont, Georgia, and Tennessee.

Clay and mud form shale which may in time be changed to slate. Slate is valuable because it is extremely fine grained, splits into thin layers, and is hard and impervious. Deposits of pure clay vary considerably in their qualities. Some are extremely

valuable in the making of brick, tile, pottery, and fine chinaware.

Gypsum is a relatively abundant mineral, often found in thick beds of sedimentary rocks. It is mainly white to gray in color. Deposits of commercial value are mined in a number of localities in the United States. The mineral is put to a large variety of uses. It is employed in making plaster used to finish the interior walls of buildings. It forms plaster of Paris, a powder that when moistened can be molded; exposure to the air causes

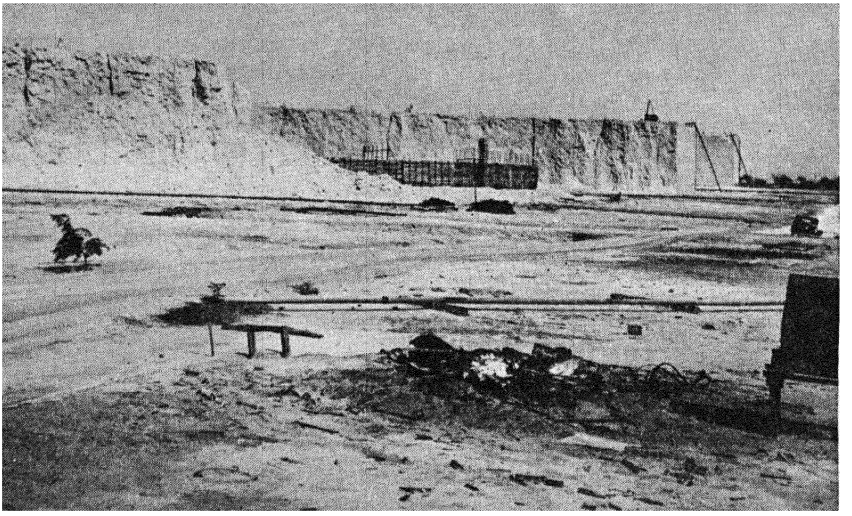


FIG. 367.—Part of a million tons of sulphur in storage, near Matagorda, Tex.

the molded material to harden. Gypsum building-block and roofing materials are used extensively. A variety of gypsum, called *alabaster*, can be carved or shaped into beautiful designs. A good grade of alabaster is mined not far from Fort Collins, Colo.

Salt. Salt is one of the common rock minerals of the earth. Because of its solubility in water, it is not abundant in the zone of free ground-water circulation. Inexhaustible supplies are available for human use, however, from the following sources: (1) the sea, which contains $2\frac{3}{4}$ pounds of salt for every 100 pounds of water; (2) salt lakes, such as the Dead Sea in Palestine and Great Salt Lake in Utah; (3) natural brines, which are the

waters of ancient seas trapped in sediments, deep underground and cut off from ground-water circulation; (4) deposits of rock salt, which probably were formed by the evaporation of salt water in the arms of ancient seas or in former arid interior drainage basins. Salt is used not only as a food and a preservative of food but also in large quantities in chemical industries. It is the basic raw material from which a number of the compounds of sodium are made. Thick beds of rock salt underlie large areas in New York, Michigan, Ohio, Kansas, and Ontario (Fig. 366). Other large reserves are found in the buried "salt domes" of the Louisiana-Texas Gulf Coast.

Sulphur. This mineral has many uses in modern industry, especially in the form of sulphuric acid and for various uses in connection with the manufacture of steel, oil, rubber, and explosives, and in other chemical industries. It has long been obtained from deposits associated with recent volcanic activity. Some still is mined from these sources in Italy, Spain, Japan, and Chile. In the United States, which now produces more than four-fifths of the world's supply, the deposits have no immediate volcanic connection. Instead, they are found in association with petroleum and the rock-salt deposits of the Louisiana-Texas coast. There the sulphur is recovered by means of wells through which superheated water is pumped underground to the sulphur beds and molten sulphur is returned to the surface (Fig. 367).

Mineral Fertilizers. Four critical elements of soil fertility have been mentioned previously as subject to depletion by crop production and the leaching action of ground water. These are *calcium*, *potash*, *phosphorus*, and *nitrogen*. For each of these there are known sources of mineral supply that are drawn upon in the manufacture of commercial fertilizers. Some sulphur also is employed for this purpose. Soil lime, in the form of calcium carbonate, is readily available in the local limestones of many regions. The location of supplies is not a matter of national concern. The other three are much less abundant, and notable deposits of them are items of earth resource of great importance.

Nitrogen is the most abundant element in the air, and methods are now in use for transforming it into nitrogenous

compounds by means of electric energy. Until recently, however, the principal world supply was from mineral sources. Most important of these were the surface deposits of the desert of Atacama, in northern Chile (Fig. 368). There we find the accumulations of ages of seepage and surface evaporation. The valuable mineral *nitrate of soda* is intermingled with sand, common salt, and other substances from which it is separated by a simple manufacturing process. So much in world demand was this mineral that, for many years, taxation upon its export was the principal financial resource of the Chilean government and the business of its extraction and shipment supported a considerable population in the midst of a desert and in several seaports.

Potash forms a part of many plant tissues and is obtained in small quantities from the ashes of wood, seaweed, and other substances. The principal commercial sources are complex minerals containing potash which are found in beds like rock salt, with which they are in some places associated. The largest known deposits are located in western Europe, mainly in Germany and Alsace, where the greater part of the world's present supply is obtained from mines 1,000 feet or more beneath the surface. A reserve of potash is located in a region that lies a few miles east of Carlsbad, N.M.

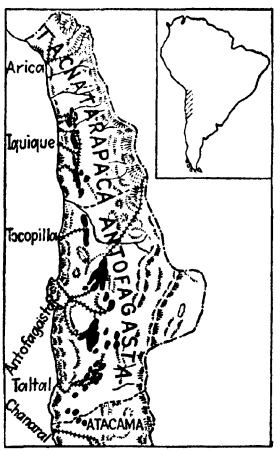


FIG. 368.—The location of the principal nitrate of soda deposits in the desert of northern Chile. (*After Tower, in Miller and Singewald's "Mineral Deposits of South America."*)

Phosphorus is present in certain rock minerals and from them is supplied to the soil. It is also an important constituent of the grains and other plant materials, but it is stored mainly in animal substances, especially in bones, animal manures, and fish. From these sources some is returned to the land as fertilizer. The principal mineral sources of phosphorus occur in the form of calcium phosphate, a rock. Valuable beds of phosphate rock usually occur as local pockets in limestone strata and are known to exist in several parts of the world. The United States is supplied

largely from beds in western Florida and central Tennessee (Fig. 369).

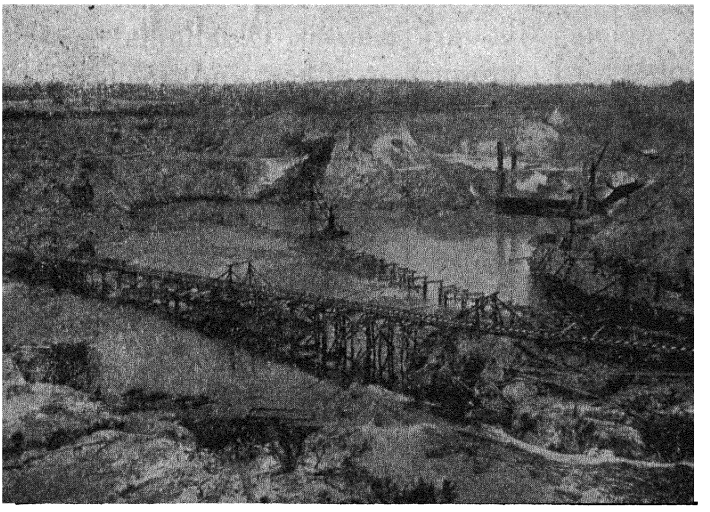


FIG. 369.—Mining phosphatic limestone for its phosphorus content, in central western Florida.

Summary

Coal beds represent long periods of accumulation during which the remains of plant life were preserved from the ordinary processes of complete decay. The various types of coal are known as peat, lignite, bituminous, semianthracite, and anthracite. In North America the principal coal fields are (1) the Appalachian, (2) that which extends from Illinois and Iowa south into Texas, and (3) the widely scattered beds of the Rocky Mountain region. Asia is believed to rank second to North America in coal reserves.

Petroleum, natural gas, and asphalt are related earth resources, probably of organic origin. At the present time the United States is by far the principal producer of petroleum. Other producing areas are found in Russia, Venezuela, Rumania, Iran (Persia), the East Indies, and Mexico. The petroleum resources of the world are being consumed at an enormous rate.

The metallic ores are especially valuable to industrial nations. Of these ores, iron ore probably is of greatest importance. The United States mines and uses more iron ore than any other

country in the world. The leading producing states are Minnesota, Michigan, and Alabama.

Deposits of bauxite, the principal ore of aluminum, are found in Arkansas, Georgia, Alabama, and Tennessee. The famous Tri-State region (Missouri, Kansas, Oklahoma) around Joplin, Mo., is noted for its production of lead and zinc ores.

Among the important nonmetallic minerals of great value to man are lime, gypsum, clay, sand, salt, and sulphur. In the manufacture of mineral fertilizers, lime, potash, phosphorus, and nitrogen are of major importance.

Questions

1. List three important sources of power.
2. From what material is coal derived?
3. Why is the horizontal position of many coal beds an advantage in the processes of mining?
4. Mention one method used by geologists in estimating coal reserves.
5. Name and describe the principal varieties of coal.
6. What is meant by the accessibility of coal deposits?
7. Why do folding and faulting often increase the difficulties of mining?
8. Locate the principal anthracite region of the United States. Why is anthracite an expensive fuel?
9. Locate the Appalachian bituminous region. What is coking coal? Why is it valuable?
10. Mention several reasons for Pittsburgh's importance as an iron and steel center.
11. Account for the fact that Birmingham is noted for its iron and steel manufactures.
12. Locate additional coal fields in the United States other than the Appalachian field.
13. Make a statement concerning the coal resources of South America.
14. What is the probable rank of the continents with regard to coal reserves?
15. Locate the more important coal fields of Europe.
16. What country is thought to rank second to the United States in coal reserves? Where are these reserves located?
17. Mention several measures that apply to coal conservation.
18. Petroleum deposits are associated with which class of rocks? Why?

19. Diagram and explain how an oil pool may be trapped in an anticline.

20. For what qualities is the petroleum of the Appalachian field noted?

21. Locate the eastern interior and Mid-Continent oil fields.

22. What proportion of the entire petroleum output of the United States is produced in the Mid-Continent field?

23. Look up the present annual production of leading oil-producing states.

24. Locate the Gulf Coast oil region.

25. Mention several ways in which oil and gasoline are transported.

26. Where are the principal California oil fields and refineries located?

27. Locate the two principal oil fields south of the United States.

28. Why is a high percentage of oil exported from the Maracaibo region?

29. Locate the island of Trinidad. For what resource is it noted?

30. Name the three leading countries in rank in oil production.

31. Where is the most productive oil field of Europe?

32. Locate the oil reserves of Asia.

33. Where are deposits of oil shale located in the United States? Why is oil shale thought to be a costly source of petroleum?

34. Mention two or three ways in which we might conserve the oil supply.

35. What are the two principal classes of metals? Give examples of each.

36. Define alloy. Give three examples.

37. Why is a supply of iron ore considered by the great nations a matter of major economic importance?

38. Define ore deposits. Smelting.

39. Explain three ways in which ore deposits may be formed.

40. Why are ore deposits discovered more often in mountains than in plains?

41. Name three iron ores. Which two are most abundant?

42. What are the qualifications of a good iron-ore deposit?

43. Why are ores of the Mesabi range easily mined?

44. Name the principal lake ports noted for the export of iron ore. The ore boats unload at most of the larger cities of the lower Great Lakes. Name 10 such cities.

45. Locate the greatest iron- and steel-manufacturing region in the United States.

46. Mention several reasons why the Great Lakes region is one of tremendous industrial development.

47. Locate the iron reserves of Europe.

48. What are handicaps of iron and steel manufacturing in Brazil? India? Japan? China?

49. Why is aluminum a relatively expensive metal?

50. Name the principal ore of aluminum. Where is it found in the United States? What are several valuable properties of aluminum?

51. Locate the Joplin Tri-State mining region. What are some uses of lead? Zinc?

52. Locate the four principal copper-producing regions of the United States.

53. Where are the principal regions now producing nickel and tin? Gold and silver?

54. Mention several uses of quartz sand. What is an abrasive?

55. What basic materials are used in making cement?

56. The mineral calcite ($CaCO_3$) is the most important ingredient of what two important building stones?

57. What are several uses of clay? Slate? Gypsum? For what is alabaster used?

58. Mention four sources of salt. Where are notable beds of rock salt found in the United States?

59. How is sulphur mined in the Louisiana-Texas coast region? What proportion of the world's sulphur supply is produced in the United States? What are some uses of sulphur?

60. Name the four principal chemical elements required in the manufacture of commercial fertilizers.

61. What are two sources of nitrogen? Where is the Atacama Desert? What is its importance?

62. Locate the principal regions now producing mineral potash and phosphorus.

Suggested Activities

1. By referring to a map of the world, review the location of places mentioned in this chapter.

2. Secure samples of different kinds of coal.

3. Seek the cooperation of local oil companies or distributors in the preparation of a display of petroleum products.

4. Make a list of building stones and metals used in the construction of your school building. Make note of the specific use or uses of each one.

5. Secure samples of as many metals as possible.

6. If possible, purchase from the Superintendent of Documents, Government Printing Office, Washington, D.C., two large wall maps

of the United States showing (1) the coal fields and (2) petroleum fields and pipe lines.

7. Find out if there is a state planning board in your state. If so, write for publications dealing with natural resources of the state and for information concerning any steps being taken toward conservation of resources.

8. Secure specimens of the minerals, both metallic and nonmetallic, mentioned in this chapter. You will probably be interested in learning to identify these materials.

9. Perhaps you can obtain motion pictures or slides that will show (1) iron-ore production and shipping on the Great Lakes and (2) iron and steel manufacturing.

10. Find out all you can about the uses of gypsum. If possible, plan an exhibit of gypsum products.

11. If it is possible, make field trips to local quarries, mines, or industrial establishments that might in any way be related to the subject matter of this chapter.

12. Plot curves to show production of coal, iron ore, and petroleum for the past 20 years in the United States.

13. On a large wall outline map of the world, use various colors to show the location of regions noted for the production of resources mentioned in this chapter.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. The Uses of Coal
2. The Anthracite Region of Northeastern Pennsylvania
3. The Mid-Continent Oil Field of the United States
4. The Asphalt Lake of Trinidad
5. The Copper-producing Area of Bingham, Utah
6. The Lake Superior Iron Region
7. The Iron- and Steel-manufacturing Region of Pennsylvania and Ohio
8. Aluminum Resources and Industry of the United States
9. Coal Mining in West Virginia
10. The Anaconda-Butte Mining Region of Montana

REFERENCES

BAYLEY, W. S.: *A Guide to the Study of Non-metallic Mineral Products*, Henry Holt & Company, Inc., New York, 1930.

EMMONS, W. H.: *Geology of Petroleum*, McGraw-Hill Book Company, Inc., New York, 1931.

LEITH, C. K.: *World Minerals and World Politics*, McGraw-Hill Book Company, Inc., New York, 1931.

Mineral Resources, U.S. Bureau of Mines, Washington, D.C. (published annually).

Report of the National Resources Board, Washington, D.C., 1934.

RIES, H.: *Economic Geology*, John Wiley & Sons, Inc., New York, 1930.

TARR, W. A.: *Introductory Economic Geology*, McGraw-Hill Book Company, Inc., New York, 1930.

Chapter XIX. Major Physical Regions and Resources of the United States

The United States may be thought of as a huge, outdoor laboratory where variations in climate, landforms, natural resources, and land utilization can be observed and studied. If we were to make an automobile trip from Chicago to San Francisco via Denver, we should first travel for several hundred miles through a region of rich farming country. From central Nebraska or Kansas to the Rocky Mountains we should see the vast, rolling, semiarid steppe lands of the Great Plains. Immediately west of Denver we should climb the Rockies, crossing the continental divide at an elevation of about 11,000 feet above sea level. Then on to Utah, where a low divide provides an easy crossing of the Wasatch Mountains, from which we should descend into Salt Lake City. Our route now leads us across the vast, arid Great Basin to the Sierra Nevada Mountains, the Great California Valley, and finally through the Coastal Ranges to San Francisco.

This trip would lead us across several regions. Each has certain physical characteristics and possibilities for human use that set it apart from the others. This chapter consists mainly of descriptions of these major regions of the United States (Fig. 370). The descriptions deal principally with landforms but include, as well, brief mention of climatic conditions, resources, and human activities. For convenience, the regions will be discussed in order, beginning with the Pacific Coast area, then advancing eastward to the mountain and plateau provinces, the Middle West, the South, and the East.

As we study these major regions, we should observe their relation to the principal agricultural regions of the United States (Fig. 371).

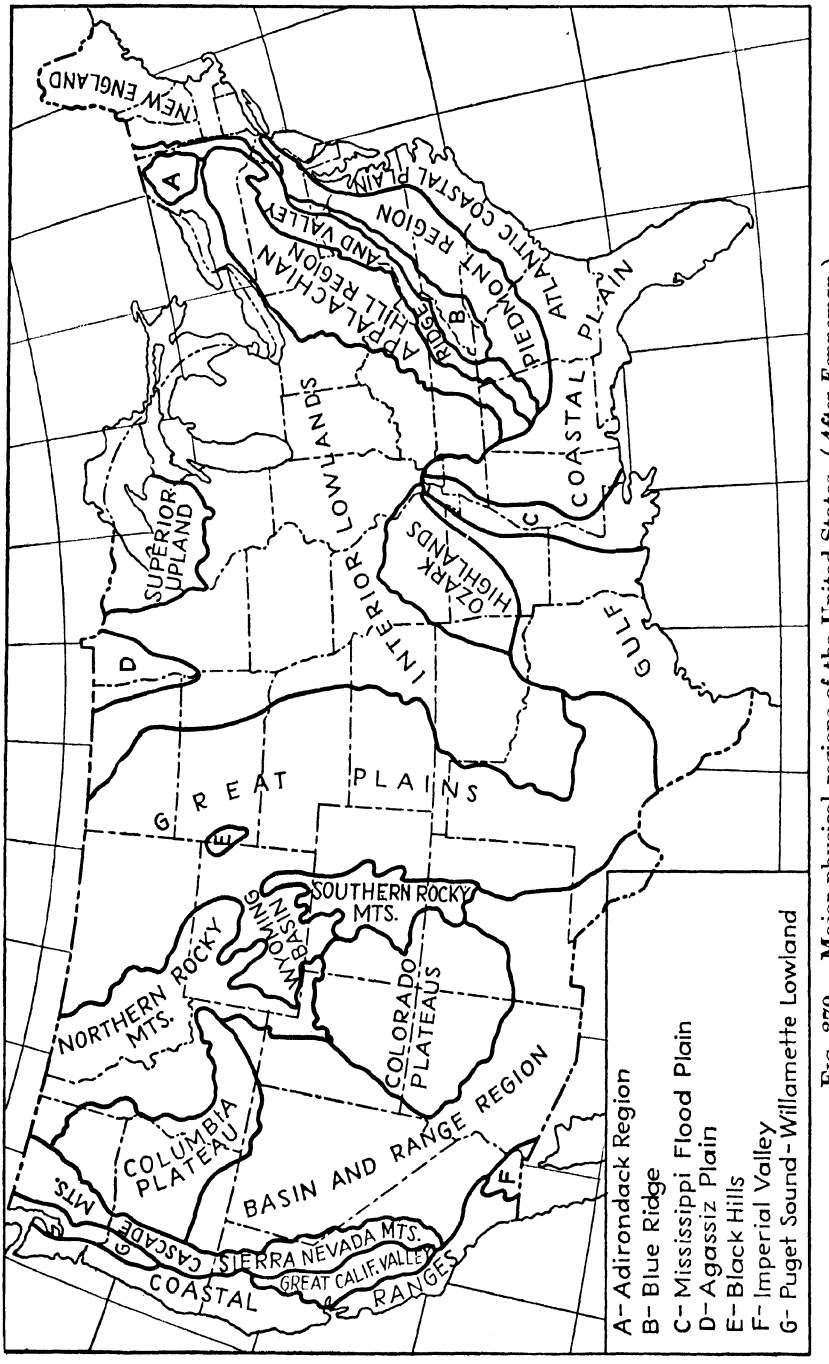


FIG. 370.—Major physical regions of the United States. (*After Fenneman.*)

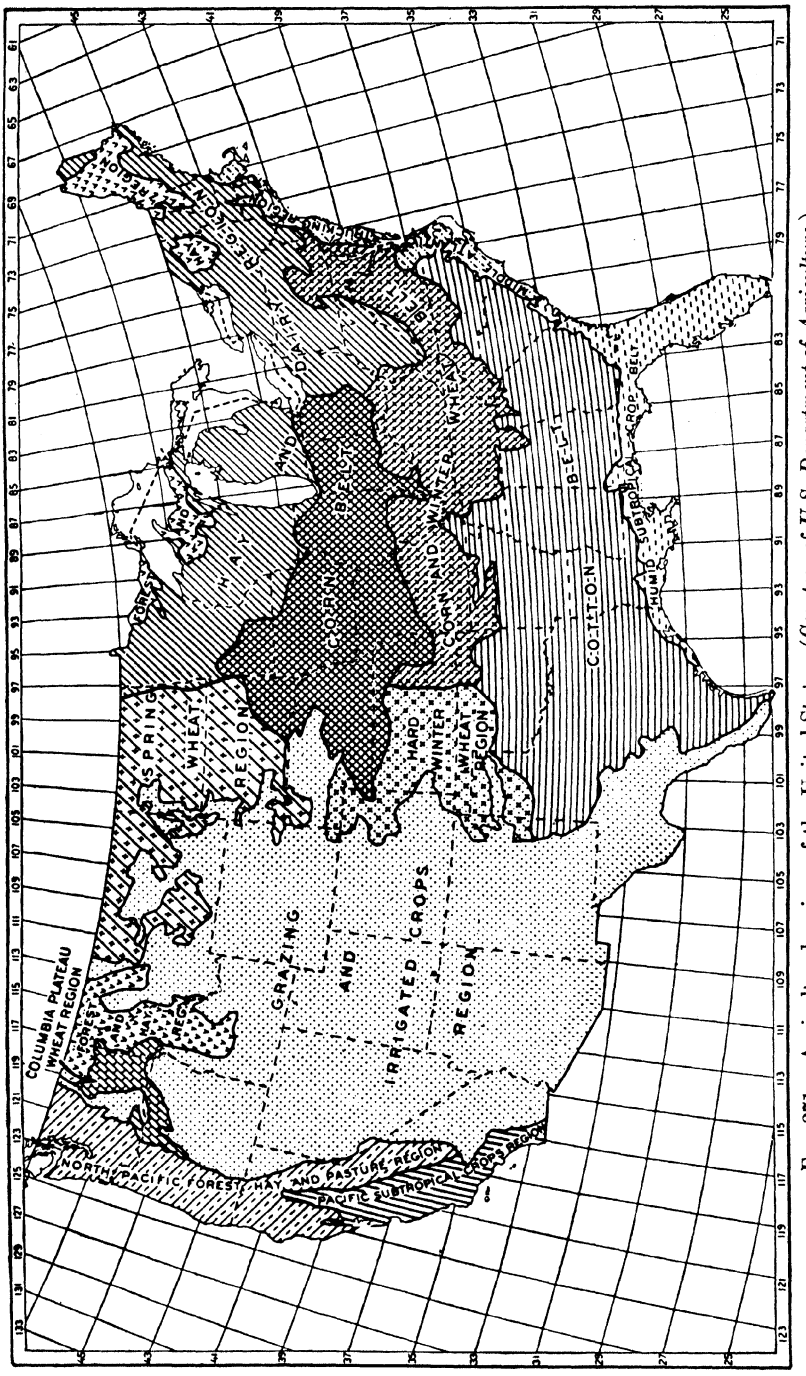


FIG. 371.—Agricultural regions of the United States. (*Courtesy of U.S. Department of Agriculture.*)

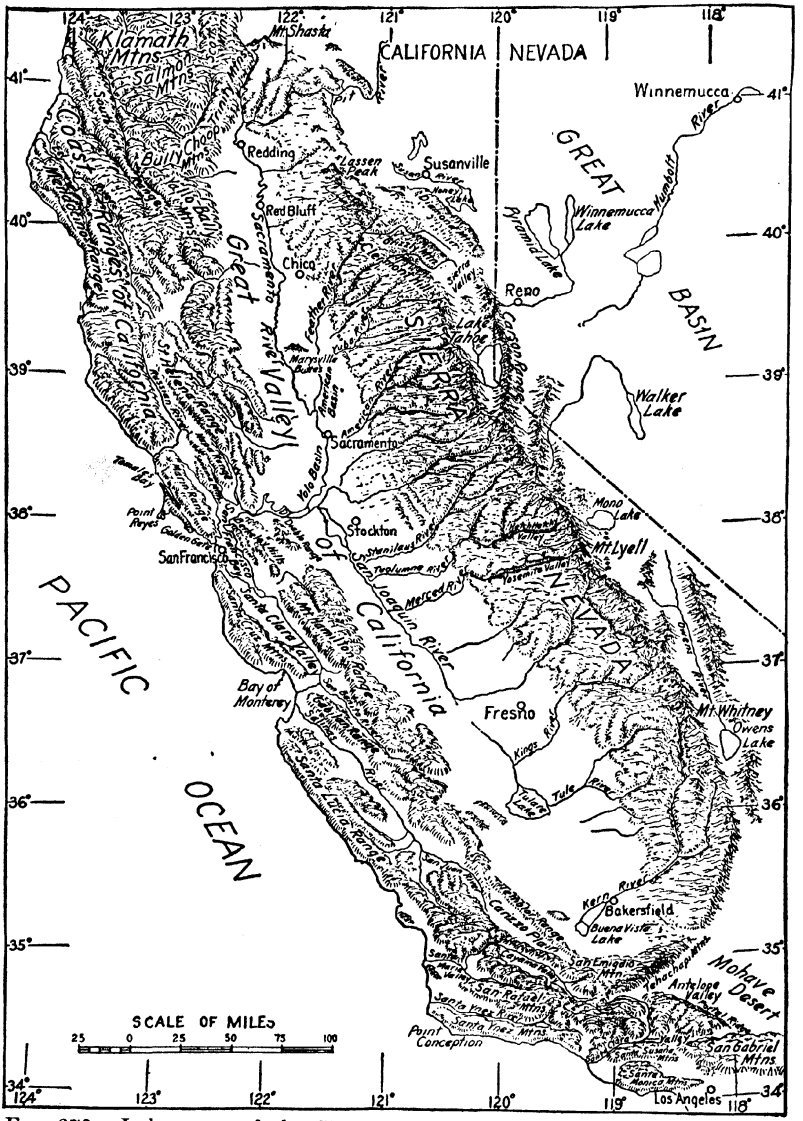


FIG. 372.—Index map of the Sierra Nevada and adjacent sections. (*Drawn by Guy-Harold Smith. Courtesy of N. M. Fenneman, from Physiography of Western United States.*)

The Pacific Coast

Let us study a physical map of the United States, giving our attention first to the Pacific Coast states. Immediately we note that these states are very mountainous. The mountains trend in a north-south direction. They are arranged roughly in the shape of a letter H, the Coastal Ranges forming the left,

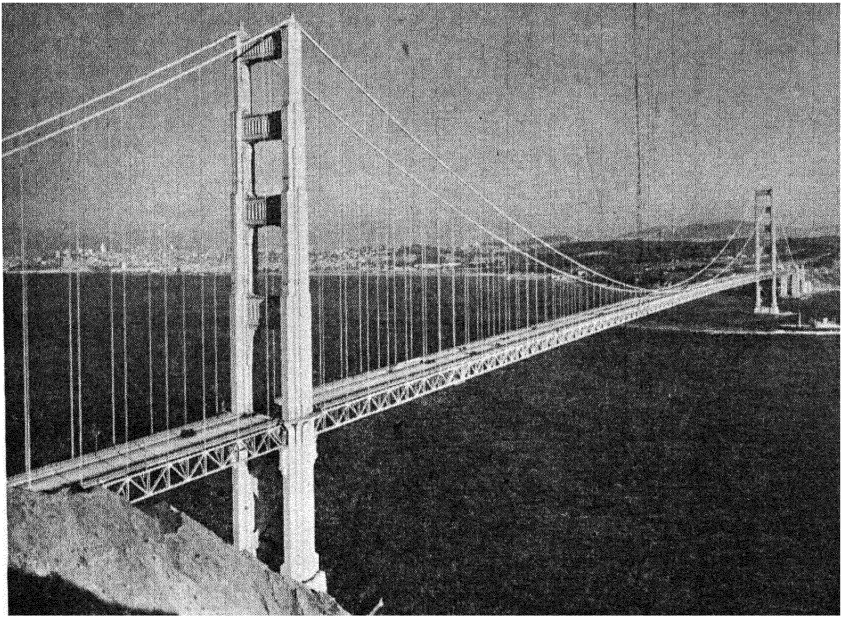


FIG. 373.—The Golden Gate Bridge, built at a cost of 35 million dollars, joins metropolitan San Francisco and north bay counties. Its two main cable towers are 746 feet tall and 4,200 feet apart, making the structure the tallest and longest single-span suspension bridge in the world. (*Courtesy of Redwood Empire Assn.*)

or west, upright line, the Sierra Nevada-Cascades the right, or east, line, and the Klamath Mountains in southern Oregon the crossbar. North of the crossbar is the lowland occupied in part by Puget Sound, and to the south lies the Sacramento-San Joaquin Valley of California (Fig. 372). Since the Coastal Ranges border the ocean shore, the Pacific Coast is one that, unlike the Atlantic, has practically no coastal plain. Furthermore, the Pacific is a fairly regular coast, whereas the Atlantic, throughout much of its length, is irregular. This means, of course, that there are fewer natural harbors on the Pacific than

on the Atlantic. The climate of the Pacific Coast is marine, being much influenced by westerly winds from the ocean. Roughly, north of San Francisco, marine west-coast climate prevails; to the south the Mediterranean type is characteristic.

Coastal Ranges. The Coastal Ranges border the Pacific Coast from Washington to and including the peninsula of Lower California. These mountains are not high, yet they have sufficient elevation to influence rainfall, especially in California. In the main they consist of folded and faulted sedimentary rocks,

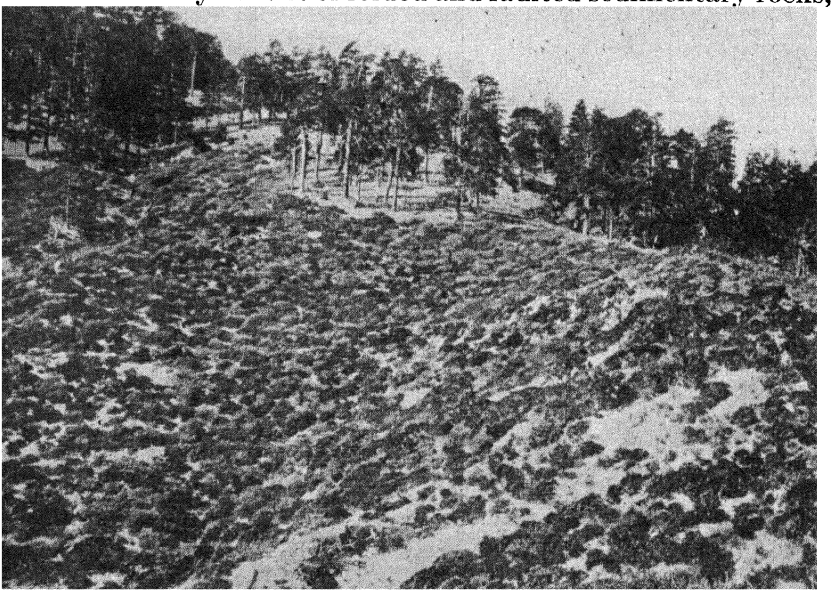


FIG. 374.—Many of the hills of the Coastal Ranges in southern California are covered with chaparral. The transition between chaparral and timber may be seen in this picture. (*Courtesy of U.S. Forest Service.*)

and in many places they rise abruptly from the ocean. One of the important breaks that occurs in the Coastal Ranges is San Francisco Bay (Fig. 373), on which are located the three important cities San Francisco, Oakland, and Berkeley. Another break is the estuary of the lower Columbia River. At considerable expense, this waterway has been made wide and deep enough to accommodate ocean liners which move upstream to Portland, an important seaport. Farther north, the Straits of Juan de Fuca provide a passageway from the ocean to Puget Sound, on which are located Seattle and Tacoma.

Since the Coastal Ranges lie almost at right angles to the westerly winds, they receive abundant rain on their western slopes, north of San Francisco, but the eastern slopes are relatively dry. The heaviest annual rainfall in the United States, over 150 inches, has been recorded in the Olympic Mountains, located west of Puget Sound in Washington. The abundant moisture, aided by the moderating effect of winds from the ocean, has produced one of the finest forests in the world. North of San Francisco in California are the great redwood forests, and farther north in Oregon and Washington are considerable stands of the magnificent Douglas fir. Lumbering, therefore, is an important industry in the Pacific Northwest. South of San Francisco the trees give way to chaparral (Fig. 374), a vegetation cover characteristic of certain areas having the subhumid Mediterranean type of climate.

Among the Coastal Ranges are many valleys filled with rich alluvial soil, much of which in California is in the form of alluvial fans. These areas are irrigated in many places and are highly productive. The Santa Clara Valley near San Francisco is noted for the production of prunes; the Rogue River Valley in southwestern Oregon, for pears. Irrigated valleys in southern California have made that region famous for citrus-fruit production. Thousands of cars of oranges and lemons are shipped each year to Central and Eastern states. Fresh and dried fruits are exported from San Francisco and Los Angeles.

Hollywood, a suburb of Los Angeles, is the motion-picture center of the world. The industry owes its development in part to certain advantages of Mediterranean climate and to a variety of scenery provided by near-by mountains, valleys, deserts, and ocean shore. A natural harbor behind an offshore bar at San Diego, in addition to a mild climate, early established that port as a naval base and in recent years as an aviation base. It is the headquarters of the Pacific fleet. The rich oil fields along the southern California coast, especially near Long Beach, have provided an abundant supply of petroleum and natural gas.

Lowlands of the Pacific States

General Characteristics. Immediately east of the Coastal Ranges are several important lowlands where soils consist in

large part of sediments washed from near-by mountains. These alluvial soils, many of which must be irrigated, constitute some of the principal agricultural lands of the Pacific states. The lowlands have a sort of linear arrangement and from north to south are known as (1) the Puget Sound-Willamette lowland; (2) the Sacramento-San Joaquin lowland, or Great California Valley; and (3) the Imperial Valley.

Puget Sound-Willamette Lowland. This lowland is located between the Cascade Mountains and the Coastal Ranges. The land surface is by no means level. Some glacial drift is found in the Washington lowland, and in parts of the Willamette Valley large hills project through deposits of alluvial soil. The climate is typically marine. Annual rainfall varies from 20 to 60 inches, being less than on the western slopes of either bordering mountain range. Much of the lowland is cut-over forest, and a considerable problem in some localities is the removal of stumps which may be 6 to 8 feet in diameter. Owing to mild and moist climate, pastures are excellent most of the year so that dairying thrives near the larger cities.

This lowland is the most densely populated part of Washington and Oregon. From north to south the more important cities are Seattle, Tacoma, Olympia, Longview, Portland, Salem, and Eugene. Seattle, Tacoma, and Portland are outstanding as commercial cities. They lie in the path of trade between the United States and the Orient, much of which utilizes the Columbia River passageway through the Cascades. Puget Sound is an excellent harbor, although anchorage is somewhat difficult because of the depth of the water. Near Seattle is Lake Washington, a fresh-water lake connected by canal with Puget Sound. Ships may anchor in the lake long enough for barnacles to die and fall to the bottom.[1] Prominent among the exports of the region are lumber and lumber products, fresh and canned fruits, and canned fish, especially the salmon of the Columbia River. Imports include many commodities from the Orient. The large volume of international trade that passes through the

[1] Barnacles are small, salt-water animals that fasten themselves on ships' bottoms. They increase friction between the ship and water, thus retarding the ship's speed. They cannot live in fresh water.

important seaports of this lowland brings considerable wealth to the region.

Great California Valley. This lowland is a downfolded, structural trench between the Sierra Nevada Mountains and the Coastal Ranges. In the north it is drained by the Sacramento River and in the south by the San Joaquin, both of which reach the Pacific through San Francisco Bay. Tributaries from the mountains, especially the Sierras, have floored the valley with alluvial soil and gravel. At the base of the mountains these deposits mainly take the form of piedmont alluvial plains. The slope of the alluvium is so gentle that the valley floor often appears flat. In some places there is considerable swampland.

The Mediterranean type of the climate is characteristic of the northern part of this region, and dry climates prevail in the south. Annual rainfall varies from 12 to 30 inches. Winter temperatures are moderate. The frost-free season is around 240 days.

Irrigation of the piedmont alluvial plains is accomplished best on the east side of the great valley where the water of streams flowing down the western slopes of the Sierras can be retained in reservoirs and used as needed. Near the lower edges of the fans deep wells sometimes supply irrigation water. In the northern valley the principal crops are rice, alfalfa, and vegetables. In the southern part fruit production is more important. Fresno is famous as a fruit-drying center and is known as the *raisin capital* of the world. High summer temperatures of 95° to 105°F., low relative humidity of 10 to 25 per cent, and the almost complete absence of summer rain and cloudiness promote the fruit-drying industry. Great quantities of apricots and peaches are canned and dried. Citrus fruits and olive, almond, and walnut trees occupy thousands of acres. Orchards are planted on slopes where air drainage decreases the probability of frost. Some alluvial deposits cannot be irrigated and are used mainly for grain, hay, and pasture land. Near Bakersfield, south of Fresno and just north of the Mohave Desert, are important oil fields.

The Imperial Valley. In extreme southern California and extending into Mexico is a small lowland somewhat similar to

the Great California Valley. It is called the *Imperial Valley* and is irrigated by water from the Colorado River (Fig. 375). The climate is that of the low-latitude desert, summers being extremely hot and dry. Since frosts are practically unknown in this region, agricultural production is at a maximum. The occurrence of abundant alluvial deposits in this lowland has been explained in Chap. X.

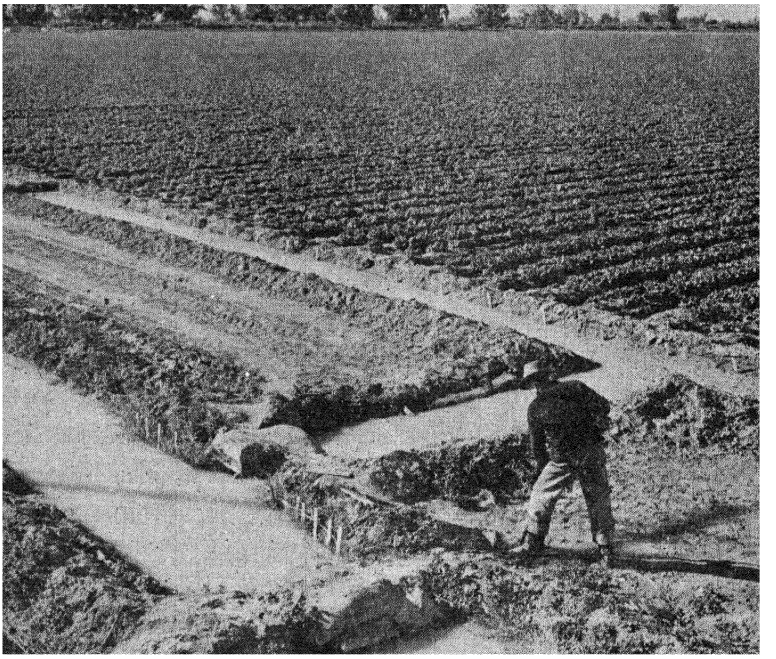


FIG. 375.—An irrigated field in the Imperial Valley of California. (*Courtesy of U.S. Bureau of Reclamation.*)

The Sierra Nevada-Cascade Mountains

Sierra Nevada Mountains. These mountains are located in eastern California. They are mainly block mountains of igneous rocks, with the steep side facing Nevada and the more gentle slopes extending westward beneath the Great California Valley. In the southern Sierras is Mt. Whitney, elevation 14,500 feet, the highest mountain in the United States. In the northern Sierras is Mt. Shasta, a high volcanic cone, at the top of which are several valley glaciers. South of Mt. Shasta is Mt. Lassen, the only active volcano in the United States. Rain and snow are

abundant on the western slopes of the Sierras, resulting in the formation of glaciers and several deep canyons and the growth of magnificent trees. One of the deep canyons with its high waterfalls and steep granite bluffs is the main feature of Yosemite National Park (Fig. 376). Farther south are General Grant and

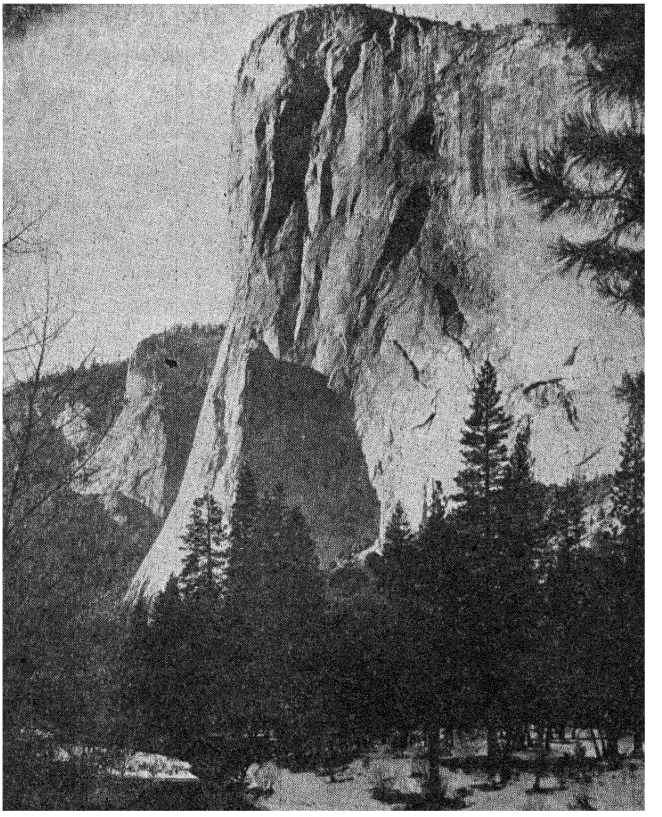


FIG. 376.—El Capitan, a huge mass of granite, rises more than 3,000 feet above the valley floor in Yosemite National Park, California. (*Courtesy of U.S. Department of the Interior.*)

Sequoia national parks where the giant sequoia tree reaches its maximum size. Good roads lead to these points of interest. As previously noted, the numerous streams that flow westward from this highland toward the Great California Valley furnish water for irrigation. Some of these streams in the distant past washed considerable gold from the mountains into the gravel beds below, resulting in placer deposits, the discovery of which was responsible for the California gold rush of 1849.

Cascade Mountains. These mountains extend north and south through Oregon and Washington. They are volcanic in origin. Numerous cinder cones are found in the rolling mountain upland. Several high volcanic cones extend much higher than the general mountain level. Among these peaks are Mt. Hood in Oregon and Mt. Rainier, Mt. Adams, and Mt. Baker in Washington. Crater Lake National Park is in the Cascades of southern Oregon. This lake occupies a caldera in the top of an

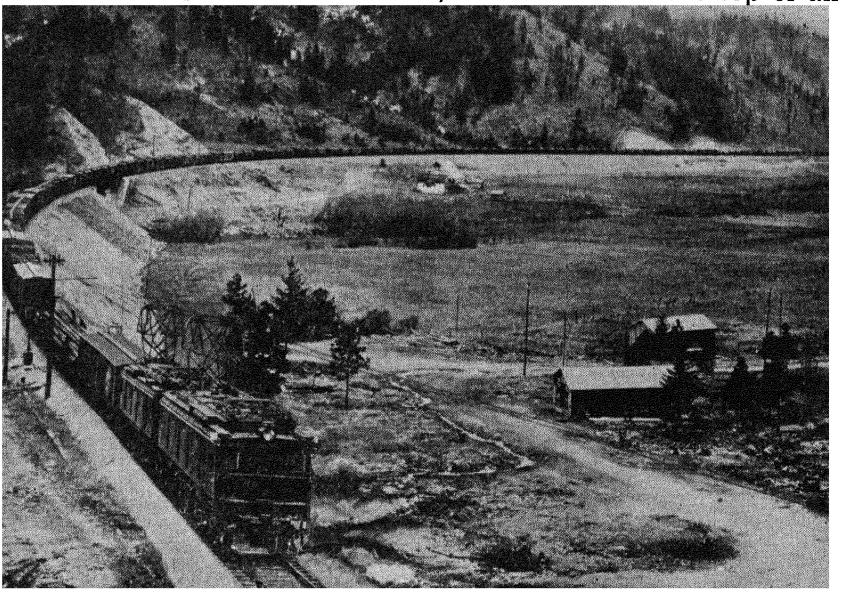


FIG. 377.—This view in the Cascade Mountains of Washington shows how a railroad makes use of available hydroelectric power. (*Courtesy of Great Northern Railway.*)

ancient volcano, Mt. Mazama. The lake is roughly circular, about 5 miles in diameter and almost 2,000 feet deep. Mt. Rainier when not hidden by clouds, which is rare, is visible from Puget Sound cities. Atop the mountain are several long valley glaciers. Railroads and the famous Columbia River Highway pass through the water gap cut by the Columbia River through the Cascades. Abundant precipitation falls on the western slopes of these mountains and supports the growth of extensive forests of Douglas fir and pine. The heavy rain and snow also contribute to the great water-power resources of the Pacific Northwest, along with other factors that include (1)

the steep mountain slopes, (2) the forest cover, (3) numerous lakes and glaciers, and (4) glaciated valleys with waterfalls and rapids. This water power is used for the domestic and industrial supply of electricity and by railroads that use electric power in parts of their systems (Fig. 377).

Western Plateaus and the Basin-Range Region

General Characteristics. Between the Sierra Nevada-Cascade Mountains and the Rockies is a vast intermontane area characterized largely by plateaus and interior basins. Lying in the rain shadow of the Pacific mountains, this entire area is one of low annual rainfall and, because of its location inland, also one where extremes of temperatures are greater than in the Pacific Coast regions. The climatic type, therefore, has been designated as steppe and desert. As might be expected, numerous irrigation projects, both large and small, spot the land surface. Beginning at the north, this area may be subdivided into three regions: (1) the Columbia Plateau, (2) the Basin-Range Region, and (3) the Colorado plateaus.

Columbia Plateau. This plateau is located in eastern Washington and Oregon and southern Idaho. The bedrock of the region is igneous, mainly basalt, formed by successive flows of lava. Through the layers of lava the Snake and Columbia rivers have cut canyons. In places the Snake River canyon is more than 4,000 feet deep, and its walls sometimes show 10 or more separate lava flows. The plateau surface is flat to rolling in nature. The northern part in Washington was glaciated, at which time the Columbia River was diverted through a temporary channel. This ancient channel, now abandoned, is a part of the Grand Coulee hydroelectric and irrigation project.

Annual rainfall in general is less than 20 inches throughout this region. In the western part, where the rain shadow is more effective, desert conditions exist, and here irrigation plays an important role in crop production. The bright, warm summer encourages the production of fruit, especially apples. Three valleys on the eastern slopes of the Cascade Mountains—the Hood River, Yakima, and Wenatchee—are famous for their fruit production (Fig. 378). On the rolling uplands of eastern Washington, portions of which are covered with loess, wheat

is one of the principal crops. In this section, Spokane is the important city. It is a railway center and in addition has grain elevators, flour mills, meat-packing plants, and supply houses for the mining and forest industries of the adjacent mountain regions. The waters of the Snake River are used for irrigation in eastern and southern Idaho. Near Boise is the large Arrow Rock reservoir. The irrigated lands produce grain and potatoes in considerable quantities.

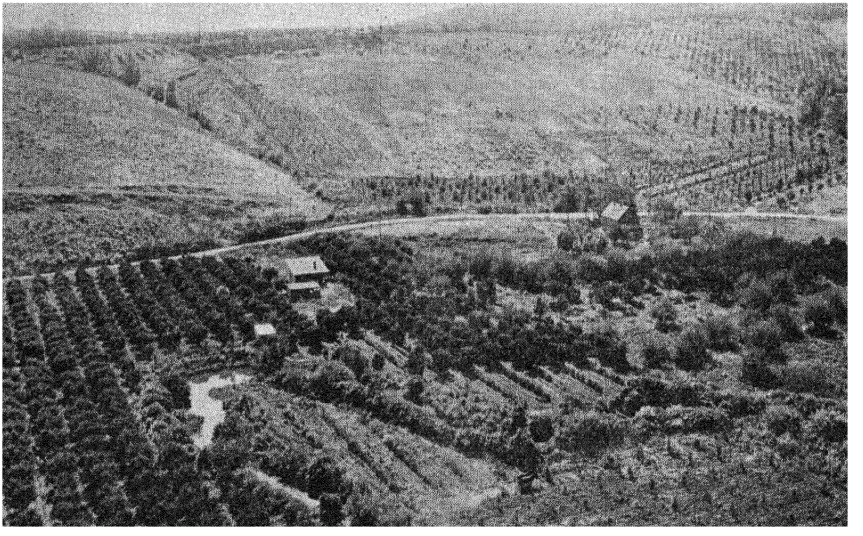


FIG. 378.—Apple orchards in the Yakima Valley, south central Washington. (*Courtesy of U.S. Department of Agriculture.*)

Basin and Range Region. This region occupies most of Nevada, western Utah, southern Arizona, and parts of southern California and New Mexico. Herein lie the largest deserts of the United States. The long summers in the southern part of the region are extremely hot, and relative humidity is so low that evaporation is unusually rapid. The Nevada-Utah portion is higher than the southern portion, and the winters are much colder. Especially in Nevada are found parallel ridges of block mountains between which are basins filled with alluvium (Fig. 379). In southeastern California is Death Valley which holds the record for the highest temperature ever recorded in the United States. The valley, over 200 feet below sea level, is

the lowest point in the United States and is only a short distance from Mt. Whitney, the highest.

In Nevada and western Utah, interior drainage prevails, so that this region often is called the Great Basin. The streams that do exist flow into basins, creating salt lakes from which the water is continually evaporating or sinking into the ground. The Humboldt River, for example, flows westward into Carson Sink, its waters never reaching the ocean by surface drainage.

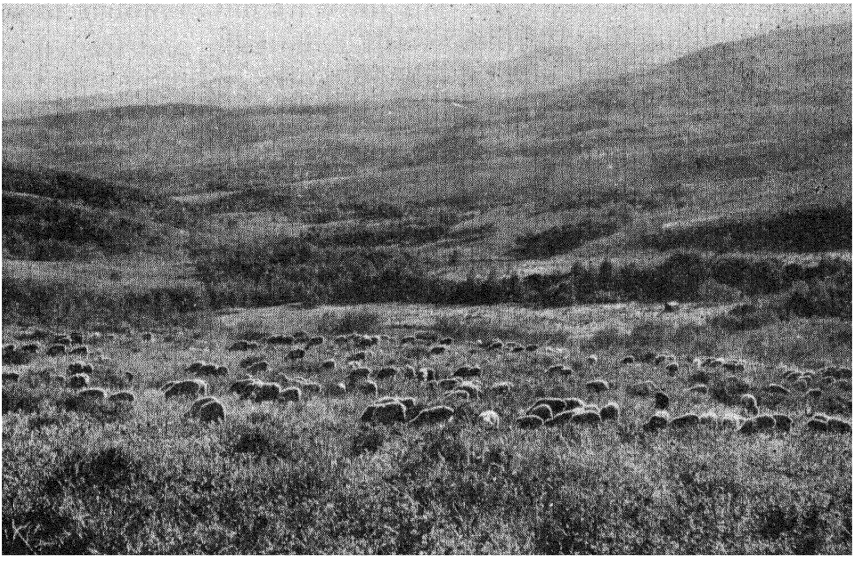


FIG. 379.—This valley in Nevada, which is flanked by low mountains, provides grazing land for sheep. (*Courtesy of U.S. Forest Service.*)

Farther south such is not the case. Waters of the Colorado, Salt, Gila, and Rio Grande rivers reach the sea.

Among the larger irrigated areas that spot the region are (1) the Salt River project, made possible by the Roosevelt Dam; (2) the Elephant Butte Reservoir on the Rio Grande; and (3) the Newlands project in western Nevada. The huge Boulder Dam, previously described, is on the Colorado River between Arizona and Nevada.

Great Salt Lake is the shallow remnant of ancient Lake Bonneville, a much larger and deeper lake which existed when the climate of the region probably was more humid than at

present. The shorelines of this ancient lake are plainly visible on near-by hills and mountains. The present lake is so shallow that a railroad is built across it. The water has a salinity of about 20 per cent and is the source of a commercial supply of salt which is obtained by evaporating the water in flat, shallow basins. West of the lake is the Great Salt Lake Desert. On the east side rise the Wasatch Mountains which are high enough to receive some 20 to 30 inches of rain annually. The streams flowing down the western slopes of these mountains have formed deposits of alluvial soil which, under irrigation, are highly productive. This is the land that owes its development to the great courage of the Mormons. Salt Lake City and Ogden are the principal cities.

The basin and range region is rich in minerals. Great quantities of copper are mined at Bisbee, Ariz., and Bingham, Utah. Nevada and Utah produce considerable quantities of silver and gold.

Colorado Plateaus. This region covers western Colorado, eastern Utah, northeastern Arizona, and northwestern New Mexico. The plateaus are composed largely of uplifted sedimentary rocks, generally horizontal, in which a number of canyons have been eroded. In northern Arizona is the magnificent Grand Canyon of the Colorado River.

The annual rainfall over the Colorado plateaus varies from 5 to 20 inches. Summers are hot and dry. Because of greater elevation, however, the heat is less severe than in southern Arizona. Rainfall is sufficient in the higher sections to support the growth of forests.

In addition to canyons, the region is marked by other interesting relief features. The volcanic San Francisco Mountains near Flagstaff, Ariz., reach an elevation of over 12,000 feet. The high Uinta Mountains, located in northern Utah and at the northern edge of this region, are anticlinal in structure and are notable because they constitute about the only east-west range in the United States. Throughout the Colorado plateaus are numerous mesas, some of which are capped by resistant volcanic rock. This indeed is a region of interest to the traveler. In addition to the Grand Canyon National Park there are the Mesa Verde, Zion, and Bryce Canyon national parks. Among

additional points of interest are the Painted Desert, Petrified Forest, Navajo National Monument, and Meteor Crater.

The Rocky Mountains

General Characteristics. The Rocky Mountains are essentially an uplift of crystalline rocks, mainly granite and gneiss, from the tops of which the sedimentary rocks largely have been worn away. These mountains are divided into two parts, the *Northern* and the *Southern* Rockies, by the Wyoming Basin, which is located in southern Wyoming.

The Southern Rockies. These are mainly in Colorado. The mountains that rise abruptly from the plains just west of Colorado Springs, Denver, and Boulder are known as the *Front Range*. Farther west are the *Sawatch Range* and others that extend well into New Mexico. The southern Rockies have been glaciated, and several small valley glaciers still exist. Cirques, moraines, and glacial lakes are to be found in many places. Rocky Mountain National Park, in the Front Range of northern Colorado, includes magnificent mountains. Within the park an automobile highway crosses the continental divide at an elevation of over 11,000 feet, far above the timber line. Colorado Springs is situated at the foot of Pikes Peak, southwest of which is Cripple Creek, the famous old gold-mining city. Among the assets of this region may be mentioned (1) the mineral resources, (2) the scenery of high mountains, and (3) the cool summer climate. It is the last two items that largely attract thousands of vacationists to the mountains in summer.

Northern Rockies. These mountains cover parts of western Montana and Wyoming and northern Idaho. They include the Wasatch Mountains of northern Utah and the Big Horn Mountains of central Wyoming. In northwestern Montana is Glacier National Park, where may be observed a number of small glaciers and all the interesting features of glaciated mountains. Yellowstone National Park, in northwestern Wyoming, is the largest of the national parks and, with its geysers, hot springs, lakes, waterfalls, canyons, and animal life, offers the greatest variety of attractions to the tourist. Scenic attractions, however, are not the only asset of these mountains. Butte, Mont., for example, with its great production of copper, gold, and silver,

is one of the richest mining regions in the world. Idaho ranks high in the production of several minerals. Lumbering and the grazing of cattle and sheep are important occupations in certain sections of the mountains.

The Middle West

General Characteristics. Stretching from the Rockies to the Appalachian highlands is an extensive structural-plains area, with relatively flat-lying sedimentary rocks, the northern portions of which have been glaciated. Within this area are some of the finest farm lands in the world. These plains are well covered with transportation lines of various kinds. Few other areas of equal size have such a complete network of railroads and highways as has the state of Iowa. In the central and eastern portions of this plains area, the humid continental type of climate prevails, and the southern portions blend into the humid subtropical. The "high plains" which lie immediately east of the Rockies are classified as middle-latitude steppes. In this entire area the major regions that may be discussed are (1) the Great Plains; (2) the interior lowlands, including the Agassiz Plain; (3) the superior upland; and (4) the Ozark Highland.

Great Plains. Extending roughly from the meridian of 100°W. Long. to the Rocky Mountains and from southern Texas northward into Canada are the Great Plains. Much of the surface relief is that which is characteristic of young stream-eroded plains. For the most part, the region consists essentially of a vast piedmont alluvial plain formed of sediments washed long ago from the Rocky Mountains. The larger mountain rivers, such as the Canadian, Arkansas, Platte, Yellowstone, and Missouri, wind their way eastward across this area of level to rolling country, their waters being used for irrigation in many places. The original vegetation cover of this region consisted mostly of short, native grasses and, in the south, of sagebrush and patches of cactus. Certain interruptions occur within the plains area, such as the Black Hills; the Bad Lands; the sand-dune region of western Nebraska; the buttes of Montana; and the mesas of Texas, New Mexico, and Colorado. Sedimentary rocks underlie most of the region.

The Great Plains are semiarid to arid. The annual rainfall varies from 10 to 20 inches, with a summer maximum. The daily range of temperature is greater than in plains of lower elevation. A well-known characteristic of the high-plains climate is the prevalence of strong winds, resulting largely from the level nature of the land. These winds increase the bitterness of the cold winters and cause hot waves and rapid evaporation in the summer. Severe dust storms may occur in any season. Man puts the high wind to work turning windmills which operate electrical

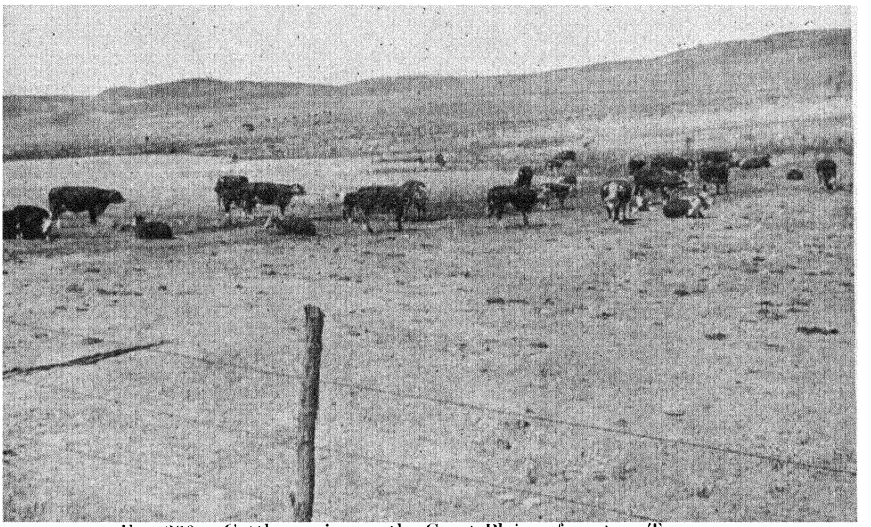


FIG. 380.—Cattle grazing on the Great Plains of western Texas.

generators or water pumps. Near the Rocky Mountains, chinook winds often cause a quick moderation of cold winter weather.

The grazing of cattle is an important occupation in the Great Plains, especially in the south (Fig. 380). The production of farm crops is a gamble because of uncertain rainfall. The perennial growth of grasses has produced a fairly rich, brown soil over much of the region. In the northern half of Colorado this soil is irrigated by water from mountain streams. A portion of this area, which is known as the *Colorado Piedmont*, is noted for its production of sugar beets. The principal mineral resources of the Great Plains are (1) the rock salt deposits of Kansas; (2) the natural gas and petroleum of Texas, New Mexico,

Oklahoma, Kansas, and Wyoming; and (3) the lignite deposits in the Dakotas and Montana.

The Black Hills, one of the interruptions within the central plains area, are located mainly in western South Dakota. The center core of these hills consists of an uplift of igneous rocks, mainly granite, from which the sedimentary rocks have been eroded. The sandstone that outcrops around the central core is the source of much artesian water, especially in eastern South Dakota. Surrounded by dry plains, the Black Hills reach an elevation (Harney Peak is over 7,000 feet) sufficient to receive

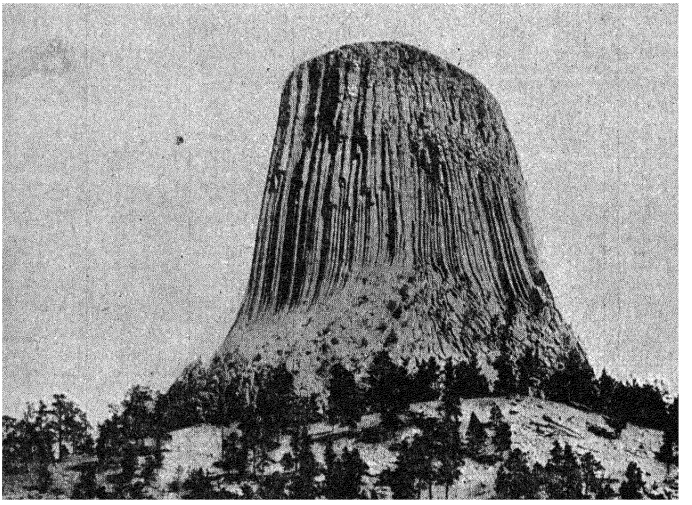


FIG. 381.—The Devil's Tower National Monument in Wyoming. (*Darton, U.S. Geological Survey. Courtesy of E. B. Branson and W. A. Tarr, from "Introduction to Geology."*)

enough rain to support forests of pine and spruce. The hills are rich in minerals, the Homestake mine at Lead having produced over 200 million dollars' worth of gold ore. A short distance west of the Black Hills in Wyoming is a national monument called the *Devil's Tower*. It is the core of an ancient volcano and rises almost a thousand feet above the surrounding plains (Fig. 381).

Interior Lowland. This extends from New York southwest to Oklahoma and Texas and from Tennessee to North Dakota. Bedrock in this area consists of nearly horizontal layers of sedimentary rocks deposited beneath great seas that covered the area in the geological past. In general, the surface relief consists

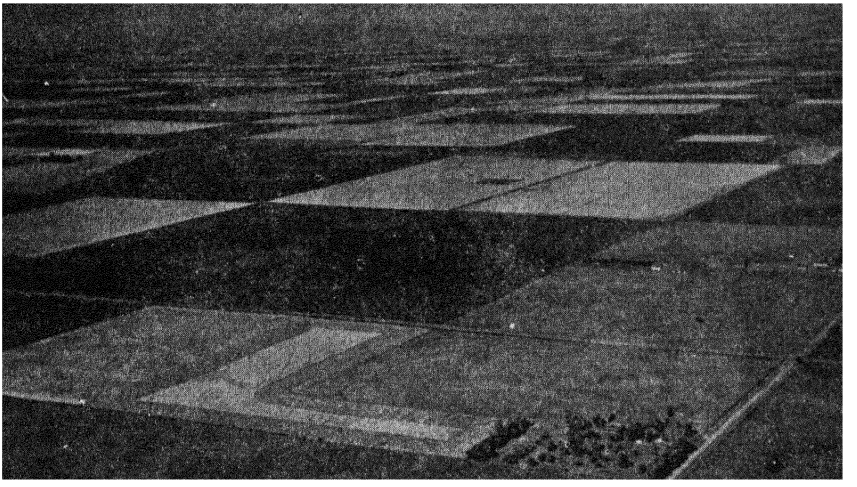
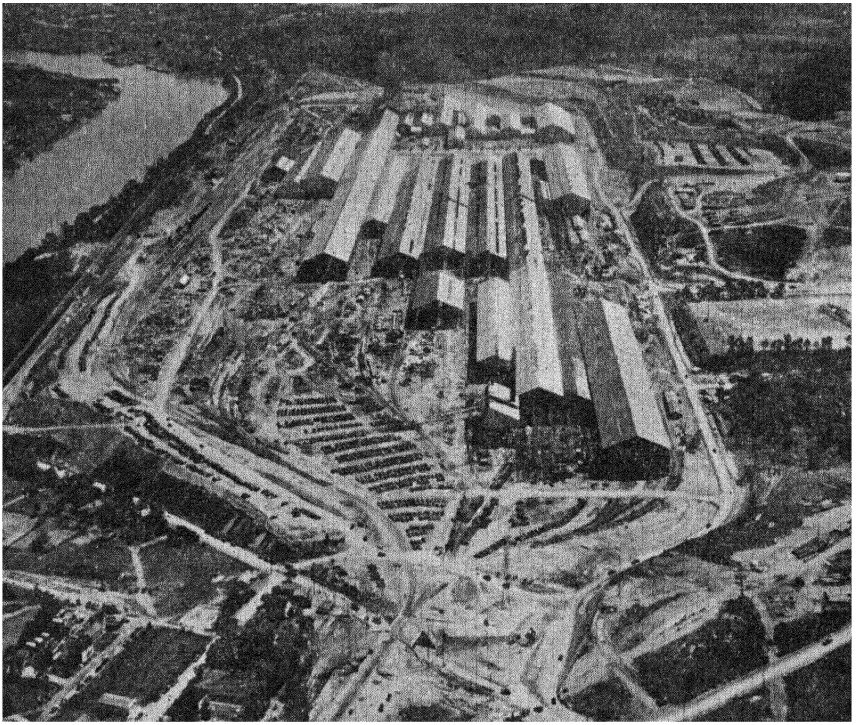


FIG. 382.—The rectangular field pattern of the Illinois prairie is clearly shown in this aerial view. The dark clusters of trees indicate the location of farmhouses. (*United*



FIG. 383.—This small Illinois market town is surrounded by productive farm land. (*United Photo Shop.*)

of undulating to level plains. Most of the region north of the Missouri and Ohio rivers is covered with glacial drift, the southward portion of which is much older and greatly modified. The climate is characterized by hot, humid summers and moderately cold winters. Annual rainfall varies from 20 to 40 inches, with a summer maximum. Largely as a result of sufficient rain during the growing season, grasses and deciduous trees constitute the



native vegetation. Over much of the region, soils are rich and highly productive.

The corn belt, which extends from Ohio to South Dakota, occupies the heart of the interior lowland (Fig. 371). Within this belt about three-fourths of the world's corn is produced. Wheat, oats, barley, and hay are other important farm crops (Figs. 382, 383). These crops provide such abundant feed that this has become one of the principal livestock regions of the world. Southern Minnesota, southern Wisconsin, northern Illinois, and northeastern Iowa are noted for fine dairy cattle. Associated with the production of livestock are the great

meat-packing plants, such as those in Chicago, Kansas City, Omaha, Sioux City, Fort Worth, and St. Paul. Wheat is grown over much of the interior lowland, Kansas ranking first in production. Minneapolis, Buffalo, and Greater Kansas City are important flour-milling centers.

Manufacturing is of considerable importance in many cities of the interior lowlands (Fig. 384) but especially in those located on or near the Great Lakes, *e.g.*, Milwaukee, Chicago, Gary,



FIG. 385.—The Lake Michigan water front is shown in this aerial view of Chicago, Ill. The Chicago Canal, spanned by several bridges, may be seen at the left. (*Courtesy of United Air Lines.*)

Grand Rapids, Detroit, Toledo, Cleveland, and Buffalo (Fig. 385). Detroit is outstanding in the field of automobile manufacturing. This belt of industrial cities largely owes its existence to (1) cheap transportation on the Great Lakes, (2) the iron ore of the Superior upland, (3) the relative nearness of both hard- and softwood forests, (4) the available supplies of coal and petroleum, (5) the position on the east-west trunk-line railroads, and (6) the great energy of the people. Farther south, river transportation aided in establishing such industrial cities as Cincinnati, Louisville, St. Louis, and Kansas City.

The Agassiz Plain, which may be considered as a portion of the interior lowland, is located in northwestern Minnesota; eastern North Dakota; and Manitoba, Canada. Flowing through this glacial-lake plain (see Chap. XI), much of which is extremely level and fertile, is the Red River of the North, which empties into the Canadian Lake Winnipeg. The humid continental climate of this region is characterized by short summers and long, cold winters. There is no natural obstruction to check

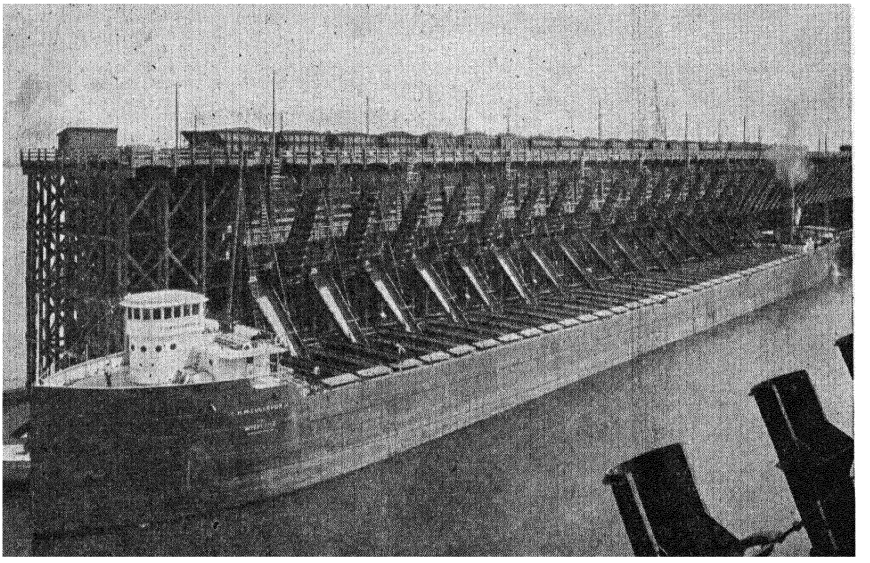


FIG. 386.—Giant freighters such as this carry an average of 35 million tons of iron ore from Duluth and the Head-of-the-Lakes to the great blast furnaces and steel mills of the lower lake ports. By gravity the freighter pictured here is filled in the amazingly short period of 3 hours. Its capacity is 14,000 tons of ore. (*Courtesy of Duluth Chamber of Commerce.*)

the southward movement of cold polar-continental air masses. Annual rainfall is in the neighborhood of 20 to 25 inches, with a summer maximum. This fortunate seasonal distribution of rain and the long summer days make this a region noted for its production of spring wheat, "Red River" potatoes, and flax. The wheat moves to Minneapolis, Duluth, and Winnipeg, the last being the greatest primary wheat market in the world. Fargo, Moorhead, and Grand Forks are other important cities located in this region.

Superior Upland. This includes the rather hilly region located in northeastern Minnesota, northern Wisconsin, and

the western part of the upper peninsula of Michigan. It is an extension of the vast area of ice-scoured crystalline rocks, with its forests and thousands of lakes, that lies north of the Great Lakes. As in the Agassiz Plain, the more severe type of humid continental climate prevails. Much of the region once was well covered with coniferous forests.

This relatively small region is noted especially for its iron mines. North of Duluth is the Mesabi Range of hills in the vicinity of Hibbing and Virginia. The great open-pit mines of this area easily place Minnesota first in iron-ore production. The mines near Bessemer, Marquette, and Escanaba put Michigan in second place. At Duluth, Superior, and other lake ports, great iron-ore docks are built out into the lake. Trains of iron ore move along the top of the docks and dump the ore into large bins, which empty into the long ore boats that anchor alongside (Fig. 386). These boats carry the ore down the Great Lakes to a number of steel-manufacturing cities, and some return loaded with coal. Huge grain elevators in the harbor at Duluth and Superior receive wheat by train and load the grain directly into ships bound for eastern ports.

Ozark Highlands. These highlands occupy most of southern Missouri and extend south into Arkansas and Oklahoma. Ages ago there occurred in what is now southeastern Missouri an uplift of igneous rock. Removal by erosion of overlying sedimentary rocks leaves the igneous rock, mainly granite, outcropping to form large hills which reach elevations in the neighborhood of 1,700 feet. From these big hills the bedrock slopes gently away in all directions (Fig. 222).

The climate of this region is similar to that of the interior lowland. Soils for the most part are residual and in general rather poor. The region is noted for its many caves and large springs of clear, cold water which feed excellent fishing streams. Around these interesting natural features several state parks have been established. The Ozark hills are well covered with deciduous trees with some conifers in the higher parts (Fig. 387). In some localities, where grasses have been well established, there are excellent grazing lands. This area is one of considerable mineral wealth. The lead mines located mainly in southeastern Missouri have placed that state first for several years in produc-

tion of this metal. Toward the western part of this region, in the vicinity of Joplin, Mo., is the Tri-State mining region, noted for its production of zinc and lead.

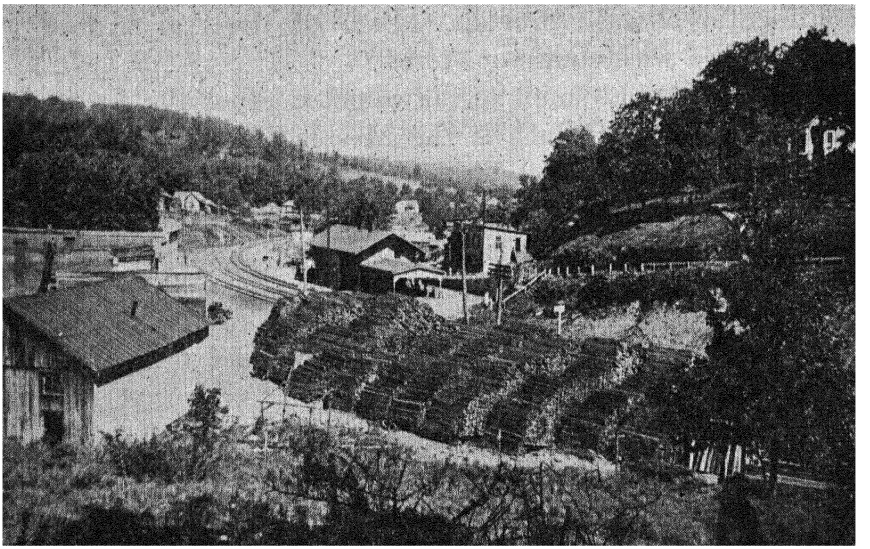


FIG. 387.—Winslow, Ark., an Ozark Valley town. The railway ties piled near the tracks were cut from the native forest.

The Regions of the South

General Characteristics. The most extensive region of the South is the Gulf Coastal Plain which extends from southern Texas around to and including western Florida. Within this large region is the Mississippi floodplain and delta, which, because of certain characteristics, is discussed separately. Humid subtropical climate prevails throughout the area. In general this climate in southern United States does not have a distinct dry season, such as that which occurs in the summer months of the Mediterranean climate of California. Because of abundant rains and the generally low, level character of the land, the Gulf Coastal Plain is a region where much soil drainage is necessary. This is in marked contrast to the irrigation that is so essential in California.

Gulf Coastal Plains. These consist for the most part of a land surface that is level to undulating in character. This coast is the emerged type, being flat and sandy, with much swamp-

land. Water alongshore is shallow. Especially along the coast of Texas are found numerous offshore bars and lagoons. Such a coast has few, if any, good natural harbors.

Within the Gulf Coastal Plains there is considerable variation in soils. In general the ruddy-colored subtropical soils of this region are not fertile. It seems unfortunate that this part of North America, which has such a productive climate, should be characterized by extensive areas of poor soils. Inland from the coast, however, the "black-earth" belts of Alabama



FIG. 388.—Cotton gin and storage yard at Trumbull, south of Dallas, Tex. These bales of cotton weigh around 500 pounds each.

and Texas, resulting largely from a bedrock of chalky limestone, are extremely fertile. Much of the coastal plain is characterized by the "piney woods" that extend from Texas to New Jersey. Yellow pine, cypress, and gum trees are a valuable resource of the region. From the pines are obtained turpentine and rosin, previously mentioned as naval stores. In the swampy, coastal lands are vast areas of tall grass.

The higher, more fertile plains form a large part of the cotton belt of the United States, the greatest cotton-producing region in the world (Fig. 388). In Florida and southern Texas are important citrus-fruit regions (Fig. 389). Near Corpus Christi, large ranches are devoted to cotton growing and the

grazing of cattle. Along the coast of eastern Texas and extending into Louisiana are extensive rice fields, valuable resources of

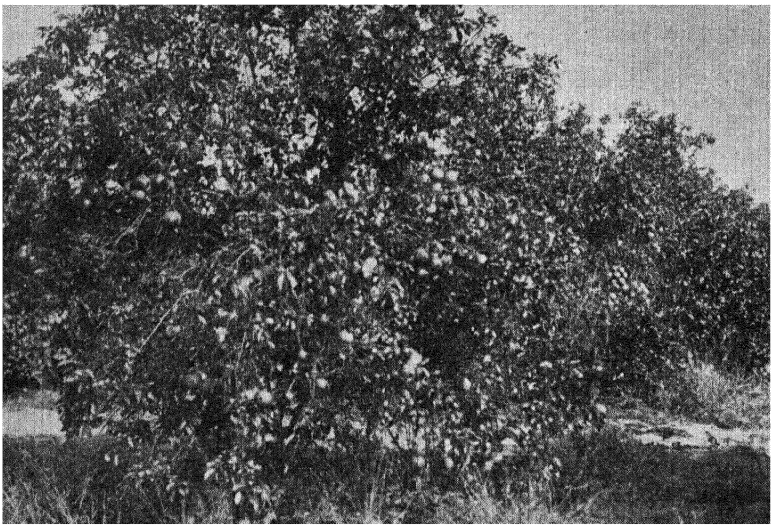


FIG. 389.—Grapefruit orchard near Lake Hamilton, Florida.

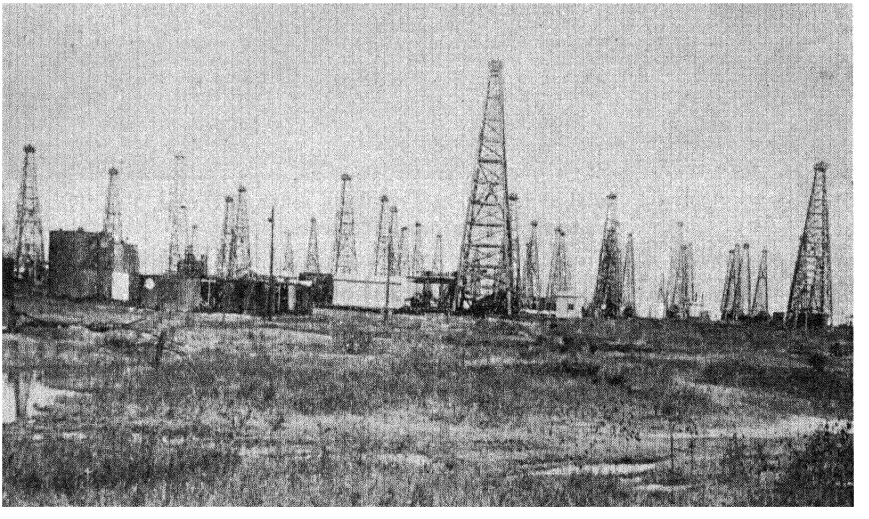


FIG. 390.—The Ged oil field at Vinton, La.

salt and petroleum, and the richest deposits of sulphur in the United States (Figs. 367, 390). East of the delta, numerous resorts which attract northerners in winter dot the smooth,

sandy shore. Houston, Galveston, Mobile, and Tampa are important coastal cities. Among the larger inland cities are Montgomery, Dallas, Fort Worth, and San Antonio.

Mississippi Floodplain and Delta. The Mississippi floodplain from the mouth of the Ohio River to the Gulf of Mexico is 50 to 75 miles wide, is bordered by bluffs in some places 200 feet high, and contains numerous oxbow lakes. Here is a region of hot, humid summers, mild winters, and abundant rain. The floodplain contains extensive areas of swampland and forests of cypress and gum trees. Especially in the lower part

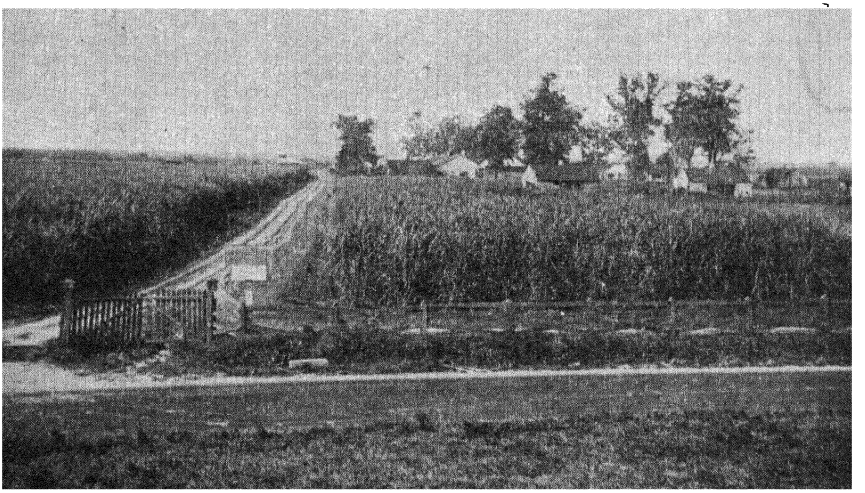


FIG. 391.—Sugar-cane plantation near the sugar mill at Laplace, not far from New Orleans, La.

of the area the formation of natural levees has raised the river above the rest of the floodplain. In many places the natural levees are reinforced by artificial levees. Since the natural levees are higher than adjacent swampland and can be artificially drained, they are the areas sought by the people who inhabit the region. Highways and railroads tend to parallel the river, using the higher parts of the levees.

The alluvial soil of the floodplain, when properly drained, is highly productive. The St. Francis and Yazoo rivers, tributaries to the Mississippi, drain portions of the floodplain to form basins noted for cotton production. Farther south, rice and sugar cane (Fig. 391) are important crops, rice being grown where

it can be easily flooded. New Orleans is built on the natural levee of the Mississippi and is situated some 90 miles upstream from the Gulf of Mexico. As a seaport the city ranks high in the exporting of cotton and importing of tropical products such as bananas, coffee, and sugar (Fig. 392).

Throughout this region disastrous floods at times have done great damage. This is the land of "Old Man River." One seldom thinks of the lower Mississippi River without recall-

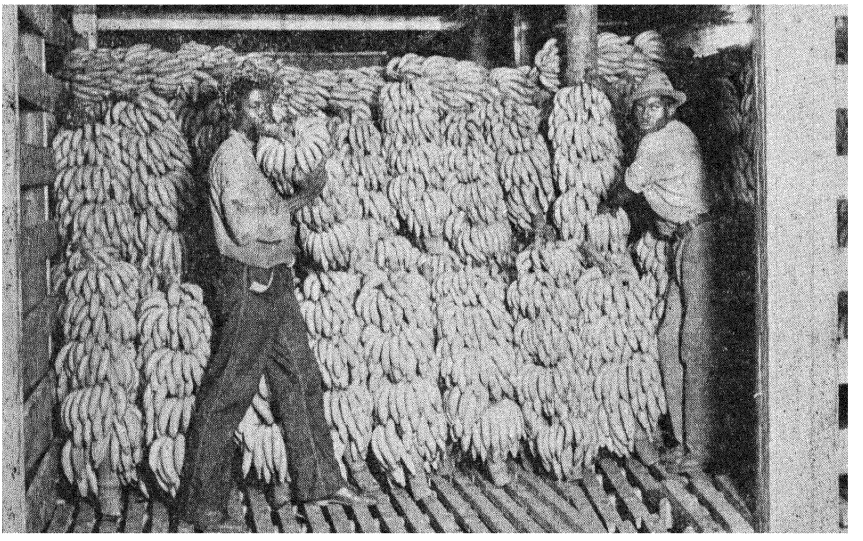


FIG. 392.—Bananas being stored in the hold of a ship. New Orleans imports great quantities of this tropical fruit. (*Courtesy of United Fruit Co.*)

ing Mark Twain's *Life on the Mississippi* or the song, "River, stay 'way from my door."

The Appalachian Highlands

General Characteristics. Extending from New York to Alabama is an upland area that may be referred to as the Appalachian highlands. Within this area are large valleys and hills (locally called *mountains*), many of which once supported considerable stands of hardwood forest. Some of the hills are resistant masses of crystalline rocks; others are the result of the stream dissection or the folding of sedimentary rocks. Over much of the more hilly country the building of transporta-

tion lines has been retarded by the roughness of the land surface and the sparse population of many localities. Most of the area has the humid continental type of climate, although the southern portions blend into the humid subtropical type. This extensive upland may be subdivided as follows: (1) The Appalachian hill region, (2) the ridge and valley region, and (3) the Blue Ridge region.

Appalachian Hill Region. This region (Figs. 221, 345, 346) is bounded on the west by the interior lowlands and on the east by the ridge and valley region (folded Appalachians). The *northern* portion in New York, western Pennsylvania, and West Virginia usually is called the *Allegheny highland;* and the *southern* portion in Kentucky, Tennessee, and Alabama, the *Cumberland Highland.* The bedrock of these highlands consists of horizontal layers of sedimentary rocks deeply cut by numerous valleys, giving much of the region a "saw-tooth" appearance rather than that of a level upland.

Of tremendous importance in this region are the great deposits of coal. Many layers of bituminous coal, much of which is suitable for coking, are exposed on the eroded valley slopes. Mining is not expensive, since it is necessary only to tunnel into the hillside. These coal deposits are probably the greatest in the world and have contributed largely to the industrial development of the United States. Pittsburgh, situated where the Allegheny and Monongahela rivers unite to form the Ohio, is outstanding in the manufacture of iron and steel products. Barges loaded with coal utilize the Monongahela River from West Virginia to Pittsburgh, some continuing southwestward to the many cities along the banks of the Ohio.

In New York, the Allegheny Highland reaches its northern limit. Along the north-facing escarpment south of Lake Ontario are the Finger Lakes, long, narrow lakes resulting largely from glacial erosion and morainal blocking of north-south valleys. North of the escarpment is the Mohawk lowland, which long has been one of the most important east-west transportation thoroughfares in the United States. To the north of this lowland are the Adirondack Mountains, an extension southward of the hard, crystalline rocks that form the bedrock of much of eastern Canada. Near Albany the Mohawk River joins the Hudson,

which flows south through a deep, glaciated valley to New York Bay, an estuary, on which is located New York City.

Ridge and Valley Region. This region, sometimes called the *folded Appalachians*, is comprised mainly of highly folded sedimentary rocks. In appearance it presents a series of parallel ridges and valleys which trend in a general northeast-southwest direction from central Pennsylvania to Alabama. The ridges are largely due to the greater resistance of the tilted layers of sandstone and conglomerate. Several antecedent rivers, includ-

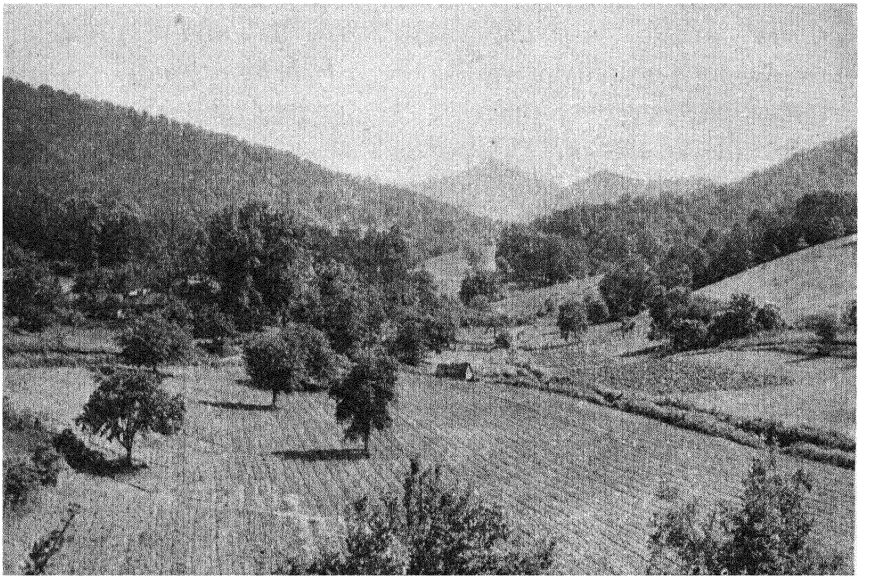


FIG. 393.—A cultivated valley in the Great Smoky Mountains near Asheville, N.C. (*Courtesy of Asheville Chamber of Commerce, photograph by Fisher.*)

ing the Lehigh, Delaware, Susquehanna, and Potomac, have cut water gaps across the ridges (Chap. XII). These gaps are much used by east-west transportation lines. Within this region is the so-called *Great Valley*, which includes the Shenandoah Valley of Virginia and the valley of east Tennessee. In portions of these valleys a bedrock of limestone has produced a fertile soil which is largely responsible for such agricultural pursuits as general farming, fruit production, and, in the south, cotton growing. The valley of east Tennessee and certain adjoining areas are now being administered by the Tennessee Valley Authority (Fig. 297).

Blue Ridge Region. This region is located mainly in Virginia and western North and South Carolina. It consists of great masses of resistant, crystalline rocks which rise some 2,000 feet above the Piedmont region immediately to the east. The Blue Ridge region was not glaciated.

The Great Smoky Mountains National Park, which includes parts of both Tennessee and North Carolina, is noted for its fine mountain scenery. Mt. Mitchell, the highest mountain in the eastern United States, is in western North Carolina. Reaching an elevation of over 6,000 feet, this peak receives the heaviest rainfall east of the Mississippi. Largely as a result of abundant precipitation, water power and timber are valuable resources of the Blue Ridge region. The valleys are well suited for agricultural use (Fig. 393).

The Atlantic Slope

Piedmont Region. This region lies between the Atlantic Coastal Plain on the east and the Blue Ridge region on the west and extends from Pennsylvania to Georgia. The western border of the Piedmont is from 800 to 1,500 feet above sea level. The land surface slopes gently toward the east and southeast. Abundant rainfall has aided in rock disintegration, and as a result the underlying bedrock of granite and associated crystalline rocks has yielded a fairly good soil, in places over 50 feet deep. Numerous streams cross the Piedmont, flowing in a southeasterly direction toward the Atlantic. A few monadnocks of more resistant rock dot the rolling upland, an example being Stone Mountain, near Atlanta, Ga. Heavy rains have made the problem of soil erosion a serious one in certain localities. Steps are being taken, such as plowing along contour lines, to check the loss of topsoil. Abandoned fields, resulting largely from soil exhaustion or sheet erosion, may be observed now supporting a growth of scrubby pine trees.

Hydroelectric power is contributing to an increase in manufacturing in the Piedmont region. Large cotton mills have been established to such an extent that they offer serious competition to those of New England. For the most part the land surface of the region, except near the mountains, is not extremely rough, so that a good network of railroads has been established. As a

result of the latitudinal extent of this province the variety of agricultural products is very great. Cotton and tobacco are leading crops (Fig. 394).

Atlantic Coastal Plain. Throughout most of its length, from southern Florida to New Jersey, the Atlantic Coastal Plain is similar to the Gulf Coast. The smooth continental shelf has been uplifted but, in places, submerged again to create valuable estuaries such as Chesapeake and Delaware bays. Sandstone layers that dip gently toward the east outcrop farther west.



FIG. 394.—This tobacco crop, in Davidson County, North Carolina, is being harvested for curing. (*Courtesy of U.S. Department of Agriculture.*)

This stratification makes possible the drilling of many artesian wells along the coastal plain. Soils in this region tend to be sandy, badly leached in some localities, and not very fertile. As a result, farmers are forced to use great quantities of commercial fertilizers.

The climate of the southern Atlantic Coastal Plain is humid subtropical; that north of Virginia is humid continental. Rainfall is abundant throughout the entire region, which, together with the presence of much sand, is responsible for the leaching of surface soils. Swamps and extensive areas of "piney woods" are more numerous near the coast (Fig. 395). Farther inland on

higher ground agriculture becomes more important. In the south, cotton and tobacco are main crops; in the north, especially near the larger cities, truck gardening predominates. New Jersey and Maryland, for example, are well known for the production and canning of tomatoes.

The Atlantic Coastal Plain is well supplied with railroads and highways. Some of the large cities are located on the coast;



FIG. 395.—Coastal-plain woods, principally shortleaf pine, in South Carolina. Certain species of pine that mature rapidly are used in the manufacture of paper pulp. (*Courtesy of U.S. Forest Service.*)

others occupy advantageous positions along the "fall line," a line that roughly separates the coastal plain from the higher and somewhat rougher Piedmont region to the west. Along this line, where streams descend from the harder, crystalline rocks of the Piedmont to the less resistant rocks of the coastal plain, are rapids and waterfalls which are utilized for power. The fall-line cities include Richmond; Raleigh; Columbia, S. C.; Augusta; and Macon. Atlantic City is situated on an offshore bar where the smooth sand, cool sea breezes, and excellent surf bathing attract thousands of summer vacationists.

Along the Atlantic Coast are a number of important seaports, situated for the most part on estuaries. The list includes Boston, New York, Philadelphia, Baltimore, Norfolk, Wilmington, Charleston, Savannah, and Jacksonville. Important exports from southern ports are cotton and naval stores; those of the northern ports are largely manufactured goods, among which machinery, automobiles, and petroleum products are outstanding. The value of imports and exports handled at New



FIG. 396.—On the summit of Mt. Washington, New Hampshire, wind velocities of over 200 miles per hour have been recorded. (*Courtesy of New England Council.*)

York is far greater than that of any other American seaport. The city has the advantage of a good estuarine harbor, excellent transportation facilities to a hinterland highly productive both agriculturally and manufacturally, and a situation such that it lies in the path of trade between the United States and Europe.

New England Region. Throughout most of the New England region, hard, crystalline rocks, such as granite and gneiss, predominate. The entire region was glaciated. As a result, the rougher highlands in the northern part are characterized by the presence of many lakes, a thin covering of poor soil, and in places bare rock. The higher portions of crystalline rocks are

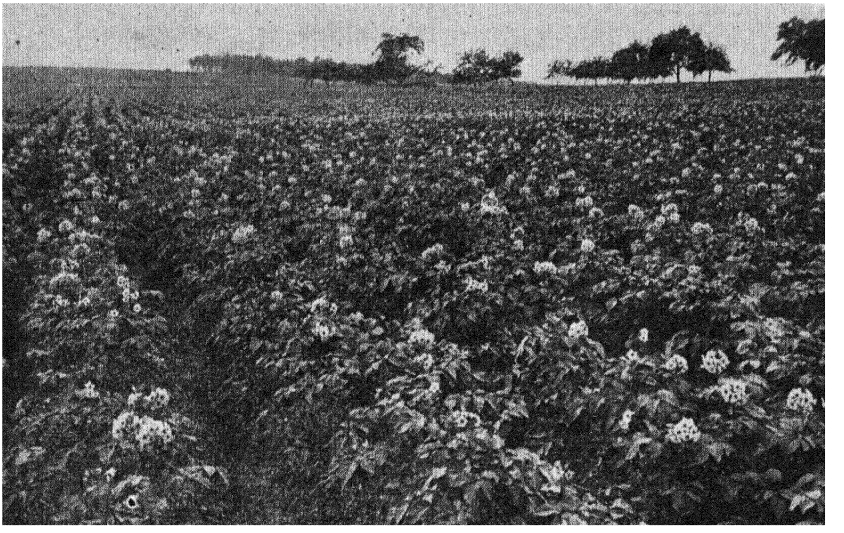


FIG. 397.—One of the chief agricultural crops of Maine is the potato. This photograph shows a potato field in Aroostook County. (*Courtesy of U.S. Department of Agriculture.*)

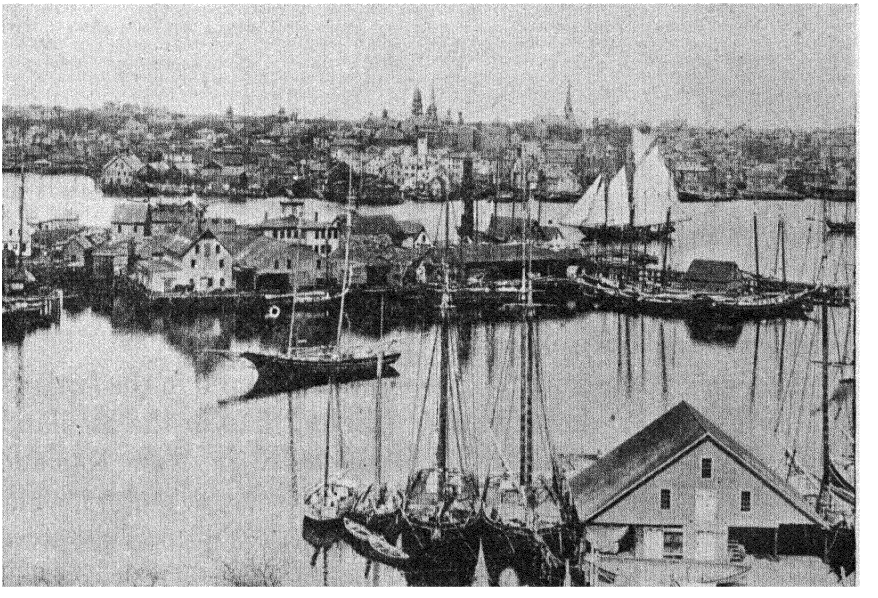


FIG. 398.—The fishing fleet is shown in this view of the harbor at Gloucester, Mass. (*Courtesy of Gloucester Chamber of Commerce.*)

known as the *White Mountains* in northern New Hampshire and the *Green Mountains* in Vermont. Mount Washington, in New Hampshire, rises over 6,000 feet above sea level (Fig. 396).

The tendency for storms to leave the United States through the St. Lawrence Valley causes a changeable climate in New England. In the highlands, winters are severe with heavy snowfall. Summers are delightful, and consequently northern New England is one of the favorite vacation spots of the East. In general, however, the highlands are sparsely populated, with agriculture, lumbering, grazing, and the quarrying of granite, marble, and slate as important occupations (Fig. 397).

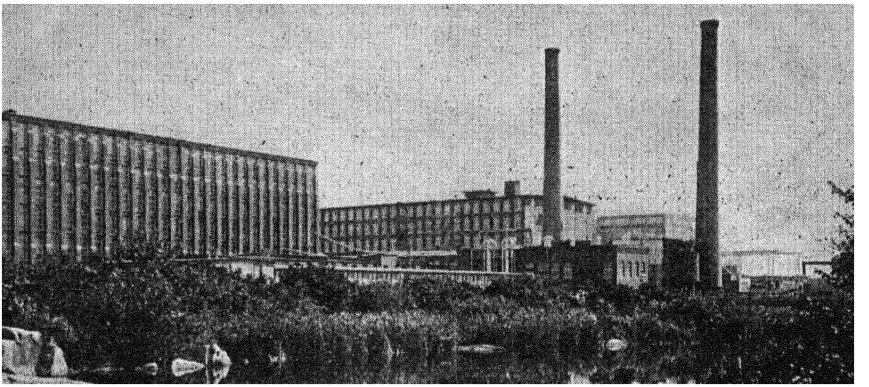


FIG. 399.—Cotton mills at Fall River, Mass.

The irregular, fiorded coast of Maine is spotted with villages from which many fishermen make regular trips to the Grand Banks off Newfoundland in search of sea food. Gloucester, Mass., is noted as a fishing port (Fig. 398).

A much greater density of population is found in the *lowlands* of New England, where industry thrives, than in the highlands farther north. Manufacturing began early in New England, largely as a result of a combination of several factors which included (1) the presence of water power, (2) a good supply of soft water, (3) an invigorating climate, and (4) a sufficient supply of labor and capital. Within this region the three most important lowlands are (1) that in the vicinity of Boston, (2) the Narragansett Bay area, and (3) the lower Connecticut Valley. The variety of industries is tremendous. The Boston area is noted especially for leather products; the Narragansett

Bay area, for cotton mills (Fig. 399); and the Connecticut Valley, for hardware, jewelry, and paper products.

Conclusion

The brief survey of the United States presented here would be incomplete without a word concerning the people and the country as a whole. A study of the various major regions of the country emphasizes the fact that the American people live under greatly contrasting environmental conditions. Life in the warm, humid lowlands of the Gulf Coast is in marked contrast with that in the northern portions of the interior lowlands where bitterly cold winters are the rule. Abundant rains and great forests characterize the western slopes of mountains in Washington, Oregon, and California; and to the east lie the arid and semiarid lands of the Great Basin and plateau provinces, with their more severe continental climates. Yet with all these contrasts, the people of the country as a whole have many interests in common and are working continually toward the attainment of certain goals. The United States has made tremendous progress in the last hundred years, and in spite of temporary setbacks, that progress must continue. Among the many problems that face the country few deserve more serious consideration than certain ones that have been emphasized in this book, *viz.*, a clear understanding of the kinds and variety of the country's natural endowment and the proper use and conservation of its natural resources.

Summary

In this chapter we have divided the United States into large sections which are subdivided into major regions. Each region is characterized by certain aspects of climate and by certain relief features of the land, soils, natural resources, and economic products. The following outline shows the method of dividing the country into sections and regions:

The Pacific Coast
  The Coastal Ranges
Lowlands of the Pacific states
  Puget Sound-Willamette lowland

Great California Valley
Imperial Valley
Sierra Nevada-Cascade Mountains
Sierra Nevada Mountains
Cascade Mountains
Western plateaus and the Basin-Range Region
Columbia Plateau
Basin and range region
Colorado plateaus
The Rocky Mountains
Southern Rockies
Northern Rockies
The Middle West
Great Plains
Interior lowlands
Superior uplands
Ozark highlands
Regions of the South
Gulf Coastal plain
Mississippi floodplain and delta
Appalachian highlands
Appalachian hill region
Ridge and valley region
Blue Ridge region
The Atlantic slope
Piedmont region
Atlantic Coastal Plain
New England region

Questions

1. Locate the Coastal Ranges. What type of mountains are they?
2. What use is made of the piedmont alluvial plains in California?
3. Locate the Santa Clara and Rogue River valleys. For what is each noted?
4. How do the Coastal Ranges influence rainfall?
5. Locate the Olympic Mountains. Why is there such heavy rainfall there?
6. Briefly describe the forests of the Pacific Coast region.
7. Discuss the climate of the Puget Sound region.
8. Where is the Willamette Valley? For what is it noted?

9. The Great California Valley is about how long? It lies between what mountain ranges?

10. Describe the climate of the Great California Valley.

11. What is a piedmont alluvial plain?

12. For what is Fresno noted? Give reasons.

13. What are citrus fruits? Where are they produced in California?

14. Where is the Imperial Valley? Why is it a highly productive region?

15. The Sierra Nevadas are what type of mountains? How were they formed?

16. What national parks are in the Sierras? For what is each noted?

17. Name and locate the higher peaks of the Cascades.

18. What is the importance of the Columbia River water gap?

19. State several reasons why the Pacific Northwest ranks high in water-power resources.

20. What is the nature of bedrock in the Columbia Plateau?

21. Where is the Snake River canyon? The Grand Coulee project?

22. For what is the Spokane region noted? The irrigated lands of Idaho?

23. Why is the Basin-Range Region arid to semiarid?

24. Interior drainage prevails in the Great Basin. Explain.

25. Where is Death Valley? What is its elevation? Locate the Mohave Desert.

26. Name and locate several irrigation projects in the Basin and Range province.

27. What are the purposes for which Boulder Dam was built?

28. What is the percentage of salt in Great Salt Lake? What effect has it on the density and buoyancy of the water?

29. What rocks form the Colorado plateaus?

30. Name and locate several places of interest in the Colorado plateaus.

31. In what states are the Southern Rockies? The Northern Rockies?

32. Where is the Front Range? The Sawatch?

33. List several relief features of glaciated mountains.

34. What national parks are in the Northern Rockies? For what is each noted?

35. Locate the Great Plains. How were they formed? Name five rivers crossing this region.

36. What native vegetation is characteristic of the Great Plains?

37. Where is the Colorado Piedmont? For what is it noted?

38. Mention the principal mineral resources of the Great Plains.

39. Locate the Black Hills. For what are they noted?

40. In what region is the corn belt? Name and locate several meat-packing centers in this region.

41. Name the principal wheat-producing states. Locate the principal flour-milling centers.

42. Why is there much manufacturing in the Great Lakes region?

43. Discuss the climate and agriculture of the Agassiz Plain.

44. For what mineral production are the Superior uplands noted? The ores are shipped from what lake ports?

45. Where has erosion exposed the uplifted center core of crystalline rocks in the Ozark region?

46. Briefly discuss the mineral resources of the Ozark region.

47. How was the Gulf Coastal Plain formed? What is an offshore bar?

48. Name the principal states in the cotton belt.

49. What trees predominate on the Gulf Coast? What are naval stores?

50. Mention the principal mineral resources of the Gulf Coast.

51. State five facts concerning the lower Mississippi floodplain.

52. Name and locate the two subdivisions of the Appalachian hill region. What is the nature of bedrock in these areas?

53. Locate Pittsburgh. Discuss its importance. Give reasons.

54. Why is the Mohawk lowland of such importance?

55. What is the principal cause of the parallel ridges in the ridge and valley region?

56. What is a water gap? What rivers have cut water gaps through the Appalachian ridges? What use is made of these openings?

57. Locate the Blue Ridge region. Structurally how does it differ from the ridge and valley region?

58. Why is there considerable soil erosion in the Piedmont region?

59. Why does plowing along contours help check soil erosion?

60. Why has manufacturing increased in the Piedmont region?

61. On the Atlantic Coast, what has been the result of coastal emergence? Submergence?

62. Why are some soils on the Atlantic Coastal Plain badly leached?

63. Why have cities developed along the fall line? Mention several.

64. Name and locate several Atlantic seaports. What advantages has New York as a seaport?

65. What are the principal occupations in the New England highlands?

66. Where are the principal lowlands of New England? For what manufactured products is each noted?

67. Why did manufacturing get an early start in New England?

68. Among the problems that face the people of the United States, what two have received considerable emphasis in this book?

Suggested Activities

1. Purchase a large outline map of the United States, about 3 by 4 feet in size. Regions should be delimited and colored on this map but not labeled. Drill yourself in naming the regions correctly and in pointing to places of interest that are mentioned in this discussion.

2. If you live in a region that has been mapped by the U.S. Geological Survey, purchase the topographic map of the region, and study it thoroughly. What is the general nature of surface relief? What relief features in the region were formed by streams? By glaciers, if any? Are the stream valleys mainly young, mature, or old? Pick out a section of land, and be able to give its number, township, and range. What and where on the map is the lowest elevation? The highest? What railroads and highways appear on the map?

3. Study other topographic maps of the various major regions of the United States.

4. In what major region discussed in this chapter do you live? Draw a large map of this region by first drawing the necessary parallels and meridians. Fill in the map to show more detailed information than is brought out in this chapter. Can you subdivide your major region into several minor ones?

5. Secure at least one geological folio from the U.S. Geological Survey. The Black Hills folio, suggested in connection with Chap. XII, may also be used here. What subjects are discussed in the folio? How many maps are there? What do they show? Note the cross-section drawings that show rock structure and the photographs that illustrate surface relief.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. The Grand Coulee Region of Washington
2. Southern California
3. Great Salt Lake and Environs
4. Yellowstone National Park
5. The Corn Belt
6. Irrigation in the Valley of the Platte River
7. The Coastal Lands Bordering the Gulf of Mexico
8. Commerce of the Great Lakes
9. The Mohawk Valley

10. The Chesapeake Bay Region
11. The Connecticut Valley
12. The Lake Plains of New York

References

ATWOOD, WALLACE W.: *The Physiographic Provinces of North America*, Ginn and Company, Boston, 1940.

CASE, EARL C., and D. R. BERGSMARK: *Modern World Geography*, Part 2, J. B. Lippincott Company, Philadelphia, 1938.

FENNEMAN, N. M.: *Physiography of Western United States*, McGraw-Hill Book Company, Inc., New York, 1931.

———: *Physiography of Eastern United States*, McGraw-Hill Book Company, Inc., New York, 1938.

LOBECK, A. K.: *Airways of America*, The Geographical Press, Columbia University, New York, 1933.

LOOMIS, F. B.: *Physiography of the United States*, Doubleday, Doran & Company, Inc., New York, 1937.

MILLER, GEORGE J., and ALMON E. PARKINS: *Geography of North America*, John Wiley & Sons, Inc., New York, 1928.

SMITH, J. RUSSELL: *Men and Resources: North America and Its Place in World Geography*, Harcourt, Brace & Company, Inc., New York, 1937.

Appendix A. The Seasons

The earth rotates on its axis once every day (24 hours) and revolves around the sun once each year ($365\frac{1}{4}$ days). The earth's axis is inclined $23\frac{1}{2}°$ toward the plane of the earth's orbit and always in the same direction, the North Pole pointing toward the North Star (Chap. I). This means that the position of the axis at any given time is parallel to the position at all other times of the year. This inclination and parallelism of the axis and the earth's revolution around the sun are responsible for the following:

1. The migration of the vertical rays of the sun $23\frac{1}{2}°$N. and $23\frac{1}{2}°$S. of the equator
2. A day-to-day change in sun altitude everywhere
3. Differences in the length of day and night

These three factors combine to produce the change of seasons. If the axis were not inclined but were perpendicular to the plane of the earth's orbit, there would be no change of seasons on the earth, and the vertical rays of the sun would remain constantly at the equator. If the axis were inclined more than $23\frac{1}{2}°$, the change of seasons would be somewhat more extreme than at present.

The migration of the vertical rays of the sun over 47° of latitude twice each year makes it possible to determine four important dates. They are:

1. The *equinoxes*—the two days on which the vertical rays of the sun cross the equator
2. The *solstices*—the two days on which the vertical rays reach their greatest distance from the equator

Twice each year the sun's noon rays are vertical at the equator (sun altitude 90°), once on March 21, called the *vernal equinox*, and again on September 22, called the *autumnal equinox* (Fig. 400). The time interval between equinoxes is exactly the same, but the dates fall on different days of the month (21, 22, 23) because of irregularities in the calendar now in use. Since the vertical noon rays strike the equator, the circle of illumination passes through both poles and cuts all the earth's parallels exactly in half. One half of each parallel (180°) is in light; the other half, in darkness. Consequently all places on the earth have equal day, 12 hours, and equal night, 12 hours. (*Equi-nox* means "equal night.") The tangent rays, where sun altitude is zero, touch the poles. Maximum solar energy is being received at the

equator and diminishes regularly toward either pole. Seasons in the north and south intermediate (or temperate) zones are reversed. This means that on March 21, for example, the season in the United States is spring and in Argentina autumn.

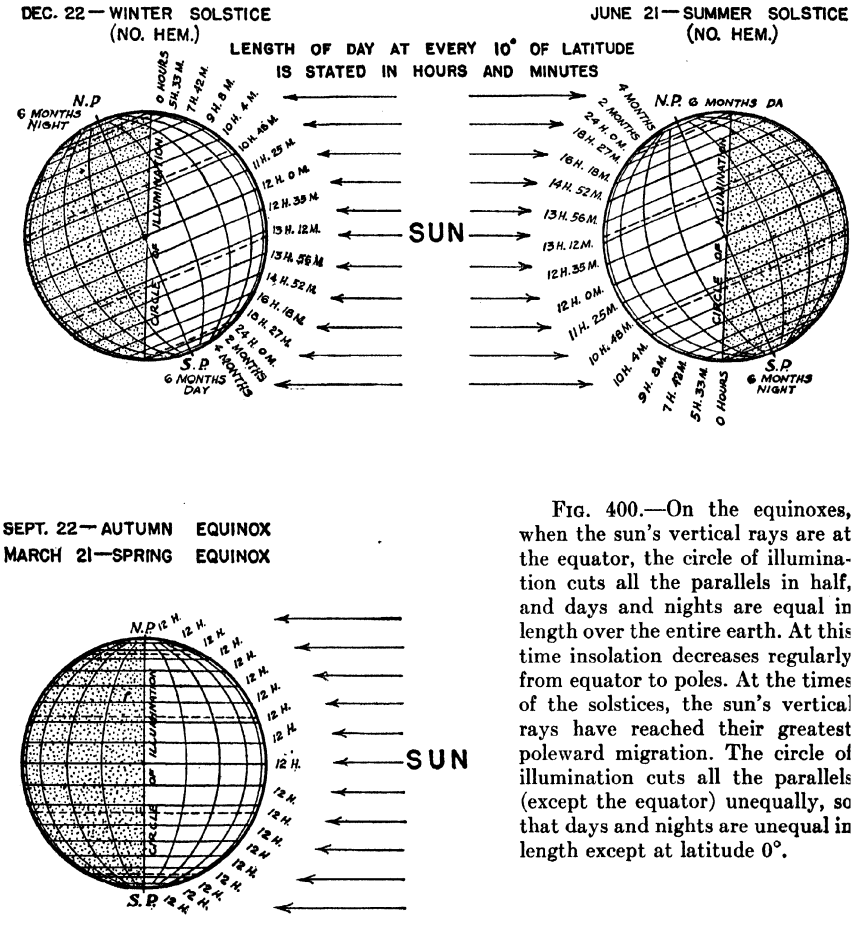


FIG. 400.—On the equinoxes, when the sun's vertical rays are at the equator, the circle of illumination cuts all the parallels in half, and days and nights are equal in length over the entire earth. At this time insolation decreases regularly from equator to poles. At the times of the solstices, the sun's vertical rays have reached their greatest poleward migration. The circle of illumination cuts all the parallels (except the equator) unequally, so that days and nights are unequal in length except at latitude 0°.

After March 21 the vertical rays continue northward in the Northern Hemisphere. On June 21, called the *summer solstice*, the earth is approximately midway in its orbit between the equinoctial positions, and the North Pole is inclined $23\frac{1}{2}°$ toward the sun (Fig. 400). The vertical rays of the sun travel the same number of degrees from the equator as the earth's axis is inclined. Thus on June 21 the vertical rays have reached their farthest point north, touching the parallel $23\frac{1}{2}°$N. which is called the *Tropic of Cancer*. The tangent rays in the Northern Hemisphere pass over the pole and reach the *Arctic Circle*, $66\frac{1}{2}°$N. In the Southern Hemisphere the tangent rays do not reach the pole but terminate at the *Antarctic Circle*, $66\frac{1}{2}°$S. Both Arctic and Antarctic

Circles are 23½° from their respective poles. All parts of the earth north of the Arctic Circle have constant daylight; south of the Antarctic Circle June 21, constant darkness. All parallels, except the equator, are cut unequally by the circle of illumination, those in the Northern Hemisphere having their larger parts toward the sun so that days are longer than nights. Longer days, plus a greater angle of the sun's rays, result in a maximum receipt of solar energy in the Northern Hemisphere, and a summer season is the result. In the Southern Hemisphere at this same time all these conditions are reversed, nights being longer than days, and the sun's rays relatively oblique (low sun altitude), so that receipts of solar radiation are at a minimum, and winter conditions prevail.

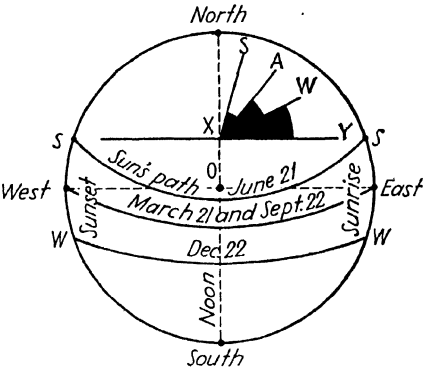


FIG. 401.—The sun's path across the sky at different seasons is shown as it appears to an observer *O* somewhere near the latitude of Philadelphia, Springfield, Ill., or Denver. Only on the equinox does the sun rise due east and set due west. In summer it rises in the northeast and sets in the northwest. In winter it rises in the southeast and sets in the southwest. On all days of the year it is south of the observer at noon. Note how the angle of the sun's rays (sun altitude) at noon decreases from summer to winter. In summer it is represented by the angle *SXY* (about 74°); in autumn and spring by *AXY* (about 50°); and in winter by *WXY* (about 26°). In general the lower the sun altitude the lower the temperature.

On December 22, called the *winter solstice*, when the earth is in the opposite position in its orbit from what it was on June 21, it is the South Pole that is inclined 23½° toward the sun (Fig. 400). The sun's noon rays are then vertical over the *Tropic of Capricorn* (23½°S.), and the tangent rays pass 23½° over the South Pole to the Antarctic Circle (66½°S.). Consequently south of 66½°S. there is constant light, and north of 66½°N. there is a continuous absence of sunlight. All parallels of the earth, except the equator, are cut unequally by the circle of illumination, with days longer and the sun's rays more nearly vertical in the Southern Hemisphere. This, therefore, is summer south of the equator but winter in the Northern Hemisphere where opposite conditions prevail.

Because of the inclination of the earth's axis, the path of the sun across the sky during the day varies greatly in different parts of the world. At the equator, at the time of an equinox, the sun rises due east, is directly overhead at noon, and sets due west. Dawn and twilight are of much shorter duration than in middle or high latitudes. On June 21 at the equator the sun rises north of east, is north at noon, and sets north of west; on December 22 it rises south of east, is south at noon, and sets south of west.

In the Northern Hemisphere, north of the Tropic of Cancer, the path of the sun is entirely unlike that in the vicinity of the equator. Since the Tropic

of Cancer is everywhere south of the United States, the noon sun is always south and never is directly overhead at any point in this country. However, at Key West, Fla., the southernmost point in the United States, the noon sun is extremely close to a vertical position on June 21. On this same date much of the country has 14 to 15 hours of sunlight, the sun swinging in a large arc across the sky, rising in the northeast, being south at noon, and setting in the northwest (Fig. 401). In Canada the hours of sunlight on June 21 vary from 16 to 24, depending upon nearness to the Arctic Circle. The farther north the longer the day. On the west shore of Lake Winnipeg is a summer resort where, especially in June and July, the long days are very noticeable and where by August the growth of grasses, bushes, and vines is so thick that it is almost impossible to see from one cabin to another. The rapid growth of vegetation during the summer is due in part to the long days. The path of the sun on the north coast of Alaska on June 21 is interesting. Barring clouds, the sun appears in the east in the morning, south at noon, west in the evening, and north at midnight, thus swinging around the observer in a huge circle, being highest above the horizon at noon and lowest at midnight. On this same date Little America in Antarctica experiences continuous darkness.

Appendix B

Supplementary Climatic Data for Selected Stations

(T., temperature in degrees Fahrenheit; Rf., rainfall in inches)

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*	*Range*
1. T.	79	79	80	81	81	80	81	82	83	83	82	81	81	4.0
Rf.	7.9	4.6	7.2	6.0	11.1	11.7	9.9	6.5	3.1	2.9	6.7	11.1	88.7	
2. T.	80	80	82	83	83	82	81	81	81	81	80	80	81	3.2
Rf.	3.3	1.9	4.3	9.7	10.9	7.3	4.4	3.2	4.8	13.4	11.8	5.1	80.1	
3. T.	80	79	80	80	80	80	80	79	80	79	79	80	80	1.1
Rf.	3.9	1.7	1.7	4.2	12.6	13.5	16.2	14.9	12.5	14.8	21.5	11.9	129.4	
4. T.	79	81	84	86	84	82	82	82	82	81	80	79	82	7.0
Rf.	0.9	0.1	0.3	1.7	8.3	12.6	11.1	11.0	13.3	11.1	3.7	3.1	77.2	
5. T.	84	83	84	84	82	79	77	80	83	86	86	85	83	8.5
Rf.	15.3	13.0	9.7	4.5	0.7	0.2	0.1	0.1	0.5	2.1	5.2	10.3	61.7	
6. T.	70	75	83	90	89	87	87	86	85	83	76	71	82	20
Rf.	0.1	0.1	0.2	1.1	5.8	5.5	3.3	4.6	5.7	4.7	1.6	0.4	35.1	
7. T.	60	62	65	64	66	64	62	61	61	62	59	59	62	7
Rf.	0.6	1.9	2.8	3.4	3.0	5.7	11.0	12.1	7.6	0.8	0.5	0.2	49.6	
8. T.	49	54	61	71	81	90	95	94	88	80	63	53	73	46
Rf.	1.2	1.3	1.3	0.9	0.2	0.0	0.0	0.0	0.0	0.1	0.8	1.2	7.0	
9. T.	60	60	59	58	57	55	55	54	55	58	59	60	58	6
Rf.	0.0	0.1	0.2	0.2	0.4	0.3	0.2	0.4	0.3	0.0	0.2	0.1	2.3	
10. T.	58	62	68	73	79	82	82	83	78	71	64	57	71	25.2
Rf.	0.5	0.5	0.7	1.1	1.2	2.3	2.1	2.0	4.4	2.4	1.3	1.0	19.5	
11. T.	19	23	33	48	64	73	76	74	63	50	36	27	49	56.9
Rf.	0.5	0.4	0.4	0.7	0.7	0.8	0.5	0.5	0.5	0.5	0.5	0.6	6.6	
12. T.	74	74	70	64	58	54	52	54	57	62	67	71	63	22.4
Rf.	0.7	0.6	1.0	1.7	2.8	3.1	2.6	2.5	2.0	1.7	1.2	1.0	20.9	
13. T.	70	70	68	63	59	56	55	56	58	61	64	68	62	15.6
Rf.	0.7	0.6	0.9	1.9	3.8	4.5	3.6	3.4	2.3	1.6	1.1	0.8	25.2	
14. T.	49	50	53	56	61	68	73	75	70	64	57	52	61	25.4
Rf.	4.0	2.6	3.3	2.0	1.7	0.7	0.1	0.1	1.1	3.4	4.1	3.9	27.0	
15. T.	74	73	69	61	55	50	49	51	55	60	66	71	61	24.7
Rf.	3.1	2.7	4.4	3.5	2.9	2.5	2.2	2.5	3.0	3.5	3.1	3.9	37.3	
16. T.	53	55	63	69	75	81	83	83	79	70	61	54	69	30.6
Rf.	1.4	1.6	1.8	2.7	3.2	2.7	2.5	2.6	3.5	2.0	2.2	1.8	28.0	
17. T.	77	77	76	72	68	65	65	66	68	70	73	75	71	12
Rf.	4.6	4.5	4.6	3.0	2.0	0.7	0.8	2.0	3.7	4.9	4.4	4.5	39.7	

Supplementary Climatic Data for Selected Stations.—(*Continued*)

(T., temperature in degrees Fahrenheit; Rf., rainfall in inches)

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*	*Range*
18. T.	34	34	35	42	49	55	58	53	53	45	39	35	45	24.3
Rf.	8.5	6.4	5.9	4.1	4.5	3.8	5.8	7.5	8.7	8.9	8.3	8.5	81.0	
19. T.	62	60	58	53	50	46	46	46	48	52	55	59	53	16.4
Rf.	2.4	3.0	5.5	9.4	15.2	17.0	16.1	13.2	8.7	5.2	5.0	4.1	104.8	
20. T.	39	40	43	48	53	57	60	60	56	50	45	42	49	21.1
Rf.	4.5	3.5	2.5	1.7	1.3	0.9	0.4	0.6	2.0	2.5	6.5	5.9	32.5	
21. T.	22	25	37	51	63	72	77	75	66	55	39	27	51	55
Rf.	0.7	0.9	1.3	2.8	4.1	4.7	4.0	3.2	3.0	2.3	1.1	0.9	29.0	
22. T.	32	38	46	55	63	70	75	73	66	56	44	36	55	42
Rf.	2.4	2.3	2.7	3.4	4.1	3.3	2.0	2.2	3.5	4.7	4.3	3.0	39.8	
23. T.	8	14	30	47	60	71	77	75	61	48	29	14	44	68.4
Rf.	0.2	0.3	0.7	1.1	2.2	3.4	5.8	5.3	3.3	1.5	0.9	0.2	24.9	
24. T.	− 4	0	15	38	52	62	60	64	54	41	21	6	35	70
Rf.	0.9	0.7	1.2	1.4	2.0	3.1	3.1	2.2	2.2	1.4	1.1	0.9	20.2	
25. T.	24	23	27	38	49	57	62	59	50	41	32	25	41	39
Rf.	1.3	1.1	1.2	1.2	1.7	2.0	2.7	2.8	2.0	2.1	1.7	1.6	21.4	
26. T.	− 3	2	13	30	47	59	64	59	48	32	13	2	31	66.9
Rf.	1.1	0.8	0.8	0.7	1.5	2.7	3.0	2.3	1.4	2.4	1.4	1.9	20.0	
27. T.	24	24	32	40	49	58	65	65	59	49	40	29	44	44.7
Rf.	6.0	4.7	5.1	4.6	3.8	3.8	3.7	4.6	4.1	5.5	5.9	5.5	57.3	
28. T.	8	9	18	30	41	53	60	56	46	34	22	12	33	52
Rf.	0.9	0.7	0.8	0.7	1.2	1.8	2.4	2.4	2.2	1.6	1.2	0.9	16.8	
29. T.	−23	−11	4	29	46	57	59	54	42	25	1	−13	23	82.4
Rf.	0.8	0.8	0.5	0.7	0.9	1.3	1.6	1.6	1.7	1.3	1.3	1.1	13.6	
30. T.	4	− 2	− 2	8	23	35	42	40	32	22	11	6	18	44
Rf.	1.4	1.3	1.1	0.9	0.5	0.4	0.6	0.6	1.0	1.2	1.0	1.5	11.8	

Stations for which data are given above:

1. Georgetown, British Guiana
2. Colombo, Ceylon
3. Colón, Canal Zone
4. Saigon, French Indochina
5. Darwin, Australia
6. Mandalay, Burma
7. Addis Ababa, Ethiopia
8. Baghdad, Iraq
9. Port Nolloth, Union of South Africa
10. Monterrey, Mex.
11. Astrakhan, U.S.S.R.
12. Adelaide, Australia
13. Capetown, Union of South Africa
14. Algers (Algiers), Algeria
15. Buenos Aires, Argentina
16. San Antonio, Tex.
17. Durban, South Africa
18. Bergen, Norway
19. Valdivia, Chile
20. Victoria, Can.
21. Omaha, Neb.
22. Milano (Milan), Italy
23. Mukden, Manchuria
24. Winnipeg, Can.
25. Uppsala, Sweden
26. Tomsk, U.S.S.R. (Siberia)
27. Halifax, Can.
28. Arkhangelsk (Archangel), U.S.S.R.
29. Dawson, Can.
30. Spitsbergen

Appendix C.
Meteorological Instruments and the Weather Map

In the study of the atmosphere it is desirable that at least a few weather instruments be available for daily observation. A complete set of meteorological instruments of the best kind is very expensive, yet a few essential ones may be purchased at reasonable cost. These should be housed in a case built outside one window of the laboratory. It should have a glass door facing the window, and the other three sides should be sufficiently open to allow free circulation of the air. At very small cost, bulletins may be secured from the U.S. Weather Bureau describing instrument cases and instrument installation. Teachers and interested students should secure the list of publications for sale by the Weather Bureau. It is sent free.

The two most essential instruments needed to forecast the weather are the *barograph* and the *wind vane.* A barograph is cheaper than a mercury barometer. It traces a curve on graph paper showing changes in air pressure. One needs simply to glance at the curve to note whether the barometer is rising or falling. Much cheaper than a barograph is the *aneroid barometer,* which, if used in forecasting, requires that the observer record the reading at least every 30 minutes in order to note changes in pressure. The wind vane is a simple arrow, free to rotate as the wind changes direction (Fig. 402). It can be made in any workshop. Metal vanes are more durable than wood. Aluminum paint is recommended. The vane should be placed on top of some building where it is visible from the laboratory. It needs to be emphasized that the arrow points *toward* the direction *from which* the wind is blowing.

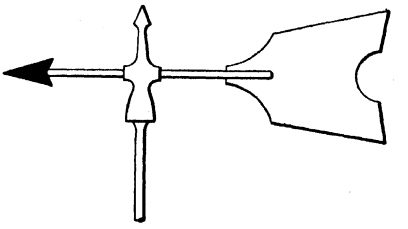


FIG. 402.—The wind vane points toward the direction from which the wind is blowing.

MEASURING TEMPERATURE

A great many thermometers employ mercury as an indicating medium. Like most metals, mercury expands when temperature rises and contracts when temperature drops. Some thermometers make use of clear or colored alcohol which has the advantage of having a much lower freezing point than mercury.

The two temperature scales most used are the *Fahrenheit* and the *centigrade* On the Fahrenheit the freezing point of water is 32° and the boiling point

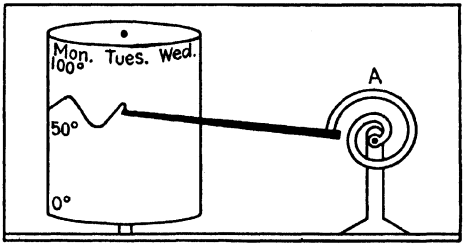


FIG. 403.—The thermograph. Clockworks inside the cylinder cause it to revolve once a week. Expansion and contraction of the sensitive metallic coil *A* is such that the temperature indicated by the pen point corresponds to the reading of a thermometer.

212°; on the centigrade the freezing point is 0° and the boiling point is 100°. Thermometers used to record air temperature should never be exposed to the direct rays of the sun.

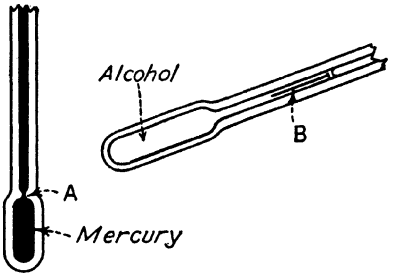


FIG. 404.—Maximum and minimum thermometers. In the maximum thermometer a constriction *A* above the bulb permits the mercury to rise in the capillary tube but does not allow it to return except when the thermometer is given a vigorous shaking. The minimum thermometer uses clear alcohol and must be placed at an angle of about 20°. The black float *B* is pulled downhill to the lowest temperature of the day by two forces: the surface tension of the top of the alcohol column and the force of gravity.

The *thermograph* is an instrument that records air temperature on graph paper. These instruments are of several designs. One consists of a cylinder made to revolve once each week by means of clockworks inside (Fig. 403). A sheet of graph paper is fastened on the outside. A pen point that rests on the paper traces the temperature curve.

A *maximum thermometer* is one in which the mercury rises to the highest temperature of the day and remains there (Fig. 404). This thermometer also is used by doctors when taking the temperature of the human body.

The *minimum thermometer,* which employs clear alcohol and a tiny black float, records the lowest temperature of the day (Fig. 404).

MEASURING ATMOSPHERIC PRESSURE

A simple *mercury barometer* is made by filling a glass tube about 32 inches long with mercury and inverting it so that the open end of the tube is below the surface of mercury in a dish of some kind (Fig. 405). The mercury column at sea level will be about 30 inches high and is equivalent to a pressure of about 15 pounds per square inch. For several thousand feet above sea level, the column decreases about 1 inch in height for each 900 feet increase in elevation. As storms come and go, the weight or pressure of the atmosphere

upon the surface of the mercury in the dish changes, and this causes the top of the column of mercury to rise and fall. Over most of the United States a falling barometer, accompanied by winds from the northeast, east, or southeast, indicates the approach of unsettled weather. A rising barometer with winds from the southwest, west, or northwest usually foretells fair weather. An accurate mercury barometer is quite expensive.

An *aneroid barometer* is made by exhausting the air from a thin, circular, metallic box (Fig. 406). With practically no air pressure on the inside and 15 pounds (or less) per square inch on the outside, it is evident that the box would collapse were it not for a strong spring inside. If one side of the box is made immovable, the other side will move owing to changes in atmospheric pressure. The surface of the metallic box is corrugated to increase the area exposed to the air. The movement of the spring causes an indicating arm, or pointer, to move over a scale of figures corresponding to the readings of a mercury barometer. Since air pressure decreases rather regularly with increase in altitude, the aneroid is used to make *altimeters* (Fig. 407). On the altimeter the indicating arm moves over a scale marked off in hundreds and thousands of feet above sea level. Good aneroids, to be used for noting changes in air pressure caused by the passing of storms, vary in price.

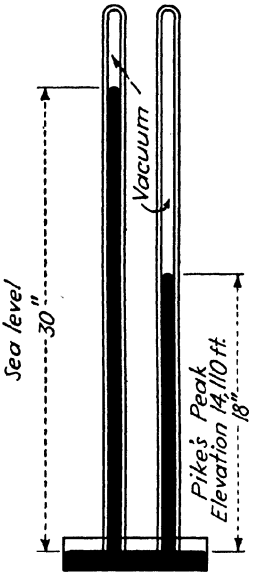


FIG. 405.—The mercury barometer. At sea level, atmospheric pressure (or weight) is sufficient to balance the weight of a column of mercury about 30 inches high. As elevation above sea level increases, atmospheric pressure decreases.

The *barograph* is an instrument that records atmospheric pressure on graph paper (Fig. 408). As in the case of the thermograph, the paper is fastened on the outside of the cylinder. Clockworks inside the cylinder cause it to

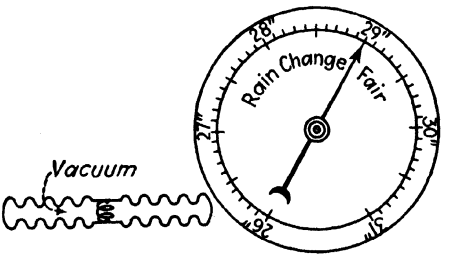


FIG. 406.—The aneroid barometer. A cross section of the circular metallic vacuum box with spring inside is shown. The walls of this box move slightly as changes in atmospheric pressure occur. This movement is transferred to an indicating arm which in turn moves over a set of figures on the face of the dial. The words "rain," "change," and "fair" cannot be used unless they are set for the elevation above sea level where the instrument is to be used.

rotate once a week. The pen point that traces the pressure curve on the paper is made to move up (rising barometer) or down (falling barometer) by means of a series of levers attached to a compound aneroid. The several aneroids in tandem provide a more pronounced response to changes in atmospheric pressure than would be indicated by a single aneroid of the same size. As stated previously, this instrument clearly shows the changes that are taking place in air pressure, and these changes often indicate the nature of weather to be expected

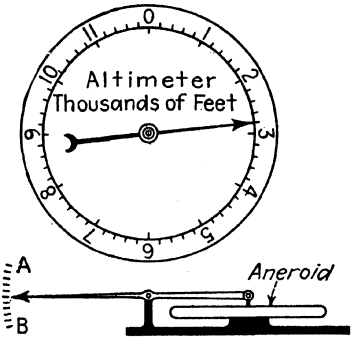


FIG. 407.—The altimeter. In the lower figure, will the pointer move toward *A* or *B* when altitude increases? Why? It should be remembered that changes in atmospheric pressure due to the passing of storms may cause considerable error in the altimeter reading. This is another reason why airplane pilots must be familiar with the weather map.

WIND VELOCITY

Wind velocity may be gauged to some extent by several methods. If the leaves on a tree are perfectly quiet, a *calm* prevails. A *strong* wind will cause tree branches to move noticeably. Winds of *gale* or *hurricane* velocity usually do considerable damage. If a small airplane propeller is fastened to the pointed end of the wind vane, some idea of wind velocity may be obtained by observing the speed at which the propeller turns.

Weather bureaus and aviation companies ascertain accurate wind velocities by means of the *anemometer* (Fig. 409). This instrument consists of three

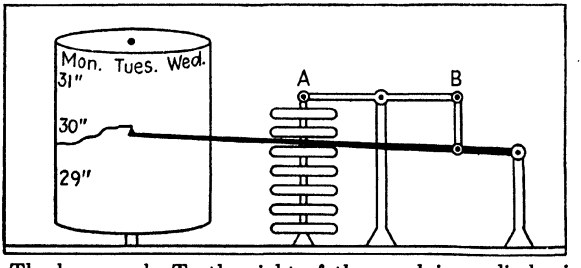


FIG. 408.—The barograph. To the right of the revolving cylinder is a compound aneroid (seven aneroids in tandem). When pressure increases, the compound aneroid is compressed, point *A* moves down, and point *B* moves up. Since *B* is connected to the pointer, the pen point moves up to record higher pressure. When pressure decreases, each of the seven aneroid springs opens slightly, causing point *A* to move up and *B* down. The levers are adjusted so that the pressure recorded by the pen will correspond with the reading of a mercury barometer.

(sometimes four) revolving cups. The stronger the wind the faster the cups will rotate. This rotation operates a complex set of gears which in turn indicates the wind velocity in miles per hour. As might be expected, an anemometer is an expensive instrument. Mechanically inclined students can build a home-

made anemometer of rough design. Three or four aluminum cups can be fastened to an upright arm pivoted at each end so that it turns easily. An electrical switch can be arranged at the bottom of the arm so that each time the cups rotate once an electrical circuit is closed, which will cause a small light in the laboratory to flash. By counting the flashes per minute, some idea of wind velocity is obtained.

The so-called "Beaufort Scale" of wind velocities was devised by Admiral Sir Francis Beaufort of the British Navy in 1805. It is a useful method of estimating wind velocities, and is given in condensed form below.

BEAUFORT SCALE OF WIND VELOCITY

Name	*Miles per Hour*	*Indicated by*
Calm	Less than 1	Tree leaves quiet. Smoke rises vertically.
Light breeze	1– 7	Leaves rustle.
Gentle breeze	8–12	Leaves and twigs in constant motion.
Moderate breeze	13–18	Raises dust. Small branches move.
Fresh breeze	19–24	Small trees in leaf begin to sway.
Strong wind	25–38	Large branches and whole trees in motion.
Gale	39–54	Tree limbs break.
Whole gale	55–75	Trees uprooted. Seldom experienced inland.
Hurricane	Above 75	Extremely destructive.

MEASURING HUMIDITY

Instruments used to determine the relative humidity of the air are called *hygrometers*. Three types will be mentioned here. They are (1) the wet- and dry-bulb hygrometer, (2) the hair hygrometer, and (3) the hygrograph.

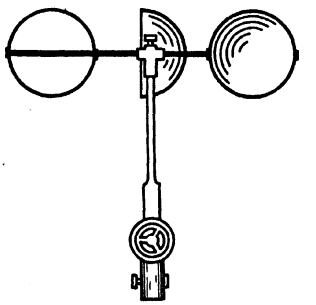


FIG. 409.—The anemometer (three cup) which measures the velocity of the wind in miles per hour.

The *wet- and dry-bulb hygrometer* provides the easiest and most accurate method of determining relative humidity. One good thermometer is all that is necessary. First the temperature of the air as shown by the thermometer is noted. Next, a piece of fine, loosely woven muslin is tied around the bulb and moistened. Then the instrument is fanned vigorously. Evaporation of water from the cloth will cause the temperature to drop. The drier the air (low relative humidity) the lower the thermometer will read. Subtract the two temperatures to get the difference between the wet- and dry-bulb readings. Now refer to the chart that accompanies the exercise on humidity in the laboratory manual. Using the figures already obtained and following the simple instructions that accompany the chart, the relative humidity can be determined.

Once the relative humidity is known, it is an easy matter to determine the absolute humidity and the dew point. Studies are being made of temperature and dew-point data in an effort to ascertain those conditions of the atmosphere which are most likely to cause icing of airplanes.

The *sling psychrometer* consists of a metal strip to which two thermometers are securely fastened. One thermometer bulb is covered with a cloth which can be moistened when making a test. The upper end of the metal strip is fastened to a handle in such a way that the two thermometers can be whirled around at a rapid rate. The rotary motion is continued until the wet-bulb temperature ceases to drop. Then the two thermometers are read, and reference is made to the relative humidity chart as explained for the wet- and dry-bulb hygrometer. Official Weather Bureau tests for humidity are made by the whirling wet- and dry-bulb method.

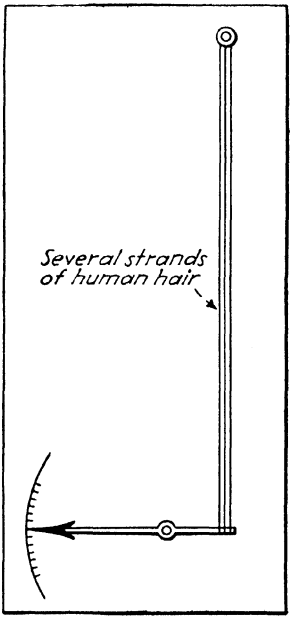


FIG. 410.—Hair hygrometer (much simplified). As relative humidity varies, the length of the human hair changes, causing an indicating arm to move over a scale of figures reading from 0 to 100 per cent.

The *hair hygrometer* is less accurate than the wet- and dry-bulb method. Human hair, from which the oil has been removed by using ether, becomes longer as the relative humidity of the air increases. This change can be made to move an indicating needle which moves over a scale, the graduations of which read from 0 to 100 per cent (Fig. 410). Exposure to the air causes the hair to become dirty and perhaps greasy, thus decreasing the accuracy of the instrument. The hair must be cleaned occasionally with ether or other suitable solvent.

The *hygrograph*, which is a form of hair hygrometer, is an instrument that records relative humidity on graph paper. As with the thermograph and barograph, a sheet of graph paper is fastened on the outside of a cylinder which rotates once each week. The pen point that traces the relative humidity curve on the graph paper is made to move up and down by an arrangement of levers fastened to several strands of human hair.

Some self-recording instruments are extremely sensitive to quick changes in meteorological conditions. Let us suppose that a warm, moist south wind is blowing and that there is an instantaneous change to a cold northwest wind. The thermograph curve may drop vertically 15° or 20°; the barograph curve will show a sharp increase in pressure; and the hygrograph reading may drop 30 per cent or more.

MEASURING PRECIPITATION

Precipitation may fall in the form of rain, snow, sleet, or hail. In case it falls in the solid form, it is melted, and the water is measured in a standard

rain gauge. Ordinarily, 8 to 12 inches of snow will equal 1 inch of rain. The rain gauge consists of a galvanized-iron cylinder 8 inches (sometimes 12) in diameter and about a foot deep. The bottom of the cylinder is funnel shaped with a small opening to allow the water to be drawn off. In order to measure small amounts of rain, the water from the large cylinder runs into a smaller cylinder (Fig. 411). Thus water that is 1 inch deep in the large cylinder is "stretched out" in the small cylinder to a length sufficient for graduations of $\frac{1}{100}$ inch to be shown.

Depth of snow may be measured by an ordinary yardstick on level ground where no drifting has occurred. A snow gauge may be constructed of an upright galvanized cylinder, about 6 inches in diameter and 3 feet deep. All rain and snow gauges must be so exposed that buildings and trees do not interfere with the fall of precipitation.

Electrical devices for recording rainfall may be observed at most weather bureaus. A sheet of graph paper is placed on the outside of a cylinder which rotates once every 12 hours (instead of once a week, as with the thermograph, barograph, and hygrograph). The more rapid rotation is necessary in order to record extremely heavy rains. A pen point resting on the graph paper records each $\frac{1}{100}$ inch of rain at the time it falls.

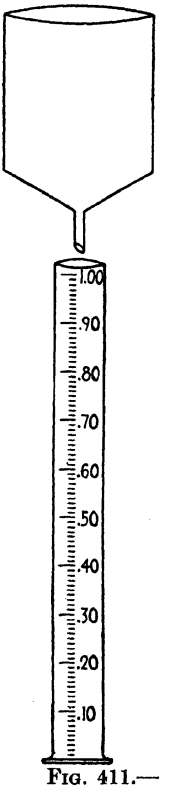


FIG. 411.—Rain gauge. In the large funnel 1 inch of water is "stretched out" in the graduated cylinder so that $\frac{1}{100}$ inch of rain can be measured.

OTHER WEATHER DATA

The *cloud ceiling* is the altitude of the bottom of a cloud layer. Low ceilings, characteristic especially of stratus clouds, constitute one of the greatest hazards in aviation. The height of the ceiling is ascertained by releasing a rubber balloon about $2\frac{1}{2}$ feet in diameter filled with a definite amount of hydrogen. Its ascent is watched carefully through a telescopic instrument called a *theodolite*. The balloon rises about 600 feet per minute. If it disappears in the clouds in 3 minutes, it is evident that the ceiling is about 1,800 feet. On clear days the balloon may be observed for a considerable length of time. Its path enables the meteorologist to determine the direction and velocity of winds aloft.

Upper air data are obtained by *meteorographs* carried aloft by airplanes. The meteorograph records temperature, pressure, and relative humidity during the entire flight. The *radio-meteorograph* has been developed. It consists of a radio transmitting unit, a battery unit, and a meteorograph. When the instrument is carried aloft by a balloon, it automatically broadcasts upper air weather data to a specially designed radio receiving set on the ground. The total weight of some radio-meteorographs is less than two pounds.

THE WEATHER MAP

Twice daily, at 7:30 A.M. and 7:30 P.M., Eastern Standard time, weather observers at about 250 stations scattered over North America make careful

weather observations. These observations (temperature, pressure, precipitation, wind direction and velocity, etc.) are reported by telegraphic code to the U S. Weather Bureau at Washington, D.C., and to regular government weather stations throughout the country. Code is used, because it increases brevity of reports, saves time, and is economical. It is not used for secrecy. At Washington, at district forecast centers, and at local centers, trained men decode the messages and transfer the information to a skeleton map of North America (or the United States). The result is a picture of weather conditions known as the *daily weather map.* Abbreviated and simplified weather maps are published in many daily newspapers.

At the more important weather stations, especially those located on transcontinental air lines, additional weather maps are made at 1:30 A.M. and 1:30 P.M., Eastern Standard time. Along the major transcontinental air lines, weather data are being transmitted and received by teletype machines at all hours of the day and night. This service makes it possible to inform aviators of the sudden changes that often take place in the atmosphere. Such information has to do especially with the location of storm centers and fog, the height of the cloud ceiling, wind direction and velocity, and the degree of visibility at various landing fields along the route.

The weather map is of value in several ways but especially (1) in showing actual weather conditions over the country at the time of observation and (2) in providing the necessary data for making weather forecasts for the next day. Since weather information is valuable in many lines of work, and since the maps are published in many newspapers, a description of the essential features of the weather map will now be considered.

On the large skeleton map used in regular weather bureau offices, the location of the 250 or more weather stations is indicated by open circles. It is customary for one man to decipher the code messages; as he recites the name of a station and its weather data, another man writes the figures on the skeleton map at the correct place. When this is completed for all stations reporting, isobars and isotherms are drawn. An *isobar* is a solid line that passes through places of equal atmospheric pressure. (All pressure readings are reduced to sea level before they are telegraphed from one station to another.) An *isotherm* (dotted line) passes through places of equal temperature. Maps printed in newspapers usually show only the isobars, temperatures being indicated by figures at a number of cities.

By using the circle at a given station the weather conditions at that station are shown by symbols, some of which are as follows:

○ Clear	® Raining	○→ West wind
◑ Partly cloudy	Ⓢ→ Snowing, W. wind.	Ⓕ Fog
Cloudy, N.E. wind.	Ⓜ Report missing	Thunderstorm

Shaded portions of the weather map indicate those areas which have received $\frac{1}{100}$ inch or more of precipitation within the past 24 hours.

Wind arrows fly with the wind. On some maps, feathers are drawn at the end of the wind arrow, the number of feathers indicating the wind velocity.

When the map is completed, it may be noted that several isobars form rough ovals about a point of low pressure. The word "low" is printed in the center of these ovals. This formation is called a *low-pressure area*, or *cyclone*. If the ovals form about a point of high pressure, the word "high" is printed in the center and an *anticyclone* is indicated. All lows and highs are not to be thought of as cyclones and anticyclones. A well-developed storm (low) usually will have four to ten encircling isobars and will be characterized by precipitation and often rather strong winds.

At some weather stations, the warm and cold fronts are indicated by colored lines and the abbreviations of air masses, such as *Tg* (Tropical Gulf) and *Pc* (Polar Continental), are stamped on the map at appropriate places (see pages 119–122).

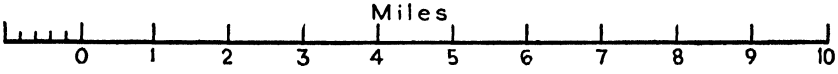
Appendix D. Interpretation of Maps

Maps are graphic representations of the surface of the earth. They are used in many fields of learning but especially in earth sciences. For the student of geography the map is an essential tool, a means of recording facts, and also a manner of expression. Maps are almost infinite in number, size, form, and meaning, and they constitute almost a language in themselves. Some indeed are works of art and demand a high degree of skill in design, construction, and coloring. A person highly trained in the art of map making is called a *cartographer.*

When studying a good map, three essential features should be noted: (1) the scale of the map, (2) the map projection, and (3) the types of things represented on the map and the meanings of the various kinds of symbols or devices used to show them.

The scale of the map may be indicated in one or more ways.

1. By a line graph. Example:



2. By a statement of the proportion used. Example:

1 inch = 50 miles.

3. By a representative fraction. Example:

$$\frac{1}{63{,}360}, \text{ or } 1{:}63{,}360,$$

which means that 1 inch on the map equals 63,360 inches on the earth's surface. Since there are 63,360 inches in 1 mile, this scale also may be written 1 inch = 1 mile. Instead of inches, other units, such as the centimeter, may be used.

A map projection, broadly speaking, is a system of drawing parallels and meridians. Many projections are the result of complicated mathematical computations. True perspective projections may be obtained by casting shadows of parallels and meridians on flat sheets of paper. Imagine a hollow globe the outer shell of which consists of two hemispheres of clear glass. Parallels and meridians are painted on the outside of the glass, and an electric

light is put inside the globe, say at the center. When placed in a dark room, the shadows of the lines, cast on a sheet of paper that is tangent to the globe surface, can be traced. By changing the position of the light or of the sheet of paper or both, different arrangements of parallels and meridians may be secured.

Some map projections are constructed so that they represent the shapes of land areas and seas correctly; others show sizes correctly. It is impossible for any projection that includes a considerable area to accomplish both these objectives. Some accomplish neither. An equal-area map may show certain land and water bodies badly distorted in shape. Likewise, a map that maintains the true shapes of areas may be very misleading if used to compare the sizes of land or sea areas. It is well to remember that *the only true representation of the whole earth is a globe.*

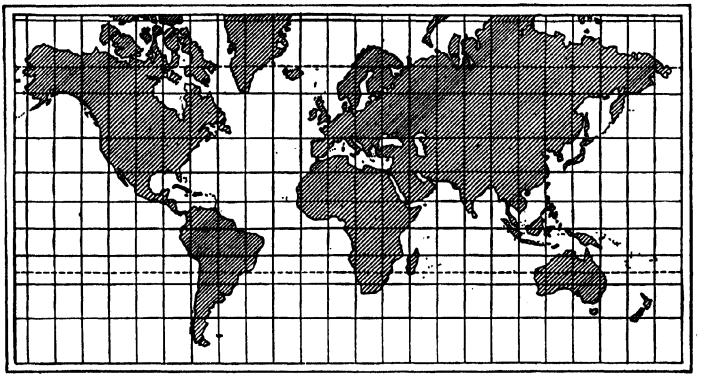


FIG. 412.—Mercator's projection.

Mercator's projection (Fig. 412), which is used for maps of the world, was first published in 1569. In this projection both meridians and parallels are straight lines, always crossing at right angles. The meridians, instead of coming together at the poles, are drawn as parallel lines and thus in high latitudes (from about the 50th parallel to the poles) are much too far apart. To balance this great distortion, the parallels also are spaced much farther apart in high latitudes than near the equator. Thus an area 10° by 10° in Alaska is much larger than one on the equator. A serious objection to the Mercator map (for school use) is that land and water bodies in high latitudes are greatly exaggerated in size. Greenland appears larger than South America when in reality its area is less than that of Argentina. Furthermore, no single scale of miles can be used for all parts of the Mercator map, and it is virtually impossible to show polar regions. Two advantages of this projection should be mentioned. One is the ease of telling the direction from one place to another. This map is especially valuable to navigators because they can draw a straight line from one place to another and thus determine the sailing course. However, the Great Circle route (shortest path) between important seaports is seldom a straight line on the Mercator map. In order to follow the Great Circle the

navigator must make frequent changes in his compass course. A second advantage of this map is that relatively small areas are fairly correct in shape.

Aitoff's projection is representative of several in which the whole earth's surface is shown in an oval (Fig. 413). It is an equal-area projection. Continents near the center of the map are shaped fairly accurately. Toward the east and west margins, however, shapes are badly distorted. Figures 288 (page 418) and 414 are drawn on the interrupted Aitoff projection. This has the advantage of showing correct size and fairly good shape of land and water bodies. It is necessary, of course, for the eye of the observer to bridge the gaps in the grid caused by the interruptions. By reducing ocean areas and shifting the relative location of Australia, the map is given a compact appearance.

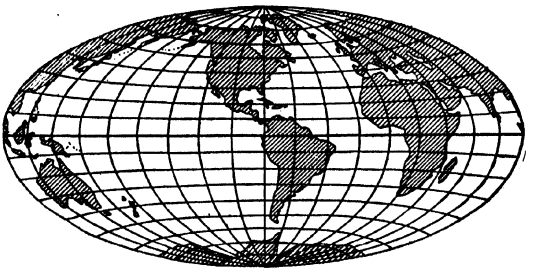


FIG. 413.—Aitoff's projection.

Goode's homolosine projection (Fig. 415) is an equal-area map of the world.[1] Since the interruptions are in the oceans, the continents show clearly and are well shaped. The parallels are straight lines, so that the map is well suited to the study of comparative latitudes. Equal-area projections of the entire earth's surface are of great value for the purpose of showing the world distribution of economic data, climatic regions, or soils. On such maps it is desirable that areas be shown in their true proportion to one another.

The *conical* projection and its modifications are used for maps of continents or smaller areas. To understand the simple form of this projection, imagine a large paper cone set down upon a globe with its apex directly above the pole of the globe. The cone is tangent to the globe along the entire circumference of a selected parallel, which is called the *standard parallel.* Because this parallel is everywhere equally distant from the apex of the cone, it becomes an arc of a circle when the cone is opened out into a plane surface, and all other parallels become arcs of concentric circles (Fig. 416). The meridians are straight lines which radiate from the apex.

Another modification of the conic projection is called the *polyconic* (Fig. 417). It is drawn as if many cones of different taper were fitted upon a globe, each tangent on a different parallel. This projection often is used as a basis of detailed surveys, such as the United States topographic maps or the Inter-

[1] J. Paul Goode, late of the department of geography, the University of Chicago, contributed much to the art of map making in the United States. *Goode's School Atlas* is widely used.

FIG. 414.

national Map of the World on a scale of 1:1,000,000. Many maps of the entire United States are drawn on the polyconic projection. In *Bonne's* projection (Fig. 418) the parallels are concentric circles, but the meridians are curved lines. This produces a grid more like that of a true globe. The great variety of maps that may be seen in a good atlas is a result of the numerous devices that are employed to represent different things. A most useful device is the *dot map* (Fig. 414). Each dot represents a definite number or quantity. Such maps are excellent in providing pictures of the areal distribution of many items such as citrus fruits, corn, or beef cattle. Round dots, triangles, or squares may be used. Maps having devices of this kind are called *cartograms*.

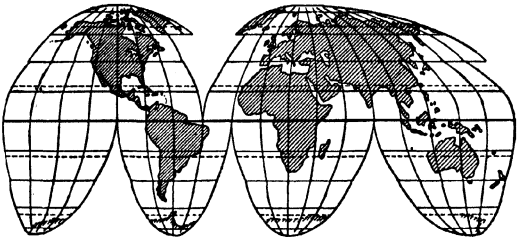


FIG. 415.—Goode's homolosine projection.

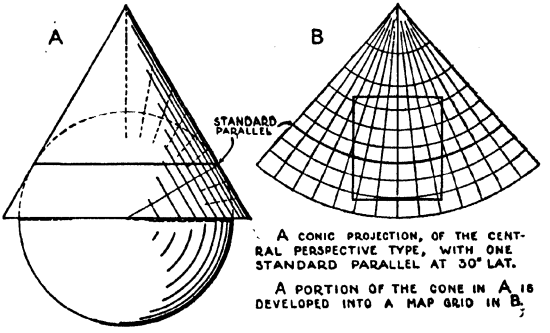


FIG. 416.

The dot map is properly effective only when shown on an equal-area projection. On some maps, dots or squares of different sizes are given graduated values. These are of particular value in showing the concentration of production, industry, or mineral wealth in certain localities (Fig. 419).

Other useful maps are made in different ways. A *political map* is one on which different colors are used for different countries, states, and counties. Another valuable device is a line that passes through places having the same characteristic. For example, on a map of the United States a line may pass through all places having an average January temperature of 10°; another line, through places that have an average of 20°; another, 30°. Such temperature lines are called *isotherms*. On other maps, lines may pass through places having the same annual rainfall, same elevation above sea level, or same relative humidity. Lines may be drawn to show the boundary line between forest and prairie or between desert and humid land.

Relief maps show elevation of the land above sea level. Various methods are employed to show relief, some of them (1) by colors, such as green for plains, light brown for low mountains, dark brown for high mountains, (2) some by shading one side of a mountain range or hill (Fig. 420), (3) by hachures (tiny lines that show hill and valley slopes), and (4) by contour lines. Relief maps are of particular value in studying the surface features of the land, in laying out railroads and highways, in solving drainage and irrigation problems, and in explaining rainfall characteristics of certain regions.

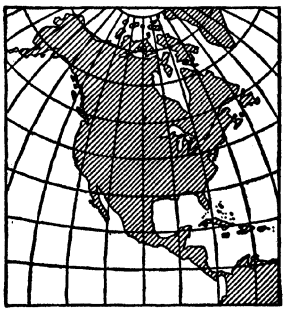


FIG. 417.—A polyconic projection.

Contour maps are probably the most valuable of relief maps because of their greater accuracy in showing elevation. A *contour line* is one that passes through places having the same elevation above sea level. The *contour interval* is the vertical distance between two adjacent contour lines. The idea of contour lines, their spacing, and their irregularities may be made clear by a simple illustration. In an open tank one may mold an oval mound of wax $6\frac{1}{2}$ inches high, steeply sloping at one end and gently sloping at the other. If 6 inches of water is permitted to flow into the tank, only $\frac{1}{2}$ inch of the mound will protrude. With a sharp point the position of the edge of the water upon the wax may be marked, and then the water level may be lowered by 1-inch stages, and the position of each stage marked on the surface of the wax. The marks made will now appear as contour lines on the wax mound, the lowest being everywhere 1 inch above the bottom of the tank, the next 2 inches, and so on to the sixth, as in Fig. 421*A*. If the mound is viewed from directly above, the arrangement of the lines will be that of Fig. 421*B*. This is the appearance of a contour map. It will be noted that, where the slope of the mount is steep, the contour lines are close together and that they are more widely spaced as the slope becomes more gentle. In this illustration the contour interval is 1 inch.

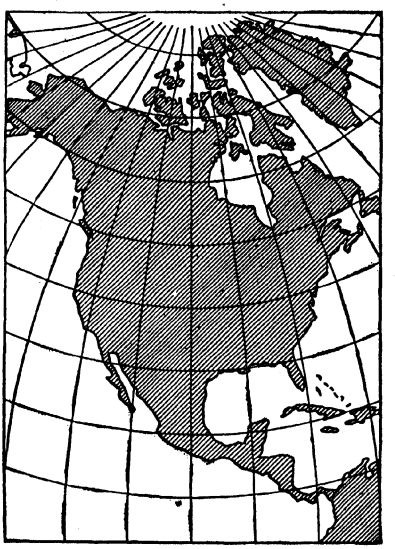


FIG. 418.—Bonne's projection.

The topographic maps of the U.S. Geological Survey depend wholly upon contour lines to produce the effect of surface relief. They are printed in either three or four colors, each having a restricted meaning. In black are shown those features in the surveyed area which may be classed as *culture*, *i.e.*, those which have human origin. In this color are roads, houses, towns, place names, bound-

ary lines, and parallels and meridians. In blue are printed all water features, both natural and man-made, such as canals, streams, marshes, millponds, lakes, or seas. The various classes of such features are distinguished by appropriate symbols in blue. In green, if that color is shown, are areas covered by timber or woodland. This feature is shown on a small number of the

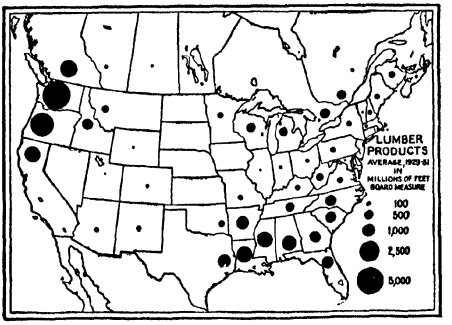


FIG. 419.—A cartogram that shows the distribution of a manufacturing industry by dots of graduated sizes.

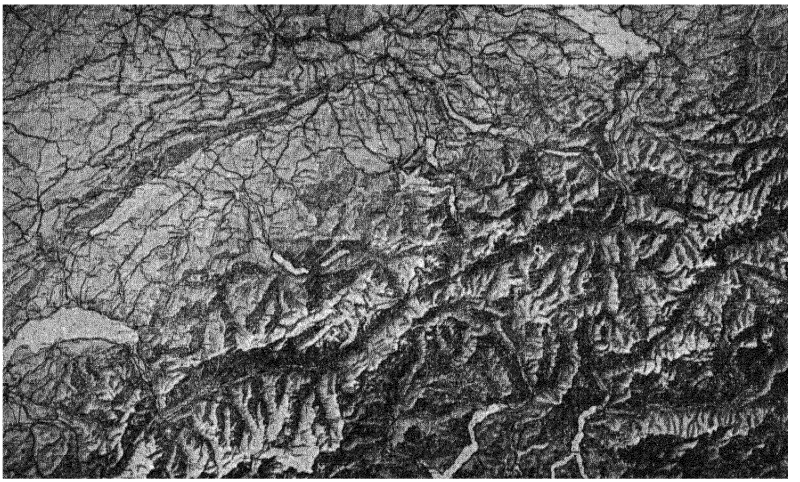


FIG. 420.—The wall map of Switzerland by Kümmerly and Frey, of which the foregoing is a photographic reproduction, is printed in subdued colors and is an example of the best in maps that simulate modeled relief.

published maps only. The contour lines and other symbols relating to the relative elevation of the land surface are shown in brown.

Each map is provided with a place title and with parallels and meridians that indicate its exact location and extent. The scale and contour intervals are printed on each map. It is important that these be noted carefully when beginning the study of a new sheet. Contour lines express the elevation of the land, in feet, above mean sea level. Every fifth contour line is heavy and numbered. In each surveyed area a few carefully measured points are given

permanent markers in the form of numbered metal posts called *bench marks*. These are indicated on the map by the letters *B.M.*, and the exact elevation of each one is given, printed in black.

The standard United States topographic sheet includes a quadrangle of 0°15′ of latitude and 0°15′ longitude. It is printed at a scale of 1/62,500, or approximately 1 inch to 1 mile. Some are drawn on different scales which are explained on the back of the map. The contour intervals employed usually

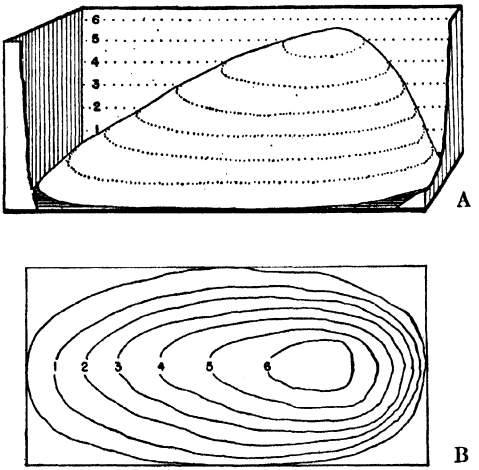


FIG. 421.

are 10, 20, 50, or 100 feet. On maps of extremely flat land an interval of 5 feet may be used; on maps of rugged mountains the interval is usually 100 feet or more.

Many relief features of the earth are discussed in this book. They can be better understood if they are illustrated by the use of topographic quadrangles. A list of specific quadrangles illustrating certain landforms is given in Appendix E.

REFERENCES

DAKE, C. L., and J. S. BROWN: *Structural Interpretation of Topographic and Geologic Maps*, McGraw-Hill Book Company, Inc., New York, 1925.

FINCH, J. K.: *Topographic Maps and Sketch Mapping*, John Wiley & Sons, Inc., New York, 1920.

RAISZ, ERWIN: *General Cartography*, McGraw-Hill Book Co., Inc., New York, 1939.

Appendix E

A Selected List of United States Topographic Quadrangles

The topographic quadrangles indicated below have been selected from those published by the United States Geological Survey because they illustrate in map form certain of the landforms discussed in the text. Some of the subjects discussed, ice-scoured plains, for example, do not find clear illustration in any of the United States Topographic Quadrangles now published and are therefore omitted from the list.

Certain of the maps named below may be used to illustrate more than one class of features, and their names are repeated. Such maps are indicated by the asterisk. In some instances two or three adjacent quadrangles are required to show adequately the extent of the feature in question. Such are indicated as a series by being listed in series.

Standard-size quadrangles may be obtained from the United States Geological Survey, Washington, D.C., very inexpensively. In the following list, sheets of sizes other than standard are marked "(*special*)."

Plains of Stream Degradation

Newly emerged plains:
- Bladen and Everett City, Ga.
- Cambon, Fla.
- Chicora, S. C.
- Moniac, Ga.-Fla.

Higher and better drained coastal plain:
- Bamberg, S. C.
- Forest, Miss.
- Springhope and Rocky Mount, N. C.

Plains with cuestiform ridges and escarpments:
- Blanchardville and Blue Mounds, Wis.
- Epes, Ala.
- Fond Du Lac and Neenah, Wis.
- Kendall and Mauston, Wis.*
- Llano, Tex.*
- Nashville, Tenn.*
- New Boston and Linden, Tex.

Knobs and outliers on cuestiform plains:
- Big Clifty, Ky.*
- Franklin, Tenn.
- Kendall and Mauston, Wis.*
- Llano, Tex.*
- Nashville, Tenn.*

Young plains (mainly in glacial drift):
- Gillespie, Ill.*
- La Salle, Ill.*
- Macon, Mo.
- Paulding, Ohio*
- Ray, N. D.*

Rough, maturely dissected plains:
- La Farge, Wis.
- Newcomerstown, Ohio
- Nortonville, Ky.

Dissected river bluffs (river breaks):
- Ray, N. D.*

PLAINS OF STREAM DEGRADATION.—(*Continued*)

Niagara, N. Y.
Pelahatchie and Morton, Miss.
Old-age plain:
Mount Carmel, Ill.-Ind.
Owensboro, Ind.-Ky.
Peneplains with monadnocks:
Atlanta and Marietta, Ga.
Gastonia, N. C.
Kings Mountain, N. C.
Porcupine Valley and Spring Creek, Mont.
Karst plains:
Big Clifty, Ky.*
Interlachen, Fla.
Mammoth Cave, Ky.
Princeton, Ky.
Williston, Fla.

PLAINS OF STREAM AGGRADATION

Delta margin:
East Delta, La.
Timbalier, La.
Narrow levees:
Bayou de Large, La.
Pt. a la Hache, La.
Quarantine, La.
Shell Beach, La.
Wide levees:
Baton Rouge, La.
Donaldsonville, La.
New Orleans, La.
Wide alluvial floodplains:
Bayou Sara, La.
Clarksdale, Miss.
Marks, Miss.
Memphis, Tenn.-Ark.
Vicksburg, Miss.
Narrow floodplains:
Chester, Ill.
Gays Mills, Wis.
Ogallala, Neb.*
Prairie du Chien, Wis.*
Alluvial terraces:
East Cincinnati, Ohio
Malaga, Wash.
Prairie du Chien, Wis.*
Tarboro, N. C.
Alluvial fans and piedmont alluvial plains:
Cucamonga and San Bernardino, Calif.
Levis, Calif.
Pacoima and Sunland, Calif.
Whittier, Calif.
Plains of older alluvium:
Assiniboine, Mont.
Colorado Springs, Colo.
Eaton, Colo.
Sanborn, Colo.
Vilas, Colo.

GLACIAL DRIFT PLAINS

Till plains (younger drift):
Poorly drained:
Chokio, Minn.
Lansing, Mich.
Neshkoro, Wis.
Well-drained:
La Salle, Ill.*
Slater, Iowa
Upper Sandusky, Ohio
With drumlins:
Boston, Mass.*
Clyde and Weedsport, N. Y.
Palmyra, N. Y.
Sun Prairie and Stoughton, Wis.
Till plains (relief controlled by bedrock features):
Baraboo, Wis.
Stonington and Moosup, Conn.
Youngstown, Ohio
Marginal moraines:
Kettle-moraine regions (large area):
Pelican Rapids and Vergas, Minn.
Kettle-moraine belts (with associated pitted outwash plains):
Rives Junction* and Stockbridge, Mich.
Schoolcraft, Mich.
St. Croix Dalles, Wis.
Whitewater, Wis.

GLACIAL DRIFT PLAINS.—(*Continued*)

With eskers:
- Fowlerville, Mich.
- Rives Junction, Mich.*
- St. Francis, Minn.

Till plains (older drift):
- Albia and Pella, Iowa
- Gillespie, Ill.*

Lake plains (glacial):
- Detroit, Mich.
- Fargo, N. D.-Minn.
- Paulding, Ohio*
- Ridgeway, N. Y.

PLAINS IN DRY CLIMATES

Eolian sand plains:
- Brown, Neb.
- Lakin, Kans.
- North Platte, Neb.
- Ogallala, Neb.*

Loess Plains (stream eroded):
- Omaha and Vicinity, Neb. and Iowa (*special*)
- Red Cloud, Neb.
- York, Neb.

SHORE FEATURES OF PLAINS

Ria shorelines:
- Bath and Boothbay, Maine
- Boston, Mass.*
- Choptank, Md.
- Kilmarnock, Va.

Deposited shore features:

Offshore bars:
- Atlantic City, Sea Island, and Barnegat,* N. J.
- Lopena Island and Saltillo Ranch, Tex.

Spits and hooks:
- Cape Henlopen, Del.*
- Erie, Pa.
- Provincetown, Mass.
- Sandy Hook, N. Y.

Shore dunes:
- Barnegat, N. J.*
- Cape Henlopen* and Rehoboth, Del.
- Fenville, Mich.
- Three Oaks, Mich.

DRY-PLATEAU FEATURES

Plateau valleys and escarpments:
- Abajo, Utah*
- Bisuka, Idaho
- Bright Angel, Ariz.
- Diamond Creek, Ariz.
- Escalante, Utah
- Hanford and Scooteney Lake, Wash.
- Henry Mountains, Utah*
- Kanab, Utah

Mesas and buttes:
- Mesa de Maya, Colo.
- Mount Trumbull, Ariz.
- Raton, N. M.
- Tascotal Mesa, Tex.

Plateau bolsons:
- Carson Sink, Nev.*
- Cienega Springs, N. M.
- Disaster, Nev.*
- Silver Peak, Nev.*

HILL LANDS

Stream-eroded hills in horizontal strata:
- Arnoldsburg, W. Va.
- Bald Knob, W. Va.
- Confluence, Pa.
- Fayetteville, W. Va. (plateau features)

Badlands:
- Rock Springs, Wyo.

Hills in complex rocks:
- Asheville, N. C.-Tenn.
- Knoxville, Tenn.-N. C.

Hills in areas of linear faulting:
- McKittrick, Calif.
- San Mateo, Calif.

HILL LANDS.—(*Continued*)

Hills in folded sedimentary strata:
- Hyndman, Pa.
- Millersburg, Lykens, and Pine Grove, Pa.
- Mount Union, Pa.
- Winding Stair, Okla.

Glaciated hill lands:
- In crystalline rock
  - Allagash, Maine
  - Bolton, N. Y.
  - Greenlaw, Maine
- In horizontal strata
  - Bath and Hammondsport, N. Y.

MOUNTAINS

Volcanic peaks:
- Crater Lake National Park, Ore.
- Lassen Volcanic National Park, Calif.

Laccolithic mountains:
- Abajo, Utah*
- Fort Benton, Mont.
- Henry Mountains, Utah*

Fault-block mountains:
- Ballarat and Furnace Creek, Calif.
- Carson Sink, Nev.*
- Disaster, Nev.*
- Sequoia and General Grant National Parks, Calif. (*special**)
- Silver Peak, Nev.*

Mountain foothills of the hogback-ridge type:
- Boulder, Colo.
- Loveland, Colo.
- Rapid City, S. D.
- Maiden Peak, Ore.
- Mount Hood, Ore.
- Mount Rainier National Park, Wash.*

Glaciated mountains:
- Glacier National Park (*special*)
- Hamilton, Mont.
- Hayden Peak, Utah
- Mount Rainier National Park, Wash.*
- Sequoia and General Grant National Parks, Calif. (*special*)*

Emerged highland shore features:
- La Jolla, Calif.
- San Diego, Calif.
- San Luis, Calif.
- Santa Ana, Calif.
- Solstice Canyon and Las Flores, Calif.

Fiords:
- Reconnaissance Map—Alaska Railroad, Seward to Matanuska Coal Field (*special*)
- Tacoma and Snohomish, Wash.

Appendix F. Rocks and Minerals

A *mineral* is defined as an inorganic substance, found in nature, having a definite chemical composition and sometimes a crystalline form.

An *ore* is a rock or mineral that contains enough of one or more metals to make mining profitable. The amount of metal in ores varies greatly. Some iron and lead ores will run as high as 50 to 75 per cent metal. On the other hand, an ounce of gold per ton of rock is considered good gold ore. Rarely do the metals occur in their native state. Many valuable ores are oxides, sulphides, or carbonates.

Identification of Minerals

A mineral may be identified by certain properties or characteristics that it possesses. Some minerals are easily identified; others require careful examination and often chemical analysis.

Properties of minerals:

1. The *color* of some minerals is very definite. For example, azurite has a deep-blue color. Certain other minerals, however, such as quartz, may occur in several colors.

2. The *streak* of a mineral is the color of a mark that it makes on unglazed porcelain. Examples: graphite, black; hematite, reddish brown; malachite, light green.

3. Certain minerals break so that smooth plane surfaces are produced. This is *cleavage*. Galena, for example, cleaves in three planes. These are at right angles to each other, so that a large piece of galena may be broken into many cubes.

4. The *luster* of a mineral is the way in which it reflects light. Many ores have a metallic luster. The diamond has a brilliant luster called *adamantine*. Chrysotile, the chief source of asbestos, has a silky luster; kaolin, a form of hard clay, a dull luster.

5. The *hardness* of minerals ranges from 1 to 10. Talc, which can be easily scratched with the fingernail, has a hardness of 1. The opposite extreme is represented by the diamond, the hardest known substance, which has a hardness of 10. The fingernail has a hardness of about $2\frac{1}{2}$, and a knife blade, about $5\frac{1}{2}$. The hardness of a specimen is ascertained by comparison with the

standard series of minerals given below. Care should be exercised in testing for hardness. If one mineral scratches another, the scratch cannot be rubbed off. If it can be rubbed off, it indicates that the powder of the softer mineral has formed on the harder one and no scratch has been made.

SCALE OF HARDNESS

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

6. *Specific gravity* is a number that represents how many times heavier 1 cubic inch (or other unit of volume) of a substance is than 1 cubic inch of

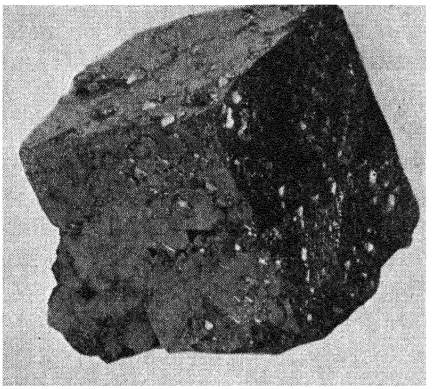


FIG. 422.—Photograph of a specimen of galena, the principal ore of lead. This mineral occurs as shiny, black cubes. Galena, because of its high percentage of lead, is one of the heaviest minerals. (*Courtesy of Ward's Natural Science Establishment, Inc., Rochester, N. Y.*)

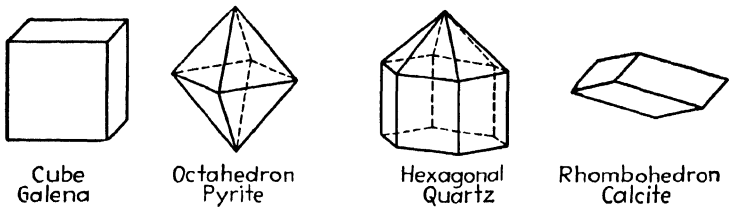


FIG. 423.—Types of crystals.

water. If 1 cubic inch of sphalerite (zinc ore) weighs four times as much as 1 cubic inch of water, then the specific gravity of sphalerite is said to be 4. The specific gravity of most minerals ranges between 2.0 and 4.0. Liquid petroleum, since it floats on water, has a specific gravity of less than 1. Pure gold has a specific gravity of 19.

7. *Effervescence in acid* is a property of some minerals. If a drop of hydrochloric acid is put on a piece of limestone, marble, or calcite, chemical reaction

will result in bubbles of gas being given off. This is called *effervescence.* It can be used as a test for certain minerals known to possess this property.

8. The *crystalline form* of minerals varies greatly. Only four crystalline forms will be mentioned here. The cubical crystal is represented by galena (Fig. 422) and halite (common salt); hexagonal (six-sided), by quartz (Fig. 115); octahedron, by pyrite and the diamond; the rhombohedron, by calcite (Fig. 423).

Classes of Rocks

A *rock* is defined as a combination of two or more minerals, although some rocks are composed almost entirely of one mineral. Granite is composed mainly of the three minerals: quartz, feldspar, and mica. On the other hand, sandstone and quartzite are mainly quartz; limestone and marble, mainly calcite. It is important to remember that minerals have definite chemical compositions, but rocks do not.

Rocks are classified as igneous, sedimentary, or metamorphic.

Igneous rocks are formed when molten rock cools and solidifies. Examples:

1. *Granite:* red or gray; composed essentially of quartz, feldspar, and mica; speckled appearance is due to different mineral crystals being visible

2. *Basalt:* dark greenish black; sometimes shows small cavities probably caused by steam; a common form of solidified lava

3. *Obsidian:* volcanic glass; black, brown, green, etc.

4. *Pumice stone:* white to gray; porous; floats on water

5. *Scoria:* black, gray, dark red; resembles cinders

Sedimentary rocks are formed of sediment deposited by water. Examples:

1. *Limestone:* white to gray; composed mainly of calcite; often contains many fossils of marine animals; effervesces in acid; may be colored yellow-brown by limonite (iron oxide)

2. *Sandstone:* gray or red; mainly quartz; sand particles visible

3. *Shale:* dark gray, black, red; usually can be broken into thin layers; clay odor when wet; oil shale is black

4. *Bituminous coal:* black; composed of carbon and carbon compounds; may contain impurities such as hard shale

5. *Conglomerate:* rounded pebbles cemented together

Metamorphic rocks are other types that have been altered by pressure and heat. Examples:

1. *Gneiss* is mainly a metamorphosed granite; the minerals quartz, feldspar, and mica often occur in layers; the mica may be the white variety (muscovite) or the black (biotite)

2. *Marble* is metamorphosed limestone; many colors; a beautiful rock when polished; effervesces in acid

3. *Quartzite* is metamorphosed sandstone; extremely hard and compact; gray or red; sand particles firmly cemented together

4. *Slate* is metamorphosed shale; usually black; splits into thin layers; harder than shale

5. *Anthracite* coal is harder and not so dusty as bituminous; a superior fuel

	Mineral	*Chemical Name*	*Formula*	*Color*	*Specific Gravity*	*Hardness*	*Remarks*
1	Quartz	Silicon dioxide	SiO_2	Colorless and transparent. Many colors	2.65	7	Crystalline is hexagonal. Forms agate, flint, chert, sand, sandstone, quartzite, amethyst, opal, rose quartz, etc.
2	Mica	.....	Complex K-Al-Si	Colorless Transparent Brown-black	2.80	2.5	Called isinglass. Appears as shiny flakes in some rocks. Muscovite—light shades, Biotite—black. Electric insulator.
3	Calcite	Calcium carbonate	$CaCO_3$	Colorless White Amber	2.70	3	Rhombohedron. Often shows double refraction. Forms limestone and marble. Effervesces. Many crystalline forms.
4	Gypsum	Hydrous calcium sulphate	$CaSO_4 \cdot 2H_2O$	Colorless White Gray Pink	2.30	2–2.5	Does not effervesce. Uses—plaster, building block, etc. Plaster of Paris. With calcite causes much hard water.
5	Hematite	Iron oxide	Fe_2O_3	Dark red to black	5.2	6	Principal ore of iron. Minnesota, Michigan, Alabama.
6	Limonite	Iron oxide	Fe_2O_3 plus water	Yellow-brown	3.8	5.5	Common iron rust. Causes yellow coloring in rocks and soil. Lower percentage of iron than hematite.
7	Pyrite	Iron disulphide	FeS_2	Pale brass-yellow	5	6–6.5	Called *fool's gold*. Cubes and octahedron. Often associated with copper and gold. Use—manufacturing sulphuric acid.
8	Chalcopyrite	Copper iron sulphide	$CuFeS_2$	Brass yellow Sometimes iridescent	4.2	3.5–4	A principal ore of copper. Widely distributed.
9	Malachite	Copper carbonate	$CuCO_3 \cdot Cu(OH)_2$	Green	4	3.5–4	Copper ore. Polished specimens often very attractive. Important ore in southern Arizona.
10	Azurite	Copper carbonate	$2CuCO_3 \cdot Cu(OH)_2$	Deep azure blue	3.8	4	Usually associated with malachite. Bisbee, Ariz., noted for excellent specimens.
11	Galena	Lead sulphide	PbS	Black with metallic luster	7.5	2.5	Most important ore of lead. Mined especially in southeastern Missouri and northern Idaho.
12	Sphalerite	Zinc sulphide	ZnS	Glassy yellow-brown or reddish brown	4	3.5–4	Principal ore of zinc. Occurs with galena. Abundant in Tri-State region around Joplin, Mo.
13	Orthoclase feldspar	Complex silicate of K-Al	.....	Pink White	2.5	6	Abundant mineral, found in granite. Used in manufacturing of porcelain. Plane faces at angle of 90°.
14	Graphite	Carbon	C	Black	2	1–2	Greasy feel. Mixed with oil and used as lubricant. Mixed with clay to form "lead" of pencils.
15	Talc	Magnesium silicate	.....	White Gray Pale green	2.7	1	Greasy feel. Forms soapstone. Uses—manufacturing of talcum powder, soap, paper, tailor's chalk, etc.
16	Halite	Sodium chloride	NaCl	Colorless White Shades of red and blue	2.2	2.5	Common salt. Important deposits of rock salt are found in New York, Michigan, Kansas, and Ohio.

Appendix G

PRINCIPAL SUBDIVISIONS OF EARTH HISTORY AND SOME OF ITS EVENTS AS THEY ARE RECORDED IN THE ROCKS OF NORTH AMERICA

EARLIER TIME ⟵ THE ENTIRE SPAN OF EARTH HISTORY IS ESTIMATED TO BE MORE THAN 1,800,000,000 YEARS. PROBABLY TWO THIRDS OF IT HAD ELAPSED BEFORE CAMBRIAN TIME. ⟵ MORE RECENT TIME

THE SPACES ALLOTTED BELOW TO THE ERAS AND PERIODS ARE NOT IN PROPORTION TO THEIR ESTIMATED DURATION

ERA	PERIOD	TOPOGRAPHIC DEVELOPMENTS	BIOLOGIC DEVELOPMENTS	PREVAILING CLASSES OF ROCKS IN THE GEOLOGIC REGIONS OF NORTH AMERICA
CENOZOIC — ERA OF MODERN LIFE — DUR. EST. AT ± 4% OF ALL GEOL. TIME	QUATERNARY — RECENT (ESTIMATED AT ± 25,000 YRS.)	PRESENT TECTONIC AND GRADATIONAL LAND FORMS	THE DEVELOPMENT AND DOMINANCE OF INTELLIGENT MAN	ALLUVIUMS-OLD & NEW-GLACIAL DRIFT, LOESS
	QUATERNARY — PLEISTOCENE	CALIF. COAST MTS. APPEAR. THE GREAT ICE AGE	NEW SPECIES OF PLANTS AND ANIMALS APPEARANCE OF PRIMITIVE MAN	
	TERTIARY — PLIOCENE, MIOCENE, OLIGOCENE, EOCENE	ELEVATION OF ROCKY, SIERRA NEVADA & CASCADE MTS., THE COLORADO & COLUMBIA PLATEAUS, AND THE GREAT BASIN	DEVELOPMENT OF MAMMALS (PRIMITIVE TYPES OF ELEPHANTS, HORSES, DEER, CATS, DOGS, WHALES & MANY OTHERS, INCLUDING FIRST APES) BIRDS & TREES SIMILAR TO MODERN TYPES	
GENERAL EROSION INTERVAL				
MESOZOIC — ERA OF MEDIEVAL LIFE — DURATION EST. AT ABOUT 8% OF ALL GEOL. TIME	CRETACEOUS (ROCKY MT. COAL DEPOSITS)	LAST GREAT SUBMERGENCE, GULF OF MEXICO TO ALASKA, FOLLOWED BY UPHEAVAL & BEGINNING OF ROCKY MTS.	RISE OF MAMMALS & BIRDS-DECLINE & EXTINCTION OF DINOSAURS. DEVELOPMENT OF MODERN FLOWERING PLANTS & DECIDUOUS TREES	YOUNGER SEDIMENTARY ROCKS — LOCAL IGNEOUS ROCKS
	JURASSIC	APPALACHIAN MTS. BASE-LEVELED — PACIFIC COAST VULCANISM-SUBMERGENCE FROM COLO. TO ALASKA.	GIANT REPTILES (DINOSAURS)-FIRST BIRDS — PRIMITIVE MAMMALS-MANY INSECTS SIMILAR TO PRESENT FORMS	
	TRIASSIC	LARGE LAND AREA-ARIDITY CONTINUED — SOME ROCKS OF LAND-DEPOSITED ORIGIN-VULCANISM	REPTILES (CRAWLING, WALKING, FLYING, SWIMMING) DIVERSE & ABUNDANT. MANY COMPLEX MARINE ANIMALS — FORESTS MAINLY CONIFEROUS	
GENERAL EROSION INTERVAL				
PALEOZOIC ERA — ERA OF ANCIENT LIFE — DURATION VARIOUSLY ESTIMATED AT ABOUT 20 PER CENT OF ALL GEOLOGIC TIME	PERMIAN	GENERAL EMERGENCE-FOLDING OF APPALACHIAN MTS. — WIDESPREAD ARIDITY	DECLINE OF FERN TREES & RISE OF CONIFERS — GREAT VARIETY IN REPTILES & INSECTS — MANY MARINE INVERTEBRATES DISAPPEAR	OLDER AND MORE RESISTANT SEDIMENTARY ROCKS — LOCAL INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS
	CARBONIFEROUS ("THE COAL AGE") — PENNSYLVANIAN	FLUCTUATING SEAS IN THE INTERIOR — FORMATION OF EXTENSIVE SWAMPS	VAST FORESTS OF FAST-GROWING TREES AND OTHER PLANTS. COMPLEX MARINE LIFE - RISE OF REPTILES AND INSECTS	
	CARBONIFEROUS ("THE COAL AGE") — MISSISSIPPIAN	WIDESPREAD SUBMERGENCE AND DEPOSITION OF SEDIMENTS	DEVELOPMENT OF SHARKS AND OTHER FISH-NUMEROUS AMPHIBIANS — ABUNDANT FORESTS OF FERNS & PRIMITIVE CONIFERS.	
	DEVONIAN	WIDESPREAD SUBMERGENCE - MOUNTAIN UPLIFT AND VULCANISM IN NEW ENG.	ABUNDANT FISHES WITH VERTEBRA AND PAIRED FINS, FIRST AMPHIBIANS, FIRST FORESTS (TREE FERNS)	
	SILURIAN	WIDESPREAD DEVELOPMENT OF PLAINS BY EROSION AND BY EMERGENCE	DEVELOPMENT OF FISHES-FIRST LAND ANIMALS (SPIDER-LIKE) — FIRST LAND PLANTS-ABUNDANT CORALS	
	ORDOVICIAN	SEDIMENTS DEPOSITED — MOUNTAIN BUILDING IN NEW ENGLAND AND CANADA	ABUNDANT MOLLUSKS AND TRILOBITES — EARLY FORMS OF FISH — NO EVIDENCE OF LAND ANIMALS OR PLANTS	
	CAMBRIAN	WIDESPREAD SUBMERGENCE AND DEPOSITION OF SEDIMENTARY ROCKS	FIRST ABUNDANT FOSSILS MAINLY OF SHELLED MARINE INVERTEBRATES (MOLLUSKS AND TRILOBITES)	
LONG INTERVAL OF UPLIFT AND EROSION				
PROTEROZOIC		MUCH MOUNTAIN BUILDING, METAMORPHISM OF ROCKS, AND VULCANISM	PRIMITIVE MARINE LIFE, MAINLY WITHOUT SHELLS, LEAVING ONLY MEAGRE FOSSIL REMAINS	ANCIENT CRYSTALLINE ROCKS
LONG INTERVAL OF UPLIFT AND EROSION				
ARCHEOZOIC	EARTH HISTORY EXTENDS BACK AND MERGES WITH EARTH ORIGIN	MOUNTAIN BUILDING AND VULCANISM — MANY EVENTS OBSCURED BY VAST LAPSE OF TIME.	PRIMITIVE FORMS OF MARINE LIFE, PERHAPS ALGAE-LIKE — NO DIRECT FOSSIL EVIDENCE	

Appendix H. Useful Data and Tables

CHEMICAL ELEMENTS
(Partial list)

Element	*Symbol*	*Atomic Weight*	*Element*	*Symbol*	*Atomic Weight*
Aluminum	Al	26.97	Mercury	Hg	200.61
Argon	A	39.94	Molybdenum	Mo	96.00
Arsenic	As	74.91	Neon	Ne	20.18
Barium	Ba	137.36	Nickel	Ni	58.69
Bismuth	Bi	209.00	Nitrogen	N	14.00
Bromine	Br	79.91	Oxygen	O	16.00
Calcium	Ca	40.08	Phosphorus	P	31.02
Carbon	C	12.00	Platinum	Pt	195.23
Chromium	Cr	52.01	Potassium	K	39.09
Chlorine	Cl	35.45	Radium	Ra	225.97
Cobalt	Co	58.94	Silicon	Si	28.06
Copper	Cu	63.57	Silver	Ag	107.88
Fluorine	F	19.00	Sodium	Na	22.99
Gold	Au	197.20	Sulphur	S	32.06
Helium	He	4.00	Tellurium	Te	127.61
Hydrogen	H	1.00	Thorium	Th	232.12
Iodine	I	126.92	Tin	Sn	118.70
Iron	Fe	55.84	Tungsten	W	184.00
Lead	Pb	207.22	Uranium	U	238.14
Lithium	Li	6.94	Vanadium	V	50.95
Magnesium	Mg	24.32	Zinc	Zn	65.38
Manganese	Mn	54.93			

Avoirdupois Weight

16 drams = 1 ounce (oz.)
16 ounces = 1 pound (lb.)
7,000 grains = 1 pound
100 pounds = 1 hundredweight (cwt.)
2,000 pounds = 1 ton
2,240 pounds = 1 long ton

Metric Weight

1 gram = 1,000 milligrams
1 gram = 100 centigrams
1 gram = 10 decigrams
10 grams = 1 decagram
100 grams = 1 hectogram
1,000 grams = 1 kilogram

1 pound = .45 kilogram
1 kilogram = 2.20 pounds
1 gram = 15.43 grains
1 metric ton = 1,000 kilograms = 2,204 pounds

Linear Measure

12	inches	= 1 foot
3	feet	= 1 yard
16½	feet	= 1 rod
40	rods	= 1 furlong
5,280	feet	= 1 statute mile
6,080	feet	= 1 nautical mile

1	meter	= 39.37 inches
1	mile	= 1.60 kilometers
1	kilometer	= 0.62 mile

Metric Linear

1	meter	= 1,000 millimeters
1	meter	= 100 centimeters
1	meter	= 10 decimeters
10	meters	= 1 decameter
100	meters	= 1 hectometer
1,000	meters	= 1 kilometer

Time

60	seconds	= 1 minute
60	minutes	= 1 hour
24	hours	= 1 day
365	days	= 1 year

Longitude and Latitude

60	seconds (″)	= 1 minute (′)
60	minutes (′)	= 1 degree (°)
Highest longitude		= 180°
Highest latitude		= 90°

Atmospheric Pressure

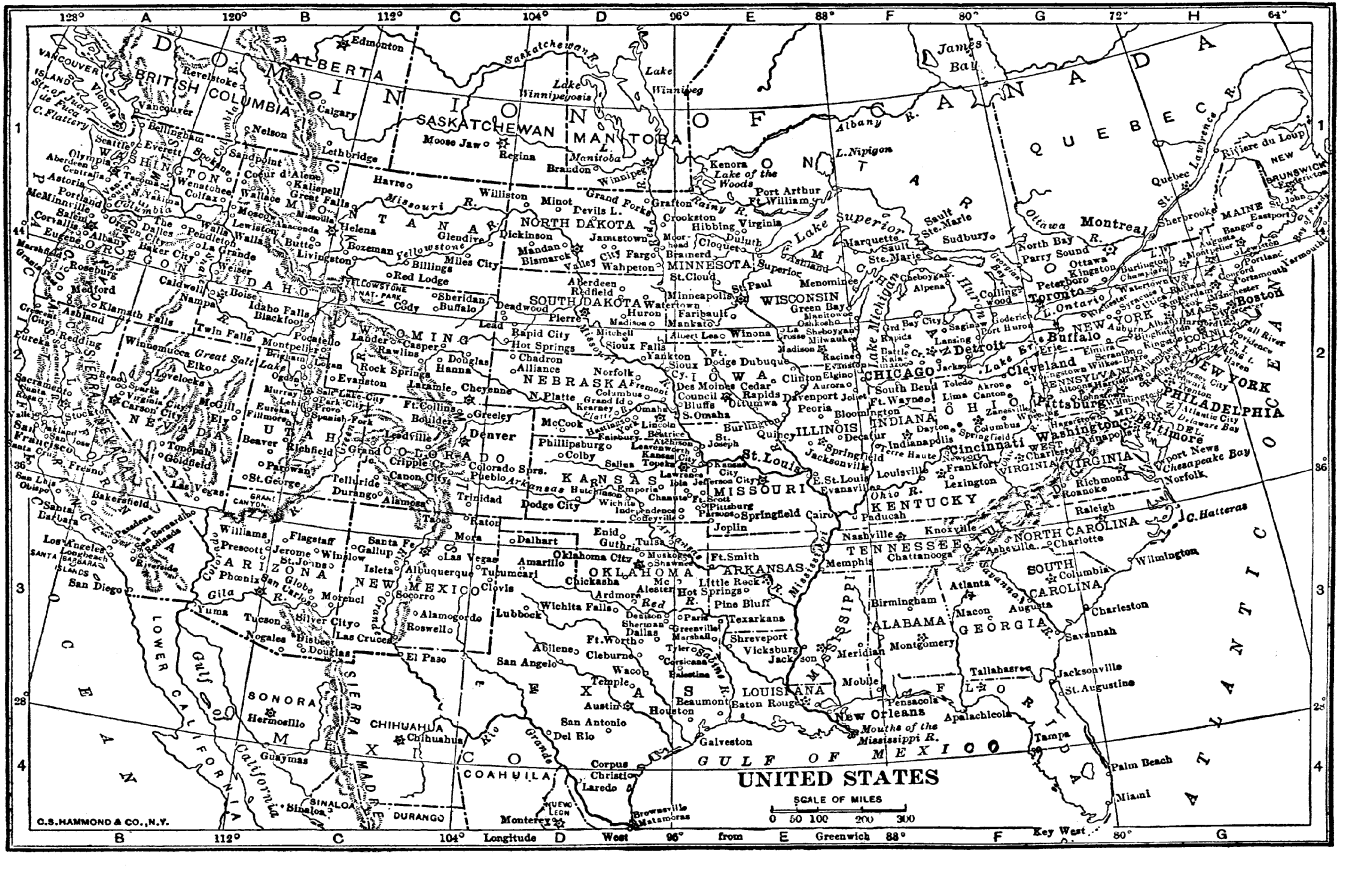
1	inch	= 25.40	millimeters	= 33.86 millibars
1	millimeter	= 0.039	inch	= 1.33 millibars
1	millibar	= 0.029	inch	= 0.75 millimeter

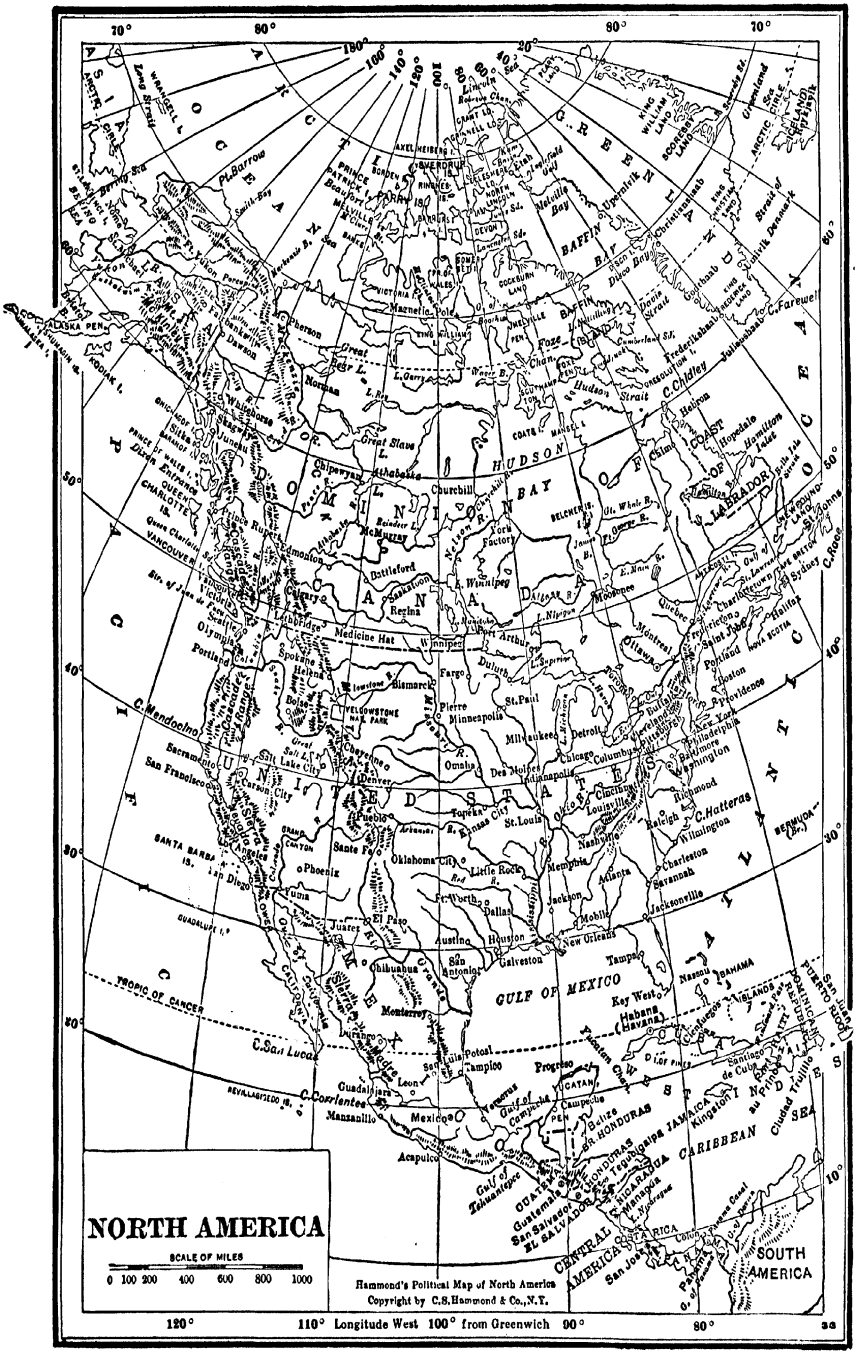
Length of Longest Rivers

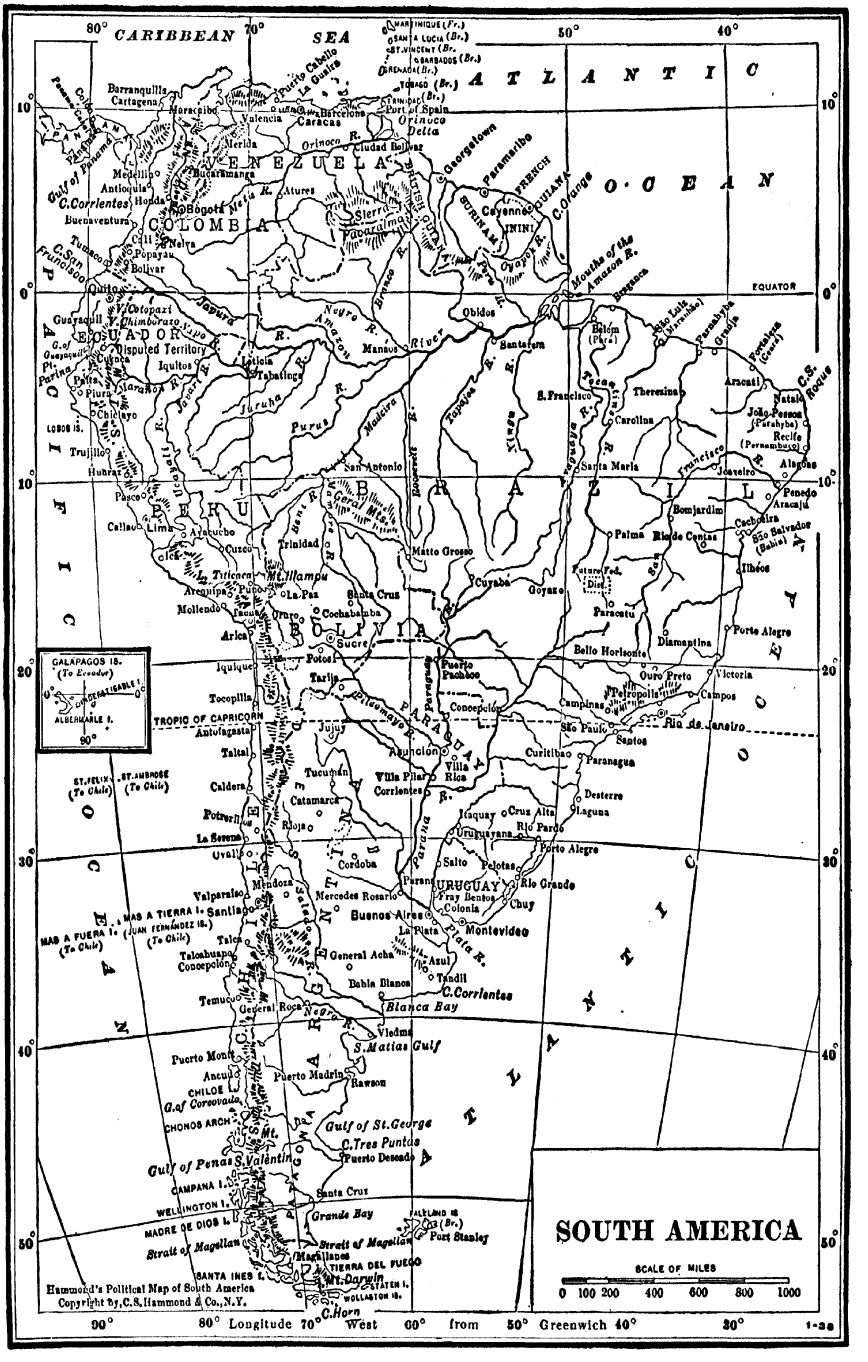
Missouri-Mississippi	4,221 miles
Nile	4,000 miles
Amazon	3,900 miles
Ob	3,200 miles
Yangtze	3,100 miles
Congo	2,900 miles
Amur	2,900 miles

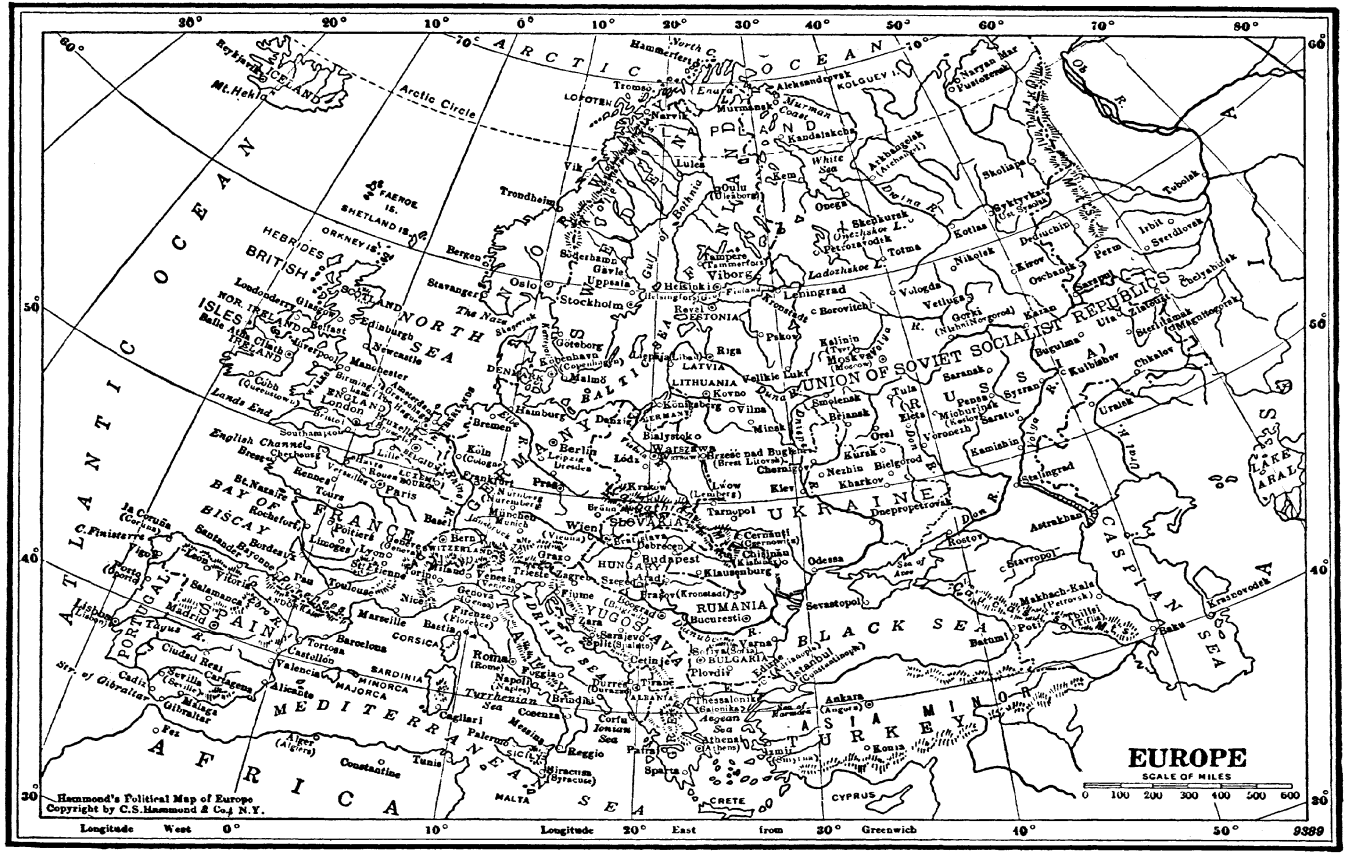
High Mountains

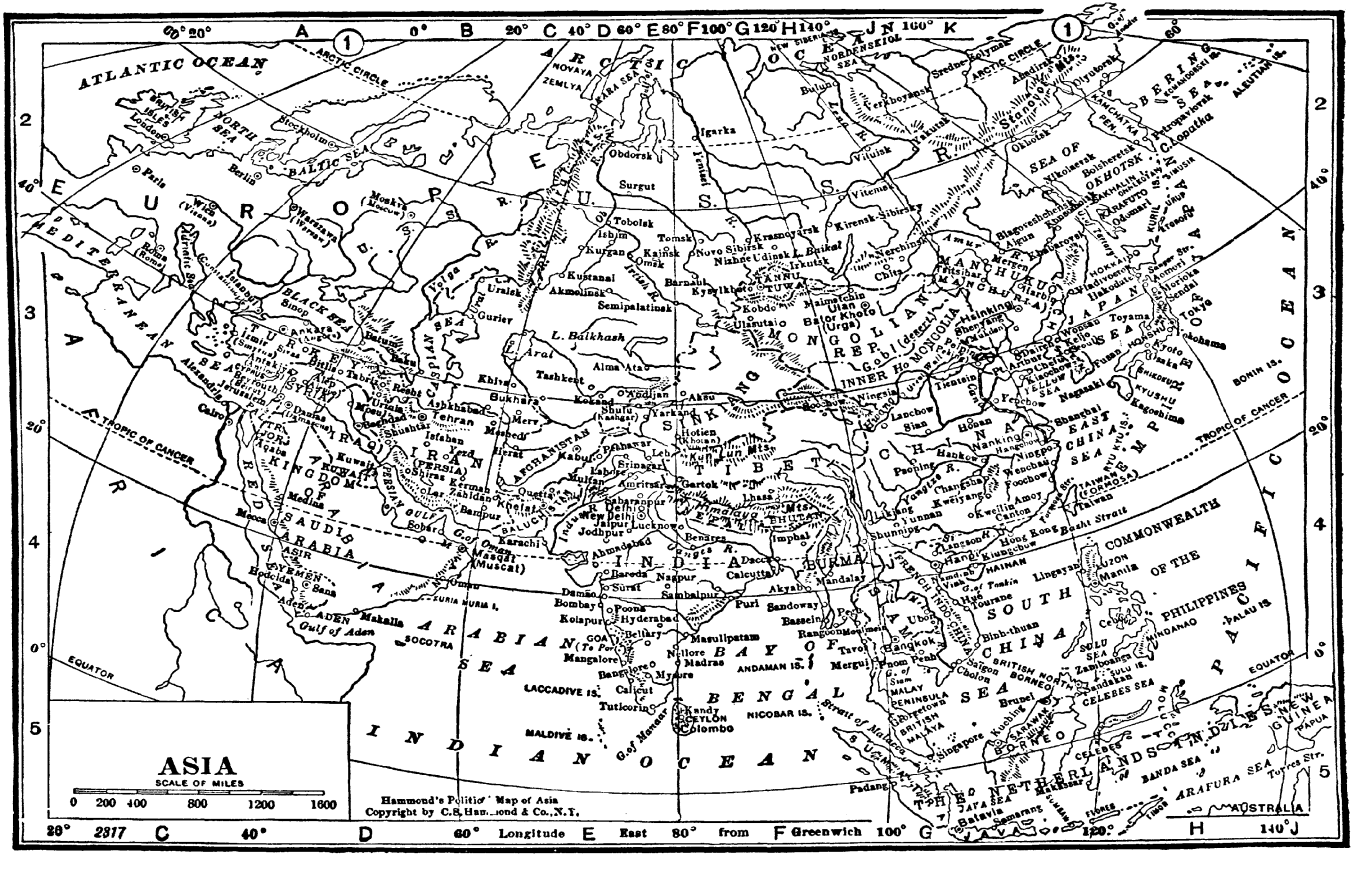
Everest	29,141 feet
Godwin Austen	28,251 feet
Aconcagua	22,830 feet
McKinley	20,300 feet
Kilimanjaro	19,324 feet
Elbrus	18,468 feet
Whitney	14,500 feet
Pikes Peak	14,110 feet


UNITED STATES
SCALE OF MILES
0 50 100 200 300
C.S.HAMMOND & CO., N.Y.
Longitude West from Greenwich
DOMINION OF CANADA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
ALBERTA
BRITISH COLUMBIA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
MICHIGAN
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
KANSAS
MISSOURI
KENTUCKY
TENNESSEE
OKLAHOMA
ARKANSAS
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE
VERMONT
NEW HAMPSHIRE
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
NEW JERSEY
MARYLAND
DELAWARE
COLORADO
WYOMING
MONTANA
IDAHO
WASHINGTON
OREGON
NEVADA
UTAH
ARIZONA
NEW MEXICO
CALIFORNIA
LOWER CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
DURANGO
SINALOA
TEXAS
LOUISIANA
GULF OF MEXICO
ATLANTIC OCEAN
PACIFIC OCEAN
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
Lake Winnipeg
Lake Winnipegosis
Lake of the Woods
Great Salt Lake
Hudson Bay
James Bay
Mississippi R.
Missouri R.
Rio Grande
Colorado R.
Columbia R.
Ohio R.
Saskatchewan R.
Yellowstone R.
Arkansas R.
Red R.
Gulf of California
Gulf of Mexico
Mouths of the Mississippi R.
Chesapeake Bay
Delaware Bay
Long Island
Vancouver Island
Queen Charlotte Islands
Cape Hatteras
Key West
Miami
Palm Beach
Jacksonville
Tampa
Savannah
Charleston
Wilmington
Norfolk
Richmond
Washington
Baltimore
Philadelphia
New York
Boston
Portland
Buffalo
Cleveland
Detroit
Chicago
Milwaukee
Minneapolis
St. Paul
Duluth
Omaha
Kansas City
St. Louis
Memphis
New Orleans
Houston
Dallas
Fort Worth
San Antonio
El Paso
Albuquerque
Denver
Cheyenne
Salt Lake City
Boise
Portland
Seattle
San Francisco
Los Angeles
San Diego
Montreal
Toronto
Ottawa
Quebec
Winnipeg
Regina
Calgary
Edmonton
Vancouver
Victoria
Nashville
Atlanta
Birmingham
Mobile
Pensacola
Tallahassee
Charlotte
Raleigh
Knoxville
Louisville
Cincinnati
Indianapolis
Columbus
Pittsburgh
Albany
Hartford
Providence
Portland
Concord
Montpelier
Burlington
Augusta
Bangor
Halifax
St. John
Fredericton
Charlottetown
Sydney
Newfoundland
Labrador
Hudson Strait
Baffin Island
Victoria Island
Great Bear Lake
Great Slave Lake
Athabasca
Peace R.
Mackenzie R.
Yukon R.
Alaska
Aleutian Islands
Bering Sea
Arctic Ocean
Beaufort Sea
Davis Strait
Greenland
Iceland
Bermuda
Cuba
Haiti
Jamaica
Puerto Rico
Bahama Islands
Yucatan
Guatemala
Belize
Honduras
Nicaragua
Costa Rica
Panama
Mexico City
Guadalajara
Monterrey
Veracruz
Tampico
Acapulco
Mazatlan
Hermosillo
Chihuahua
Durango
Saltillo
Matamoros
Brownsville
Corpus Christi
Laredo
Galveston
Waco
Austin
Abilene
Lubbock
Amarillo
Wichita Falls
Oklahoma City
Tulsa
Little Rock
Hot Springs
Pine Bluff
Shreveport
Vicksburg
Jackson
Meridian
Montgomery
Chattanooga
Knoxville
Asheville
Roanoke
Lexington
Frankfort
Evansville
Terre Haute
Springfield
Peoria
Rockford
Madison
Green Bay
Milwaukee
Chicago
Gary
South Bend
Fort Wayne
Toledo
Cleveland
Akron
Youngstown
Erie
Buffalo
Rochester
Syracuse
Utica
Albany
Binghamton
Scranton
Wilkes-Barre
Harrisburg
Lancaster
Reading
Allentown
Trenton
Atlantic City
Wilmington
Dover
Salisbury
Norfolk
Newport News
Virginia Beach
Cape Charles
Cape Henry
Cape Hatteras
Cape Lookout
Cape Fear
Myrtle Beach
Charleston
Savannah
Brunswick
Jacksonville
Daytona Beach
Orlando
Tampa
St. Petersburg
Sarasota
Fort Myers
Naples
Key West
Miami
Palm Beach
West Palm Beach
Fort Lauderdale
Boca Raton
Delray Beach
Boynton Beach
Lake Worth
Jupiter
Stuart
Vero Beach
Sebastian
Melbourne
Cocoa
Titusville
Daytona Beach
St. Augustine
Jacksonville
Fernandina Beach
Amelia Island
Key Largo
Islamorada
Marathon
Big Pine Key
Key West
Dry Tortugas
Florida Keys
Florida Bay
Everglades
Big Cypress Swamp
Lake Okeechobee
Kissimmee
Orlando
Winter Haven
Lakeland
Bradenton
Sarasota
Venice
Punta Gorda
Fort Myers
Naples
Marco Island
Everglades City
Homestead
Florida City
Miami
Miami Beach
Coral Gables
Hialeah
North Miami
North Miami Beach
Opa-locka
Hollywood
Fort Lauderdale
Pompano Beach
Deerfield Beach
Boca Raton
Delray Beach
Boynton Beach
Lake Worth
Jupiter
Stuart
Vero Beach
Sebastian
Melbourne
Cocoa
Titusville
Daytona Beach
St. Augustine
Jacksonville
Fernandina Beach
Amelia Island
Key Largo
Islamorada
Marathon
Big Pine Key
Key West
Dry Tortugas
Florida Keys
Florida Bay
Everglades
Big Cypress Swamp
Lake Okeechobee
Kissimmee
Orlando
Winter Haven
Lakeland
Bradenton
Sarasota
Venice
Punta Gorda
Fort Myers
Naples
Marco Island
Everglades City
Homestead
Florida City
Miami
Miami Beach
Coral Gables
Hialeah
North Miami
North Miami Beach
Opa-locka
Hollywood
Fort Lauderdale
Pompano Beach
Deerfield Beach

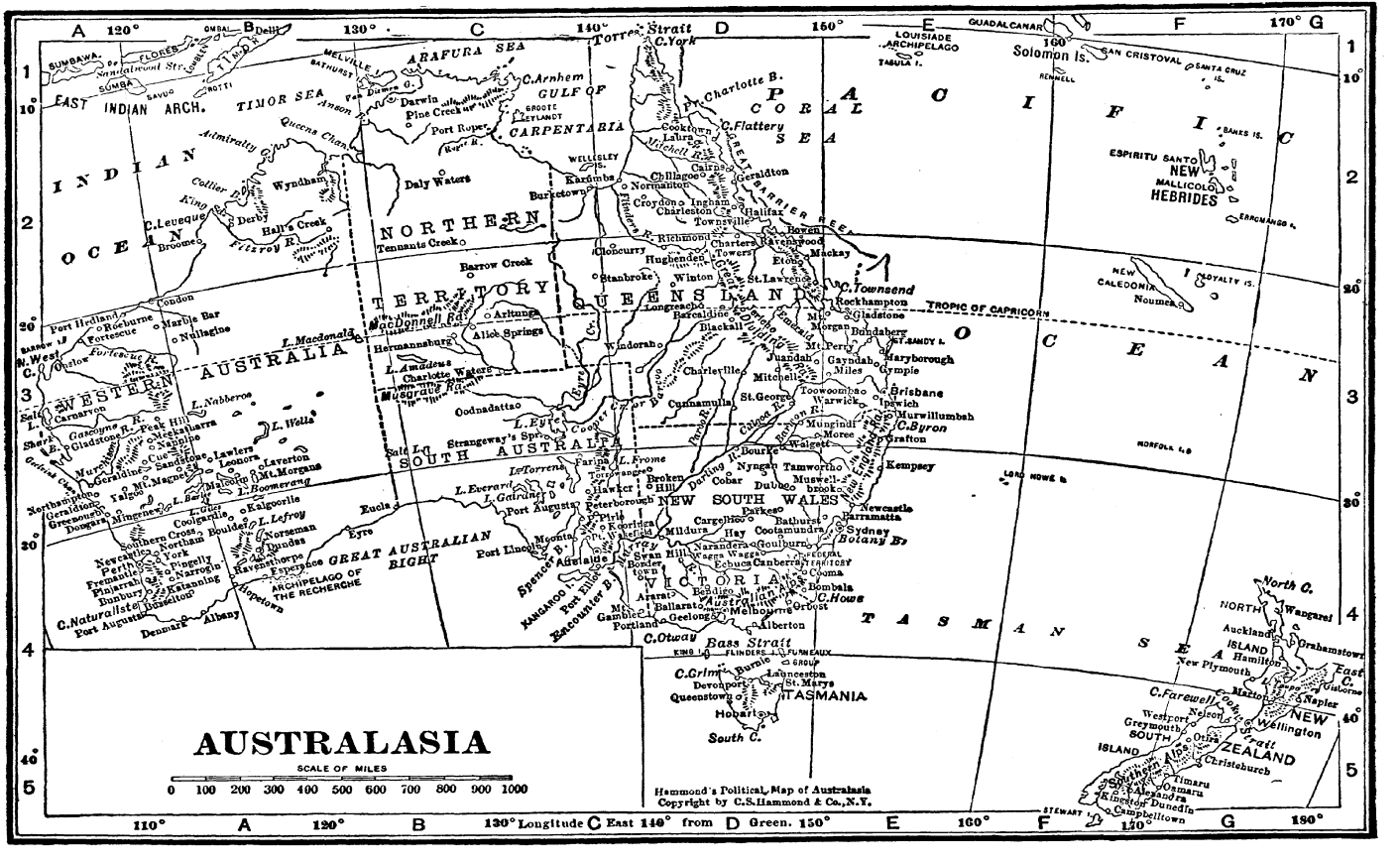

NORTH AMERICA
SCALE OF MILES
0 100 200 400 600 800 1000
Hammond's Political Map of North America
Copyright by C.S.Hammond & Co.,N.Y.
Longitude West 100° from Greenwich
120°
110°
90°
80°
70°
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
HUDSON BAY
GULF OF MEXICO
CARIBBEAN SEA
DOMINION OF CANADA
UNITED STATES
MEXICO
CENTRAL AMERICA
SOUTH AMERICA
GREENLAND
BAFFIN BAY
BAFFIN ISLAND
COAST OF LABRADOR
ALASKA PEN.
QUEEN CHARLOTTE IS.
VANCOUVER I.
YELLOWSTONE NAT. PARK
GRAND CANYON
SANTA BARBARA IS.
GUADALUPE I.
REVILLAGIGEDO IS.
TROPIC OF CANCER
C. Mendocino
C. San Lucas
C. Corrientes
C. Hatteras
C. Race
C. Farewel
C. Chidley
Pt. Barrow
Dawson
Whitehorse
Skagway
Juneau
Sitka
Prince Rupert
Edmonton
Calgary
Lethbridge
Victoria
Seattle
Olympia
Portland
Spokane
Helena
Boise
Salt Lake City
Carson City
Sacramento
San Francisco
Los Angeles
San Diego
Yuma
Phoenix
Tucson
Juarez
El Paso
Santa Fe
Denver
Cheyenne
Pueblo
Medicine Hat
Regina
Winnipeg
Port Arthur
Duluth
Fargo
Bismarck
Pierre
Minneapolis
St. Paul
Milwaukee
Chicago
Detroit
Omaha
Des Moines
Indianapolis
Cincinnati
Louisville
Columbus
Cleveland
Buffalo
Pittsburg
Philadelphia
Baltimore
Washington
New York
Boston
Providence
Portland
Montreal
Ottawa
Quebec
Halifax
Saint John
Topeka
Kansas City
St. Louis
Oklahoma City
Little Rock
Memphis
Nashville
Atlanta
Savannah
Charleston
Wilmington
Raleigh
Richmond
Jacksonville
Mobile
New Orleans
Jackson
Dallas
Fort Worth
Austin
Houston
Galveston
San Antonio
Chihuahua
Monterrey
San Luis Potosi
Tampico
Progreso
Campeche
Guadalajara
Leon
Mexico
Manzanillo
Acapulco
Havana (Habana)
Key West
Nassau
Tampa
Kingston
Santiago de Cuba
Ciudad Trujillo
San Juan
Caracas
Panama
Guatemala
Managua
San José
Belize
Tegucigalpa
Gulf of Campeche
Gulf of Tehuantepec
Panama Canal
Hudson Strait
Davis Strait
Melville Bay
Lincoln Sea
Greenland
Iceland
Bermuda
Jamaica
Haiti
Cuba
Yucatan
Honduras
Nicaragua
Costa Rica
Salvador
Guatemala
Tehuantepec
Alaska
Yukon
Mackenzie
Saskatchewan
Manitoba
Ontario
Quebec
Labrador
Newfoundland
Nova Scotia
New Brunswick
Prince Edward Is.
Texas
Arizona
New Mexico
Colorado
Nebraska
Kansas
Oklahoma
Arkansas
Missouri
Iowa
Illinois
Indiana
Ohio
Michigan
Wisconsin
Minnesota
Dakotas
Montana
Wyoming
Idaho
Nevada
Utah
California
Oregon
Washington
Florida
Georgia
Alabama
Mississippi
Tennessee
Kentucky
Virginia
Maryland
Delaware
New Jersey
Pennsylvania
New York
Vermont
New Hampshire
Maine
Massachusetts
Connecticut
Rhode Island
Alaska Pen.
Queen Charlotte Is.
Vancouver I.
Sir. of Juan de Fuca
Puget Sound
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
Lake Winnipeg
Great Slave L.
Great Bear L.
Athabasca
Nelson R.
Saskatchewan
Red R.
Mississippi
Missouri
Rio Grande
Colorado
Columbia
Snake R.
Yukon
Mackenzie
Saint Lawrence
Hudson Strait
Davis Strait
Baffin Bay
Melville Bay
Lincoln Sea
Greenland
Iceland
Bermuda
Jamaica
Haiti
Cuba
Yucatan
Honduras
Nicaragua
Costa Rica
Salvador
Guatemala
Tehuantepec
Alaska
Yukon
Mackenzie
Saskatchewan
Manitoba
Ontario
Quebec
Labrador
Newfoundland
Nova Scotia
New Brunswick
Prince Edward Is.
Texas
Arizona
New Mexico
Colorado
Nebraska
Kansas
Oklahoma
Arkansas
Missouri
Iowa
Illinois
Indiana
Ohio
Michigan
Wisconsin
Minnesota
Dakotas
Montana
Wyoming
Idaho
Nevada
Utah
California
Oregon
Washington
Florida
Georgia
Alabama
Mississippi
Tennessee
Kentucky
Virginia
Maryland
Delaware
New Jersey
Pennsylvania
New York
Vermont
New Hampshire
Maine
Massachusetts
Connecticut
Rhode Island


SOUTH AMERICA
SCALE OF MILES
0 100 200 400 600 800 1000
Hammond's Political Map of South America
Copyright by C.S. Hammond & Co., N.Y.
CARIBBEAN SEA
ATLANTIC OCEAN
PACIFIC OCEAN
VENEZUELA
COLOMBIA
ECUADOR
PERU
BOLIVIA
PARAGUAY
URUGUAY
BRAZIL
CHILE
ARGENTINA
GALAPAGOS IS. (To Ecuador)
ALBEMARLE I.
TROPIC OF CAPRICORN
EQUATOR
Longitude 90° 80° 70° West 60° from 50° Greenwich 40° 30°


EUROPE
SCALE OF MILES
0 100 200 300 400 500 600
Hammond's Political Map of Europe
Copyright by C.S.Hammond & Co. N.Y.
Longitude West 0° 10° Longitude 20° East from 30° Greenwich 40° 50°
9389
ARCTIC OCEAN
ATLANTIC OCEAN
NORTH SEA
BALTIC SEA
BLACK SEA
CASPIAN SEA
ARAL SEA
MEDITERRANEAN SEA
BAY OF BISCAY
Arctic Circle
Mt. Hekla
ICELAND
FAEROE IS.
SHETLAND IS.
ORKNEY IS.
HEBRIDES
BRITISH ISLES
NOR. IRELAND
IRELAND
Land's End
English Channel
C. Finisterre
Str. of Gibraltar
Gulf of Bothnia
Gulf of Finland
NORWAY
SWEDEN
FINLAND
DENMARK
ESTONIA
LATVIA
LITHUANIA
POLAND
GERMANY
NETHERLANDS
BELGIUM
FRANCE
SWITZERLAND
PORTUGAL
SPAIN
ITALY
YUGOSLAVIA
HUNGARY
RUMANIA
BULGARIA
ALBANIA
GREECE
TURKEY
ASIA MINOR
AFRICA
UNION OF SOVIET SOCIALIST REPUBLICS
UKRAINE
CRIMEA
CORSICA
SARDINIA
MINORCA
MAJORCA
CRETE
CYPRUS
MALTA
Murman Coast
White Sea
Gulf of Finland
Gulf of Bothnia
Sea of Azov
Dnieper R.
Don R.
Volga R.
Ural R.
Ural Mts.
Caucasus Mts.
Pyrenees Mts.
Alps Mts.
Apennines Mts.
Dinaric Alps
Balkan Mts.
Carpathian Mts.
Black Forest
Tyrrhenian Sea
Aegean Sea
Ionian Sea
Adriatic Sea
Sea of Marmora
Dead Sea
Caspian Sea
Leningrad
Moscow
Stockholm
Oslo
Copenhagen
Berlin
Warsaw
Paris
London
Madrid
Rome
Vienna
Budapest
Bucharest
Belgrade
Sofia
Athens
Istanbul
Ankara
Odessa
Sevastopol
Kharkov
Kiev
Minsk
Riga
Helsinki
Archangel
Murmansk
Volgograd
Kazan
Perm
Sverdlovsk
Chelyabinsk
Omsk
Novosibirsk
Irkutsk
Yakutsk
Tashkent
Baku
Tiflis
Batum
Rostov
Stalingrad
Saratov
Kuibishev
Gorki
Kirov
Archangel
Murmansk
Tobolsk
Tyumen
Ekaterinburg
Magnitogorsk
Orenburg
Astrakhan
Krasnovodsk
Lisbon
Gibraltar
Algiers
Tunis
Constantine
Fez
Casablanca
Oran
Tripoli
Benghazi
Alexandria
Cairo
Suez
Port Said
Jerusalem
Beirut
Damascus
Baghdad
Tehran
Mecca
Medina
Aden
Red Sea
Persian Gulf
Arabian Sea
Indian Ocean
Mediterranean Sea
Black Sea
Caspian Sea
Aral Sea
Lake Ladoga
Lake Onega
Lake Peipus
Lake Ilmen
Lake Chudskoye
Lake Baikal
Lake Balkhash
Lake Issyk-Kul
Lake Van
Lake Urmia
Lake Tiberias
Lake Victoria
Lake Tana
Lake Chad
Lake Tchad
Lake Nyasa
Lake Tanganyika
Lake Rudolf
Lake Albert
Lake Edward
Lake Kivu
Lake Mweru
Lake Bangweulu
Lake Ngami
Lake Eyre
Lake Torrens
Lake Gairdner
Lake Amadeus
Lake Mackay
Lake Frome
Lake Callabonna
Lake Blanche
Lake Hope
Lake Gregory
Lake Disappointment
Lake Macdonnell
Lake Nash
Lake Nicholson
Lake Woods
Lake Wellington
Lake Alexandrina
Lake Albert
Lake Victoria
Lake Tyrrell
Lake Buchanan
Lake Eildon
Lake Eucumbene
Lake Hume
Lake Mulwala
Lake Wakool
Lake Victoria
Lake Cowal
Lake Brewster
Lake Cargelligo
Lake Forbes
Lake Bathurst
Lake George
Lake Bega
Lake Tuross
Lake Conjola
Lake Illawarra
Lake Macquarie
Lake Wallis
Lake Cowan
Lake Barlee
Lake Lefroy
Lake Moore
Lake Grace
Lake Dumbleyung
Lake Toolibin
Lake Muir
Lake Unicup
Lake Gnarabup
Lake Jasper
Lake Clifton
Lake Preston
Lake Kepwari
Lake Navarino
Lake Argyle
Lake Gregory
Lake Nash
Lake Nicholson
Lake Woods
Lake Wellington
Lake Alexandrina
Lake Albert
Lake Victoria
Lake Tyrrell
Lake Buchanan
Lake Eildon
Lake Eucumbene
Lake Hume
Lake Mulwala
Lake Wakool
Lake Victoria
Lake Cowal
Lake Brewster
Lake Cargelligo
Lake Forbes
Lake Bathurst
Lake George
Lake Bega
Lake Tuross
Lake Conjola
Lake Illawarra
Lake Macquarie


ASIA
SCALE OF MILES
0 200 400 800 1200 1600
Hammond's Political Map of Asia
Copyright by C.S. Hammond & Co., N.Y.
ATLANTIC OCEAN
ARCTIC OCEAN
EUROPE
U.S.S.R.
ARABIA
INDIA
CHINA
MONGOLIA
TIBET
SINKIANG
BURMA
SOUTH CHINA
EAST CHINA SEA
SEA OF OKHOTSK
BERING SEA
PACIFIC OCEAN
INDIAN OCEAN
ARABIAN SEA
BAY OF BENGAL
COMMONWEALTH OF THE PHILIPPINES
THE NETHERLANDS INDIES
NEW GUINEA
AUSTRALIA
ARAFURA SEA
BANDA SEA
CELEBES SEA
SULU SEA
SOCOTRA
LACCADIVE IS.
MALDIVE IS.
NICOBAR IS.
ANDAMAN IS.
EQUATOR
TROPIC OF CANCER
ARCTIC CIRCLE
Longitude East from Greenwich
2317


AFRICA
SCALE OF MILES
0 200 400 600 800 1000 1200
CAPE VERDE IS.
(To Port.)
Same scale as main map
ATLANTIC OCEAN
INDIAN OCEAN
SOUTH ATLANTIC OCEAN
SOUTH AFRICA
SAHARA
Libyan Desert
Nubian Desert
FRENCH WEST AFRICA
ANGLO EGYPTIAN SUDAN
ITALIAN SOMALILAND
BELGIAN CONGO
FRENCH EQUATORIAL AFRICA
NIGERIA
ABYSSINIA (Ethiopia)
EAST AFRICA
BECHUANALAND PROT.
SOUTHERN RHODESIA
NORTHERN RHODESIA
NYASALAND
TANGANYIKA TERRITORY
KENYA
UGANDA
UNION OF SOUTH AFRICA
PORTUGUESE EAST AFRICA
SOUTHERN TERRITORIES
SOUTH WEST AFRICA
ANGOLA
TROPIC OF CANCER
TROPIC OF CAPRICORN
EQUATOR
Timbuktu
Agades
NIGER TERRITORY
FRENCH SUDAN
Niamey
Zinder
Kano
Bauchi
Khartoum
Omdurman
Port Sudan
Suakin
Asmara
Addis Ababa
Djibouti
Berbera
Mogadiscio
Cairo
Suez
Alexandria
Port Said
Tripoli
Benghazi
Tobruk
Gadames
Ghat
Tummo
Kharga
Aswan
Wady Halfa
Asyut
Suez Canal
Lake Nyasa
Lake Victoria
Lake Albert
Lake Rudolph
Lake Tanganyika
Lake Chad
Lake Kivu
Lake Kioga
Lake Mweru
Lake Bangweulu
Lake Ngami
Victoria Falls
Kariba Gorge
Kafue R.
Zambesi R.
Limpopo R.
Orange R.
Vaal R.
Congo R.
Niger R.
Nile R.
Senegal R.
Gambia R.
Volta R.
Shire R.
Rovuma R.
Juba R.
Tana R.
Sabaki R.
Pangani R.
Ruvuma R.
Kafue R.
Kasai R.
Ubangi R.
Shari R.
Benue R.
Kwango R.
Kwando R.
Cunene R.
Kunene R.
Okavango


AUSTRALASIA
SCALE OF MILES
0 100 200 300 400 500 600 700 800 900 1000
Hammond's Political Map of Australasia
Copyright by C.S.Hammond & Co.,N.Y.
INDIAN OCEAN
PACIFIC OCEAN
TASMAN SEA
EAST INDIAN ARCH.
TIMOR SEA
ARAFURA SEA
GULF OF CARPENTARIA
CORAL SEA
Torres Strait
C.York
C.Arnhem
Darwin
Pine Creek
Port Ruper.
Queens Chan.
Admiralty G.
Wyndham
Collier B.
King Sd.
C.Leveque
Broome
Hall's Creek
Fitzroy R.
Daly Waters
Tennants Creek
Barrow Creek
Alice Springs
Macdonnell Ra.
L.Macdonald
L.Amadeus
Charlotte Waters
Musgrave Ra.
Oodnadatta
L.Eyre
Strangeway's Spr.
Farina
L.Frome
Lake Torrens
L.Everard
L.Gairdner
Port Augusta
Eucla
Eyre
Port Lincoln
Spencer G.
Kangaroo I.
Port Phillip B.
Encounter B.
Adelaide
GREAT AUSTRALIAN BIGHT
ARCHIPELAGO OF THE RECHERCHE
Esperance
Albany
Denmark
Augusta
C.Naturaliste
Geraldton
Carnarvon
Perth
Fremantle
Pinjarah
Bunbury
Busselton
Northam
York
Pingelly
Narrogin
Wyalkatchem
Merredin
Kalgoorlie
Coolgardie
Boulder
Norseman
Hyden
Newcastle
Southern Cross
Greenough
Geraldton
Northampton
Dongara
Mingenew
Gascoyne R.
Peak Hill
Meekatharra
Wiluna
Sandstone
Leonora
Laverton
Mt.Morgans
Malcolm
Mt.Magnet
Cue
Lawlers
Nannine
Murchison R.
Sherlock R.
Ashburton R.
Fortescue R.
Roebourne
Marble Bar
Nullagine
Port Hedland
Onslow
L.Nabberoo
L.Wells
L.Boomerang
L.Lefroy
L.Barlee
Coolgardie
Kalgoorlie
Boulder
Norseman
Hyden
Esperance
Albany
Denmark
Augusta
Busselton
Bunbury
Fremantle
Perth
Geraldton
Carnarvon
Onslow
Port Hedland
Broome
Derby
Wyndham
Darwin
Pine Creek
Port Ruper.
Daly Waters
Tennants Creek
Barrow Creek
Alice Springs
Oodnadatta
Farina
Strangeway's Spr.
Eucla
Port Augusta
Port Lincoln
Adelaide
Spencer G.
Kangaroo I.
Port Phillip B.
Encounter B.
Portland
Geelong
Melbourne
Ballarat
Bendigo
Sandhurst
Echuca
Swan Hill
Mildura
Broken Hill
Cobar
Dubbo
Parkes
Forbes
Cowra
Bathurst
Orange
Goulburn
Canberra
Wagga Wagga
Narrandera
Hay
Cootamundra
Albury
Tumut
Gundagai
Tumbarumba
Yass
Queanbeyan
Cooma
Bombala
Orbost
Sale
Warragul
Dandenong
Port Albert
Wilsons Prom.
Flinders I.
King I.
Launceston
Deloraine
Devonport
Queenstown
Hobart
South C.
Burnie
St.Marys
Swansea
Bass Strait
C.Otway
C.Grim
C.Howe
Sydney
Botany B.
Newcastle
Parramatta
Bathurst
Orange
Dubbo
Cobar
Broken Hill
Mildura
Hay
Coolamundra
Goulburn
Canberra
Wagga Wagga
Narrandera

INDEX

A

Abrasion by wind, 251
Acadia National Park, 249, 392, 393
Acid soils, 482, 483
Africa, southern plateau, 317, 318
Agassiz, Louis, 306
Agassiz plain, 306, 307, 560
Aggradation, 209, 227, 232
Agonic line, 19
Agricultural regions of United States, 539
Air conditioning, 83
Air drainage, 36, 545
Air lines of United States, 121
Air masses, 30
  analysis, 116–122
  Polar Atlantic, 119
  Polar Continental, 120
  Polar Pacific, 119
  sources of, 119
  Tropical Atlantic, 122
  Tropical Gulf, 120
  Tropical Pacific, 122
Aitoff's projection, 598
Alabaster, 528
Aleutian low, 61
Alfalfa, 424, 485
Alkali, 151
Alkali waters, 408
Alkaline soils, 483
Allegheny hill region, 325–328, 567
Alloy, 518
Alluvial fans, 242, 243, 281, 323, 343, 543
Alluvial soils, 479
Alluvial terraces, 279
Alluvium, 240, 268, 479
Altimeter, 589
Aluminum, 523
Anemometer, 55, 58, 590, 591
Aneroid barometer, 587, 589
Antarctic Circle, 14, 582
Antarctica, climate of, 190
  glaciers of, 245
  ice plateau of, 324
Antecedent rivers, 330, 331
Anthracite coal, 206, 503, 504
Anticline, 211, 212, 330, 509, 510
Anticyclone, 108–112
  Great Basin high, 115
  over Southeastern states, 172
  paths of, 114
  temperature in, 111
  winds in, 108
Appalachian coal field, 504, 505
Appalachian oil field, 510, 511
Appalachian plateaus, 325, 567
Appalachian ridge and valley region, 329–332, 568
Arctic Circle, 14, 582
Arroyos, 322
Artesian wells, 413, 414
Asphalt, 514
Asteroids, 5
Atacama Desert, 149, 150
Atlantic Coastal Plain, 570–572

Atmosphere, 7
composition of, 24
compression of, 31
cooling of, 31, 32
heating of, 29–31
Atolls, 394, 395

B

Backing wind shift, 116
Bad Lands, 263, 264
Bagnell Dam, 430, 431
Banana tree, 139, 141, 451
Barnacles, 544
Barograph, 113, 587, 590
Barometer, 49
types of, Appendix C, 587–590
Base level, 237
Base line, 265
Basin and range region, 550–552
Bauxite, 523
Bayous, 277, 278
Bear Butte, South Dakota, 217–219
Beaufort scale, 591
Bedford limestone, 204, 527
Bedrock of United States, 207
Bench marks, 603
Berthoud pass, 351
Big Horn mountains and basin, 350, 553
Bituminous coal, 206, 502, 505, 506
Black Hills, 201, 333, 556
Black-earth belts, 186
Blizzard, 112, 180, 181
in Antarctica, 190
Blue Ridge Mountains, 333, 569
Bolivia, plateau of, 315
Bonne's projection, 600
Bonneville, Lake, 551, 552
Bonneville dam, 425, 426, 428
Boulder Dam, 202, 322, 421–424
Breakers, 370
Buttes, 217–219

C

Cacao tree, 140, 142
Cactus, 153
Calcite, 527
Calcium, in soil, 481, 482
Caldera, 347–349
California, fogs of, 86
Great Valley, 282, 540, 545
Imperial Valley, 274
ocean current, 377
oil region, 512
Campos of Brazil, 143
Canal, 398, 399
All-American, 424
Canary current, 376
Canyons, 320–322
Capacity of air for water vapor, 80
Capillary water in soil, 485
Capulin volcanic cone, 215, 334
Carbonation, 228
Caribou, value of, 189
Carlsbad Caverns, 203, 234, 235
Cartograms, 600, 602
Cartographer, 596
Cascade Mountains, 94, 345, 548
Cascade tunnel, 352, 354, 426
Caves, 234, 235
Cement, 204, 527
Centrifugal force, 9
Cereals, 185
Chalk, 203
Chaparral, 169, 453, 542
Chemical elements, 613
Chemical weathering, 228
Chernozem soils, 490, 491
Cherrapunji, India, 145
Chert, 203
Chesapeake Bay, 380, 381
Chile, desert of, 147, 149
China, delta region, 271, 272
loess region, 252
Chinook wind, 158, 159, 555
Chronometer, 16
Cinchona tree, 451
Circle of illumination, 8
Cirques, 358–360
Citrus fruits, 169
Climate, types of, 135–191
data for selected places, 585, 586
dry, 147–159
humid continental, 177–186
humid subtropical, 169–174
ice cap, 190
low-latitude desert, 149–153
low-latitude steppe, 154
marine west-coast, 174–177
Mediterranean, 164–169

Climate, types of, middle-latitude desert, 154–157
middle-latitude steppe, 157–159
mountain, 190, 191
savanna, 143–147
subarctic, 186–188
tropical rainforest, 136–143
tundra, 189, 190
Climatic regions, 134, 135
Clouds, 87–91
ceiling, 118, 593
cirrus, 89, 91
cumulus, 87, 88
effect on temperature, 34
nimbus, 91
number of days with, 90
stratus, 91
Coal, 205, 501–509
accessibility of, 503
anthracite, 206, 503, 504
bituminous, 206, 505, 506
conservation of, 509
Coal fields, in Africa and Australia, 508, 509
in Asia, 507, 508
in Europe, 506, 507
in South America, 506
in United States, 504–506
Coastal ranges, California, 333, 540, 542, 543
Coconut tree, 140
Coffee tree, 146
Cold front, 107, 120
Cold wave, 181
Colorado Piedmont, 283, 555
Colorado Plateau, 315–319, 552
Colorado River, delta, 273, 274
Grand Canyon, 321–322
use for irrigation, 420–422
Columbia Plateau, 216, 319, 549
Columbia River, 380
Compass, magnetic, 19
Condensation, 79
cause of, 83, 84, 87
forms of, 84–91
latent heat of, 79
Conduction, 29
Conglomerate, 205
Conical projection, 598, 600
Coniferous forests, 457–461
Conservation of natural resources, 406
of coal, 509
of forests, 462, 463
of grasslands, 469
of ground water, 414
of petroleum, 516
of soils, 496, 497
Continental divide, 351
Continental glaciation, results of, 309, 310
Continental glaciers, 244
Continental plateaus, 317, 318
Continental shelf, 259, 260
Contour line, 601
Convectional currents, 30
Copper, 524–526
Coral, shorelines and reefs, 394, 395
Cork oak, 168, 453
Corn belt, 182, 183, 258, 558
soils of, 490, 491
Cotton, 173, 174
Cotton belt of United States, 563
Crater Lake, 348, 548
Craters of the Moon National Monument, 199
Crevasses, glacial, 244, 324
Crystals, mineral, 609
Cumberland hill region, 325–328
Cyclones, 103–114
precipitation in, 108–110
pressure in, 103, 104, 113
speed of, 105
temperature in, 112
tracks of, 104, 113, 114
winds in, 105–107

D

Dakota sandstone, 219
Dead Sea, 211
Death Valley, California, 550
Deccan Plateau of India, 217, 324
Deflation by wind, 251
Degradation, 209, 227
Delta, 242
Colorado River, 273, 274
Mississippi, 269
Nile, 272, 273
of North China, 271, 272
plains, 268–274
Rhine, 271
Dendritic drainage, 265, 326, 327

Deserts, 147–159
Gobi, 155
low latitude, 149–153
middle latitude, 154–157
Sahara, 149, 150
vegetation of, 469–471
Devil's Tower National Monument, 216, 556
Dew, 85
Dew point, 82
Diastrophism, 209–214
Differential weathering, 229
Dike, igneous, 217
Distributaries, 242
Divide, 236
continental, 351
Doldrums, 62, 63
Douglas fir, 177, 459, 460
Drainage, dendritic, 265, 326, 327
of floodplains, 280, 281
of ice-scoured plains, 290
interior, 315, 323
of soils, 485–487
trellis, 331, 332
Drainage basin, 236
Driftless area, 246
Drought, 182
Drumlins, 295, 296, 394
Dust storms, 120, 158, 159, 494

E

Earth, 6–8
age of, 208
axis, inclination of, 10, 11
grid, 11
orbit of, 10, 11
revolution around sun, 9
rotation on axis, 8
seasons, 581–584
shape of, 6
size of, 7
speed of, 9
Earthquakes, 220–222
East Indies, 345
Eolian soils, 480
Equator, 11
Equinox, 14, 581–584
Erie Canal, 299
Erosion, 231–253
of soils, 492–496
Erratic boulders, 293–295
Eskimos, 190
Estuary, 380, 381, 572
Ethiopia, 217, 273
Etna, Mt., 346
Evaporation, 79
Everest, Mt., 340
Everglades of Florida, 261
Exfoliation, 230
Exotic streams, 152, 272, 320
Extrusive igneous rock, 200, 216

F

Fall line, 261, 262, 571
Fathom, 368
Fathometer, 369
Fault, 210
Fault scarp, 210, 342
Feldspar, 206
Fertilizers, mineral, 529–531
Finger Lakes, 335, 336
Fiords, 384, 385
Fishing banks, 473
Flint, 203, 204
Floodplains, 238, 241–243, 274–281
Floods, 279, 280
Florida, big springs, 410
coast of, 399
Everglades, 261
karst region of, 267
Florida Keys, 395
Fog, advection, 86
of California, 168
of London, 84
Newfoundland, 86
radiation, 84
relation to ocean currents, 378
Folded Appalachians, 568
Folding of rock layers, 211, 212
Forest, conservation, 462, 463
hardwood, 185, 186, 453–457
marine west-coast, 176, 177
middle latitude, 452–460
regions of, United States, 454
softwood, 457–461
southern pine, 460, 461
taiga, 186
tropical, 139, 446–452
types of, 444
Fossils, 204, 208, 213

Frost, 36–38
in California, 167
dry freeze, 86
white, 85
Fruit-drying industry, 169, 545
Fuji volcanic cone, 346
Fumaroles, 220
Fundy, Bay of, 86, 373

G

Galena, 609, 611
Galveston, bay of, 389
sea wall, 389
Garnet, 198
Geological ages, 612
Geysers, 220
Glacial drift plains, 292–304
Glacier National Park, 352, 359, 361
Glaciers, lakes formed by, 290, 291, 305
moraines, 248, 292, 299, 300
spillways, 306, 308
types, 243, 244
valley, 347, 348, 357–360
work of, 243–248
Glaze, 91
Gloucester, Mass., 573, 574
Gneiss, 206
Gold, 526
Goode, J. Paul, 598, 600
Gradation, 227
Gradational forces, 209
Graded stream, 237
Grand Canyon of Colorado River, 321, 322
Grand Coulee project, 425, 426, 428
Graphite, 206
Grasslands, 463–472
soils of, 490–492
Gravitation, attraction of, 9
Gravity, force of, 7
Great Barrier Reef, 394, 395
Great Basin, 540, 551
Great Circle, 11
Great high plains, 262–264, 283, 554, 555
Great Lakes of North America, 298, 299
navigation on, 434, 435
as water supply, 416
Great Lakes–St. Lawrence waterway, 298
Great Salt Lake, 323, 551
Great Smoky Mountains, 333, 569
Green Mountains, 574
Greenland, glacier of, 244, 245
ice plateau of, 324, 325
Grid, earth, 11
Ground moraine, 248
Ground water, 232–235
conservation of, 414
Growing season, 36, 37
Gulf Coastal Plain, 264, 562–565
oil field of, 512
Gulf Stream, 86, 376, 378
Gullying, in soils, 493, 495
Gypsum, 205, 528

H

Hail, 92, 126, 127
Hair hygrometer, 592
Hanging valleys, 358, 359
Harbors, 395–398
Hard water, 408, 409
Hardness, mineral scale, 608, 609
Hardwood forest belt, 185, 186
Hawaiian volcanoes, 216
Headwater erosion, 235, 236
Heating of land and water, 27, 28
Hematite, 519
Henry Mountains, 217
Hill lands, 325–336
Hinterland, 378, 396
Horse latitudes, 66, 67
Horst, 211
Hot springs, 220
Hot wave, 182
Humboldt current, 377
Humid continental climate, 177–186
Humid subtropical climate, 169–174
Humidity, 80–83
absolute, 80
problems on, 82
relative, 81
Humus, 483
Hurricane, 123, 124
in humid subtropics, 171
Hydration, 228
Hydroelectric power, 419
Hydrophone, 369
Hydrosphere, 7
Hygrograph, 592
Hygrometers, 591, 592

I

Ice formation on airplanes, 92
Ice storm, 91, 92
Icebergs, 244, 245, 325
Ice-cap climate, 190
Iceland low, 61
Ice-scoured hill regions, 334–336
Ice-scoured plains, 289–292
Igneous extrusions, 216
Igneous intrusions, 217
Igneous rocks, 200, 201
Immature soils, 487
Immediate runoff of water, 235
Imperial Dam, 421, 424
Imperial Valley, 274, 424, 545, 546
Impervious rock, 203, 409, 509, 510
India, monsoon wind system of, 71
Indian Summer, 182
Inland navigation, 432–434
Insolation, 26
  absorption by air, 27
  in mountains, 191
Interior drainage, 551
Interior lowlands of United States, 264–266, 556–559
Intermontane plateaus, 315
International Date Line, 15
Intrusive igneous rocks, 217
Iron ores, 519–523
  in Alabama, 521, 522
  bog, 205
  docks, 560
  in Europe, 522
  hematite, 611
  in Lake Superior region, 519–521
  limonite, 198
Irrigated lands of United States, 420
Irrigation, water for, 416, 417, 486
Irrigation projects, 419–428
Isentropic charts, 119
Isobars, 52–54, 594
  January, 50
  July, 51
Isogonic line, 19
Isotherms, 38, 594
  characteristics of, 41
  January, 39, 41, 42
  July, 40, 41, 42

J

Japan Current, 376
Joint planes, 209, 210, 230

K

Kaffir corn, 157
Kaibab Plateau, 319
Kalahari Desert, 149
Kame-and-kettle topography, 300, 301
Karst plains, 266
Karst topography, 233
Katmai volcano, 216
Kentucky, karst region of, 267
  Mammoth Cave, 268
Keokuk, Iowa, dam, 265, 430
Krakatao, 215

L

Labrador Current, 86, 376
Laccolith, 217, 218
Lagoons, 387, 388
Lake of the Woods, 292
Lake plains, 305–307
Lake Superior iron regions, 520, 521
Lakes, Finger, of New York, 335, 336
  glacial, 290, 291, 305
  playa, 323
  salt, 323
Land and sea breezes, 72, 73
Landforms, principal types, 207
Landscape, types of, 239
Lassen, Mt., 540, 546
Laterite soils, 489
Latitude, definition of, 12
  divisions of, 614
Lava, 199, 200
Leaching of soils, 228, 488
Lead resources of United States, 523, 524
Leeward, definition of, 56
Legumes, 481
Length of day, 27
Lightning, 127, 128
Lignite coal, 502
Lime, 204, 527
Limestone, 203, 204, 408
Liming soils, 482, 483
Limonite, 198, 519
Lithosphere, 7, 197

Llanos, 143
Loam, 483
Local relief, 258, 340
Loess, 148, 253, 480, 485
  in China, 252
  in United States, 253, 549
Long Island, 303, 392
Longitude, 14, 614
  degrees vary in length, 15
Los Angeles, water supply, 423, 424
Luster of minerals, 608

M

Magma, 217
Magnetic variation, 19
Magnetite, 519
Mahogany trees, 451
Malaspina Glacier, 244
Mammoth Cave, 203
Mantle rock, 206
Map projections, 596–601
Map scale, 596
Maps, 596–603
  topographic, list of, 604–607
Marble, 206
Marginal lakes, glacial, 305
Marginal moraines, 299, 300
Marine west-coast climate, 174–177
Mature landscape, 239, 240
Mature soils, 486, 487
Mature valleys, 238, 239
Maximum thermometer, 588
Mead, Lake, 422
Mechanical weathering, 230
Mediterranean climate, 164–169
Mercator's projection, 597
Meridian, 14
  prime, 14, 380
  principal, 265
Mesa, 152, 322, 552
Mesa Verde National Park, 152
Mesabi iron region, 520, 561
Metallic minerals, 517–526
Metamorphic rocks, 205
Metamorphism, 206
Meteors, 9, 10
Mexico, plateau of, 316
Mid-continent oil field, 511
Millibar, 103, 104, 110
Minerals, 197, 198, 608–611
  crystalline form of, 198, 609
Minimum thermometer, 588
Mirage, 156, 157
Mississippi delta, 269, 270
Mississippi floodplain, 274, 278–280, 565, 566
Mobile processes of gradation, 231–253
Moffat tunnel, 351–353
Mohave Desert, 540
Monsoon winds, 70–72, 145
  in Asia, 170
Moon, 6
  eclipse of, 6
  halo of, 87
  phases of, 6
Moraine, glacial, 248
  ground, 292
  marginal, 299, 300
  terminal or end, 299
Motion-picture industry, 543
Mountain and valley breezes, 73
Mountains, 340–362
  climate of, 190, 191
  cordillera, 342
  passes, 351
  peaks, 342, 345, 346, 614
  ranges, 342–345
  system, 342
  value of, 361
  volcanic, 345–348
Municipal water supply, 415, 416
Muscle Shoals, Alabama, 265, 332

N

Natural gas, 511, 512
Natural levee, 242, 269, 270, 565
Natural resources, classes of, 405
Naval stores, 461, 462
Neap tides, 372
New England region, 572–574
New York, bay of, 396
  city of, 397
Newfoundland, fogs of, 86
Niagara Falls, 296, 297, 431, 432
  escarpment, 297
Nickel, 525, 526
Nile River and delta, 272, 273
  cataracts, 318
Nitrate of sodium, 151, 528, 530

Nitrogen, 24
fertilizers, 529, 530
in soil, 481
Nitrogen-gathering bacteria, 481, 482
North Atlantic Drift, 174, 175
Nyasa, Lake, 435

O

Obsidian, 200
Ocean currents, 374–378
Ocean shore, features of, 378–395
Ocean water, composition, 368
depth, 368
life in, 472–474
movements of, 369–378
pressure of, 368
Offshore bars, 387, 388
Ohio Falls, 265
Oil shale, 515, 516
Old Faithful geyser, 219, 220
Old-age landscape, 239, 240
Olive tree, 453
Olympic Mountains, 543
Ontario clay belt, 307
Ore, 235
deposits of, 518, 519
iron, 519–523
Outwash plain, 248, 302, 303
Oxbow lakes, 277, 278
Oxidation, 228
Oxygen, 24
in lithosphere, 197
Ozarks, hill region, 328, 329, 561, 562
Lake of, 430, 431

P

Pampa of Argentina, 172, 283
Panama Canal, 398, 399
Parallels of latitude, 12
Parker Dam, 421, 423, 424
Parks, mountain, 343
Patagonia, 155
plateau of, 316
Peat, 299, 502
Pelee, Mt., 215
Peneplain, 330
Petrified wood, 235
Petroleum, 509–517
occurrence, 509, 510
Petroleum, pipe lines of United States, 513
supply disappearing, 516, 517
Petroleum fields, in Asia, 515
in Caribbean region, 512
in Europe, 514, 515
in United States, 510–512
Phosphorus, fertilizers, 530
in soil, 482
Physical regions of United States, 537–575
Piedmont alluvial plain, 243, 281, 282
Piedmont plateaus, 316
Piedmont region, 569
Pikes Peak, 353
Pilot balloon, use of, 118
Plains, 258–310
coastal, 259, 260
Atlantic, 261
delta, 268–274
glaciated, 288–310
interior, 259, 262–266
karst, 266, 267
old alluvial, 268, 282, 283
stream-eroded, 259–266
of United States, 264
Planets, names of, 5
Plankton, 472
Plant life, 441–472
principal groups, 444
Plateaus, 314–325
Podzol soils, 489, 490
Polder, 271
Political map, 600
Polyconic projection, 598, 601
Population, world distribution, 599
Porous rock, 203, 408, 409, 412
Porphyry, 200
Potash, 530
Potassium, in soil, 482
Prairie grasslands, 467
soils of, 491
Precipitation, 91–97
convectional, 92, 93
cyclonic, 94, 96, 109, 110
forms of, 91, 92
in mountains, 191
orographic, 93, 94
Pressure of the atmosphere, 48–54
decrease with altitude, 49
horizontal distribution, 49–53
Pressure gradient, 54
relation to winds, 54

Principal meridian, 265
Puget Sound, 386
' lowland, 544
Pumice stone, 214

Q

Quartz, 197, 199
  sand, 526
Quartzite, 206
Quebracho tree, 452

R

Radio-meteorograph, 117, 593
Radiosonde, 117
Rain, 91–96
  dash type, 93
  drizzle type, 96
  gauge, 593
  heaviest in United States, 543
  shadow, 94, 191
Rainbow, 87
Rainfall, annual, important data, 96, 97
  of United States, 95
  regime, 97
Rainier, Mt., 216, 346–348, 426, 548
Redwood forest, 176, 177, 460
Reforestation, 463, 464
Reindeer, value of, 189
Relief maps, 601–603
Residual soils, 480
Rhine delta, 271
Ridge and valley region, 568
Rift valley (graben), 211
River, antecedent, 330
  deposition of sediment, 240–243
  erosion by, 235–240
  floodplain, 241
  graded, 237
  length of longest, 614
  meander, 239
  mineral load of, 201
  navigation, 432–434
  valley and system, 236
Rock, basin, 248, 290
  classes of, 199–207, 610
  coarse-grained crystalline, 201
  definition of, 197
  extrusive, 200
  fine-grained crystalline, 200
Rock, intrusive, 200
  joints, 209, 210
  mantle, 206
  outcrop, 207
  porous and impervious, 203, 408
  structure, 213
Rocky Mountain National Park, 353
Rocky Mountains, 343, 344, 553
Rogue River Valley, Oregon, 177
Royal Gorge, 349
Rubber tree, 139, 140, 451
Rushmore, Mt., National Monument, 201

S

St. Anthony Falls, 296
St. Gotthard Tunnel, 352
Salt, lakes, 323
  rock, 205
  sources of, 528, 529
Salt River project, 425
Salton Sea, 274, 424
San Diego, harbor, 543
San Francisco Bay, 391, 392, 540–542
Sand, 197, 199, 526
Sand dunes, 148, 253, 382, 383
Sandstone, 202, 203, 408
  Dakota, 219, 413
Sandy Hook, 382, 396
Sargasso Sea, 376
Satellites, 6
Saturated air, 80
Savanna, climate, 143–147
  grasslands, 463, 465, 466
Sawatch Mountains, 344, 553
Seasons, 27
  explanation of, 581–584
Seal, fur, 473
Section of land, 265, 266
Sedimentary rocks, 201–205
Seismograph, 220
Sequoia tree, 445, 460, 547
Sextant, 12
Shale, 203
  oil, 515, 516
Shasta, Mt., 216, 346, 347, 540, 546
Sheet wash of soils, 493
Shenandoah Valley, 332, 568
Shorelines, coral reef, 394, 395
  of emergence, 386–390
  New England, 391–394

Shorelines, New Jersey-Carolina, 391
of submergence, 379–386
Shoshone Dam, 350
Siberia, forests, 187, 188
temperature of, 187
Sierra Nevada Mountains, 343, 540, 546, 547
Silicon, 197
Silicon dioxide, 197
Sills, igneous, 217
Silver, 526
Simplon Tunnel, 352
Sink holes, 234, 266, 267
Sirocco winds, 168
Slate, 206, 527
Sleet, 91
Sling psychrometer, 592
Slope wash, 93
Smelting of iron ore, 204
Smog, 25
Snow, 91
effects of, 179–181
Snow line, 355
Sodium nitrate, 151
Soils, 479–496
acid and alkaline, 483
chernozems, 490, 491
color, 485
composition of, 480
conservation of, 494–497
erosion of, 492–494
mature and immature, 486, 487
podzols, 489, 490
texture and structure, 484
in tropics, 488, 489
Solar radiation, 26
Solar system, 5
Solstice, winter and summer, 13, 14, 581–584
Solution, 228
by ground water, 233
"Soo" canals, 298
Southern pine forest, 460–462, 571
Specific gravity, 609
Specific heat, 28
Spillways, glacial, 306, 308
Spits, 382
Spring tides, 371, 372
Springs, 409–411
Stable and unstable air, 36
Stalactites, 234
Stalagmites, 234, 235
Static processes of gradation, 227–231
Steppe, low latitude, 154
middle latitude, 157–159, 160, 263, 468, 469
Stratified rocks, 202
Stratosphere, 35
Streams, work of, 235–243
Striae, glacial, 247, 289, 290, 294
Structure of soils, 484
Subtropical dry-summer climate, 164–169
Sudan of Africa, 144
Suez Canal, 398
Sulphur, 528, 529
Sun, altitude, 12, 26
diameter of, 9
eclipse of, 6
vertical rays of, 13
Superior upland, 560, 561
Surface-water supply, 415–419
Swamps, 261
Syncline, 211, 212, 330

T

Taiga, 186–188, 457, 458
Talus slope, 218, 231
Tanganyika, Lake, 435
Teak trees, 450, 452
Tectonic forces, 208, 209
Temperature of air, 24–43
annual range, 42
daily average, 32
daily range, 33
decrease with altitude, 35, 86
effect of cloud cover, 34
how decreased, 84, 86, 87
maximum, 32
minimum, 32
in mountains, 191
seasonal changes, 34
sensible, 42
Tennessee Valley Authority, 332, 427–430
Terminal or end moraines, 299
Terraces, alluvial, 279
marine, 390, 393
wave-cut and wave-built, 382
Texture of soils, 483, 484
Thames estuary, 380
Theodolite, 118, 593
Thermograph, 113, 588

Thermometers, 588
Thunderstorms, 102, 109, 124–128
  along cold front, 110, 125
  in doldrums, 126
  lightning in, 127
  number per year, 125
  thunder of, 128
  types, 124
Tidal bore, 373
Tidal glaciers, 244, 357
Tidal inlet, 388
Tidal race, 388
Tidal range, 372, 373
Tidal waves, 222
Tides, 370–374
Till sheet, 247, 294, 295, 303
Timber line, 355
Time, difference in, 16
  standard, 17
Tin, 526
Topographic maps, 601–603
  list of, 604–607
Tornado, 127, 128
Township, 265
Trade winds, 64–66
Trellis drainage, 331, 332
Trinidad, 514
Tri-state mining region, 524
Tropic of Cancer, 13, 582
Tropic of Capricorn, 13, 583
Tropical rainforest climate, 136–143
  animals of, 449, 450
  jungle of, 448, 449
Tropical soils, 488, 489
Troposphere, 35
Tundra, animal life, 471, 472
  climate, 189
  vegetation, 471
Typhoon, 123, 124
  in China, 171

U

Uinta Mountains, 552
Undertow, 249, 370

V

Valley glaciers, 243, 244
Valleys, river, 236
  glaciated, 357–360
Valleys, river, hanging, 358, 359
  mature, 238, 239, 277
  old, 240, 277
  young, 237, 277
Veering wind shift, 116
Vein of ore, 235
Velocity of wind, 58–60
Verkhoyansk, Siberia, 187
Vesuvius, Mt., 215, 346
Victoria, Lake, 273, 435
Victoria Falls, 318
Volcanic cones, 345–347
Volcanic glass, 200
Volcanoes, 214–216

W

Walrus, 474
Warm front, 120, 122
Warping of rock layers, 213
Wasatch Mountains, 343, 552
Washington, Lake, 544
  Mt., 60, 572
Water gaps, 330, 548
Water power, production of, 417–419
  world resources, 418
Water resources, 406–436
Water spout, 128
Water table, 233, 281, 407, 411, 412
Water vapor, 25
  latent energy in, 79
  sources of, 78
Wave-cut and wave-built terrace, 382
Waves, names applied to, 370
  work of, 248–250
Weather, controls of, 25
Weather forecasting, 114–116
Weather map, 114, 593–595
  importance in aviation, 123
Weathering, 227–231
Weights and measures, 613, 614
Welland Canal, 298
Wells, 411–414
Westerlies, 67–69
Wet- and dry-bulb hygrometer, 591
Whale, 474
Wheat, spring, 183
  winter, 184
White Mountains, 574
Whitney, Mt., 540, 546
Willamette lowland, 544

Wilson Dam, 427, 429
Wind, 54–73
  Beaufort scale, 591
  belts, 52, 69
  chinook, 158
  deflection, 61
  direction, 56, 57
  effect on airplane, 60
  erosion, 251
  monsoon, 70–72
  planetary, 60–69
  rose, 63
  upper, 57–59
  velocity, 58–60, 590, 591
Wind gaps, 331
Wind-shift line, 107
Windward, definition of, 55
Wyoming basin, 344, 553

Y

Yakima Valley, 549, 550
Yellowstone National Park, 220, 410
Yosemite National Park, 343, 345, 359, 547
Young valleys, 237, 238
Youthful landscape, 239, 240

Z

Zambezi River, 318
Zinc resources of United States, 524
Zone of fracture, 210