A SHORTER PHYSICAL GEOGRAPHY

By

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TRANSLATED FROM THE FRENCH

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TRANSLATOR'S FOREWORD

THE publication of this book is the outcome of the growing interest taken in Geography by the public schools. The new movement came to a head, under the leadership of Mr. C. C. Carter, of Marlborough College, at a meeting in April, 1926, in the Council Room of the Royal Geographical Society. Among other business, the meeting appointed a sub-committee to consider ways and means of improving the geography text-books available, and the present book is the first tangible result of the efforts of that sub-committee.

The issue of an English translation of de Martonne's work needs no apology, however; on the contrary, it has been long overdue. Even in France, which is far ahead of this country in respect of geographical studies, M. de Martonne is regarded as the leading exponent of Physical Geography. Perhaps the first writer to realise clearly the exact amount of scientific basis required for the subject, his work is strikingly different from English texts in the absence of over much geology and physics. His method is strictly synthetic, and consists of building up geographical principles through the examination of typical regions. In this way the reader feels that he is dealing with Geography, and not with abstract science.

The human aim of Geography is constantly in view throughout the book, and it is significant that one part is entirely devoted to vegetable and animal (including human) life and distribution. Here again the treatment is not botanical or zoological, but strictly geographical. It is an undoubted boon, both to those who teach and those who learn, to have this section of the subject under the same cover as the rest of the scientific basis..

A small, but important, feature of the book is the use of Mollweide's equal area projection, instead of the more usual and misleading Mercator's, for maps showing geographical distribution. Again, the more technical scientific matter is distinguished by being printed in more closely set type.

In the translation it has been thought expedient to insert illustrations chosen from the British Isles and North America, so as to increase the usefulness of the book to English and American readers. This has, of course, not been possible in regions specially chosen for examination by the author, since this would have involved re-writing, not translating, the book. As a rule, French measures have been converted into the English equivalents, but they have been retained occasionally to serve as an exercise in foreign systems. In the appendices to the Parts various practical exercises constructed for use in France have been omitted and similar ones substituted for English and American students. It is hoped that these changes, while preserving de Martonne's text with all its virtues, will give the book a more international character and remove the obvious disadvantages of a translation.

In conclusion, the translator's thanks are due to M. de Martonne for the assistance he has freely given, and especially for his kindness in reading the proofs. This kindly censorship has the value of ensuring that the author's ideas have been faithfully rendered. He is also grateful to Messrs. Christophers for undertaking the publication of the book and for their zeal in the improvement of diagrams and their care in making the book externally presentable. Messrs. Macmillan have very kindly allowed the illustration of the Flying Lemur on page 296 to be redrawn from their *Cambridge Natural History*.

E. D. LABORDE

Harrow-on-the-Hill
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INTRODUCTION

PHYSICAL GEOGRAPHY is that part of geography which deals with the physical phenomena that occur on the Earth's surface. To understand the aim and method of the subject, we must first define the aim and method of geography in general. This done, we must remind ourselves of the nature of the terrestrial globe and of the chief physical phenomena which are observed on its surface.

I. THE AIM OF GEOGRAPHY

The primitive peoples of Oceania use sticks with notches cut in them to indicate the position and distance of the islands they visit; the ancients regarded the author of the Odyssey as the first geographer. It seems indeed that geography answers one of the most essential needs of man, namely that of preserving, by concrete representations or by descriptions, a record of places, of their positions, and of their relation to one another. To draw these representations—or maps—correctly, man is led on to the calculation of the shape of the Earth; and thus *mathematical geography* came to be studied by the Ionian philosophers. Description tends to rise above a mere list of names, and since the days of Strabo the description of places has not been limited to their position alone, but has been extended to include details of their climate, soil, and products, their inhabitants and their history and occupations. Each step in the widening of the horizon of civilisation, each advance in the progress of science, furthers geographical knowledge. For the study of geography to be fully equipped, however, the whole of the Earth's surface has had to be explored, and the development of the natural sciences has had to follow that of the mathematical. These two conditions were not fulfilled before the 19th century.

In giving an account of places whose positions are shown on accurate maps, modern geography is not content with describing the nature of their relief, climate, vegetation, and human activities : it tries to explain the causes of all of these. Therein lies its claim to be regarded as a science. But this scientific character is acquired only at the price of calling in the aid of sciences which are not geographical in themselves, e.g., geology, meteorology, botany, statistics, or history. The risk of being sidetracked can only be avoided by a very clear knowledge of the proper aim and method of geography.

A close study of the works of the best known geographers, such as K. Ritter, Humbolt, E. Reclus and Vidal de la Blache, reveals tendencies which are really characteristic of them, and are not found in the works of non-geographical specialists who treat of the same subjects. These tendencies are a constant effort to discover the relation between human and physical phenomena —or more exactly, an attempt to follow up the chain of cause and effect, no matter what the starting point may be—and an effort to connect observed phenomena with definite regions, and to explain the causes of this distribution.

Thus, the meteorologist analyses the mechanism of climate, whilst the geographer describes its local types, and in indicating their distribution tries to show what influences bring it about, and what are its effects on rivers, vegetation, and human life. The geologist can explain the origin of a certain type of relief; but the geographer studies in addition its distribution, its causes and effects. The botanist deals with geography when he studies the distribution of plants; but he becomes a geographer altogether if he tries to discover the nature of their local associations and to explain both the physical causes and the economic effects of such a distribution.

The attempt to explain gives modern geography its scientific character; the twofold study of distribution and of the correlation of phenomena assures its place as a separate branch of knowledge.

It is all the more important to lay down these principles, since the gradual development of scientific explanation proper to a book of this kind might cause them to be forgotten. The aim here is limited to the exposition of the general principles of physical geography with the sole addition of biological geography, or bio-geography, which is closely connected with it. But an effort has been made to set out the synthetic view of geography by every means compatible with the purpose to be achieved ; to indicate briefly the effects of each phenomenon, especially on human geography ; and to give the greatest share of importance to the study of distribution.

II. THE TERRESTRIAL GLOBE

The domain of geography being the Earth's surface, all geographical phenomena depend on one essential fact, namely, the shape of the Earth and its position in the solar system.[1]

Shape of the Earth. We know that the Earth is more or less spherical. The best proof of it is the circular shape of the horizon in the open sea wherever one may be. This fact is so familiar to us that we have to make an effort to realise its geographical importance. But the Greek philosophers of twenty centuries ago, who were the first to discover the fact, were at once struck by its importance.[2]

In spite of their ignorance of almost the whole of the Earth's surface, they realised at once that it must have a variety of climates, and that the sun's heat must be distributed over it unequally, but in accordance with a comprehensible law. Since the obliqueness of the sun's rays increases from the equator to the poles, their heating effect must decrease correspondingly. Hence arose the theory of the five climatic belts : two polar, which were uninhabitable on account of the cold ; two temperate, which alone were inhabited ; whilst the hot belt was said to be desert waste.

Moreover, the ancients had recognised that all the phenomena, all the movements that take place at the surface of the Earth, must occur at opposite times on each side of a great circle dividing the sphere into two halves or hemispheres. Up to

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[1] The perfected methods of modern geodesy and astronomy have shown that the Earth is somewhat of the shape of an "ellipsoid of revolution," that is, of a solid produced by an ellipse rotating on its short axis. The bulge is at the equator, the polar axis being shorter than the equatorial diameter by about 27 miles.

[2] Thales of Milesus (in Asia Minor), the best known of the Ionian geographers, lived in the 6th century B.C. Aristotle (4th century B.C.) also taught that the Earth was round. Eratosthenes of Alexandria (3rd century B.C.) measured its dimensions (see below, p. 7).

a short time ago[1] a grotesque ceremony was practised by sailors on crossing the " line " to signalise their entry into what was indeed quite another world. For, in fact, not only do the stars change, but even the significance of the cardinal points is no longer the same. It is no longer the south, but the north, that represents light and warmth ; it is no longer from the north that the Trade Winds blow, but from the south. In studying a region in the southern hemisphere, the student cannot be too often reminded that the hottest part of it lies in the north, and that the winter months there occur during our summer. One phenomenon of economic geography illustrates the importance of realising this. As the harvest occurs in the Argentine during the winter of our hemisphere, modern fast transport enables Italian labourers to journey thither for it, and to return home for the summer harvest in their own country.

The Problem of Maps : Latitude and Longitude. No sooner had the spherical shape of the Earth been recognised than consequences of another kind appeared, e.g., the difficulty of fixing position and of representing the surface accurately by means of maps. As the surface of a sphere has neither beginning nor end, the problem was how to find a starting point for measurement. It was sought in the sky. The celestial vault resembles a hemisphere on whose surface the stars move, describing parallel circles. The axis perpendicular to all these circles is the polar axis, whose position is marked in our hemisphere more or less accurately by the pole star. This axis was imagined as passing through the Earth, thus fixing two definite points, the two poles. The great circle whose plane is perpendicular to the axis of the poles is the celestial equator, and its projection on the surface of the Earth is the terrestrial equator which separates the northern hemisphere from the southern. The great circles passing through the polar axis determine the meridians on the Earth's surface ; whilst the parallel paths of the stars correspond to circles which give the terrestrial parallels of latitude. Thus, the Earth's surface is

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[1] Though generally abandoned on the great lines, it is still maintained in smaller ships, and is observed with great completeness in the case of such public voyages as those of royal personages.—Tr.

covered with a network of co-ordinates which enable the position of any point to be fixed.

In Fig. 1 a point m is definitely fixed if its distance from the equator mB and from a given meridian mA' is known. These two measurements are latitude and longitude. They are, expressed in degrees (the circumference being divided into 360 parts) or in *grades* (the circumference containing 400 grades), the reckoning always starting from the equator for latitude, and for longitude from a zero meridian which may differ in different countries. The meridian of Greenwich Observatory near London is now almost universally accepted as the prime meridian.[1]

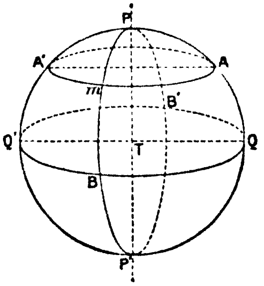

FIG. 1.—Terrestrial co-ordinates.

PP′ = polar axis; QBQ′ = the equator; AA′ = parallel of latitude; PBP′ = meridian of longitude.

Projections. By the device of co-ordinates the position of every place on the Earth's surface can be fixed. But the spherical nature of the surface is an obstacle to its representation in maps. The surface of a sphere cannot be "developed," i.e., it cannot be spread out and changed into a plane without being distorted or torn. The network of co-ordinates, or *graticule*, is therefore distorted, and with it all the geographical outlines drawn on the map. This is a most important fact, and the attention even of beginners should be drawn to it.

The name *projection* has been given to the methods of geometrical construction devised to draw on a plane surface the network of straight or curved lines representing the terrestrial co-ordinates. It is important to be able to recognise at least those projections which are most frequently used in atlases and to appreciate their advantages and defects.

Mercator's projection, which is so often used to represent the whole surface of the Earth on one map, has the advantage that its parallels and meridians are perpendicular to each other, as they are on a sphere. All its angles are identical with those

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[1] In France most atlases have retained the meridian of the Paris Observatory as the zero, the difference being 2° 20′ 14″.

on the globe, and the shapes of the continents are preserved throughout. But dimensions are absurdly exaggerated towards the poles. This is caused by its method of construction. The projection is cylindrical, i.e., the graticule is obtained by projecting the co-ordinates on a cylinder tangential to the sphere and by developing this cylinder (as in Fig. 2). The parallels, which on the sphere diminish in length as they approach the poles, are all shown equal to the equator; their distance apart, which is constant on the sphere, increases with latitude. Hence, Norway seems larger than Arabia, Spitzbergen as big as England, and Greenland of greater extent than Europe.

In this work *Mollweide's projection* has been exclusively used. Its virtue is that areas are always in the same proportion

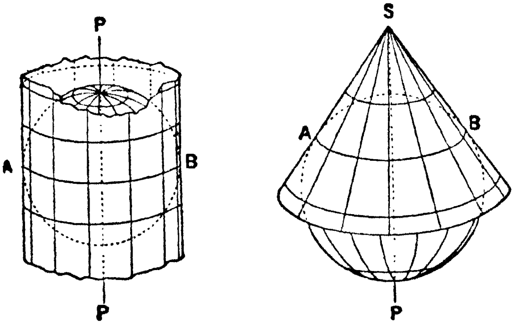

FIG. 2.—Showing the principles on which the cylindrical (left) and conical (right) projections are based.

as on a sphere. The tropical lands are shown much larger than polar lands, as in truth they are. But the meridians are not perpendicular to the parallels, nor are the shapes of countries the same as on the globe. Their distortion increases towards the edges, and one cannot fail to notice, for instance, the twisting of the American continents, or the lengthening and at the same time narrowing of New Zealand.

No map which represents the whole surface of the globe in a single drawing can be satisfactory as regards both the outlines and the proportion of areas. It is easier to represent the Earth divided into two hemispheres.[1] These are usually drawn either on the *orthographic* or on the *stereographic* projection. In these two methods the surface on to which the graticule is transferred is not a cylinder, but a plane whose position with

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[1] As is done in atlases in the "maps of the world in two hemispheres."

respect to the globe and an imaginary point of view determines the projection of the co-ordinates. Distortion increases with distance from the central meridian and the equator, which form two diameters of the circle representing the hemisphere and are perpendicular to each other. In the orthographic projection the parallels are all straight lines perpendicular to the central meridian, and consequently the angles are not the same as those on the globe. In the stereographic projection the parallels are curves, the angles are similar to those on the globe, and the outlines are preserved, as in Mercator's projection, but the proportion of areas is not kept.

Maps which represent only a continent or a country are generally based on the method of *conical* projection. The graticule is obtained theoretically by developing the surface of a cone which is tangential to the sphere (as in Fig. 2). The projections are recognised by the convergence of the meridians towards a point outside the limits of the map. Distances are strictly proportionate to actual ones along the central meridian and the parallel which touches the sphere; but distortion increases progressively with distance from these lines.

The smaller the area represented by the map, the easier it is to find a satisfactory method of projection; but the representation can never be quite accurate.

Size of the Earth; Map Scales. The ancient geographers who discovered the spherical shape of the Earth tried also to calculate its dimensions. In early times Eratosthenes[1] came very near the truth when he calculated the circumference of the Earth to be 250,000 stadia, or about 46,250,000 metres (28,000 miles). As the reader knows, the metric system is derived from a more accurate measurement carried out by the geodesists Delambre and Méchain in 1799, the metre being defined as the ten-millionth part of a quarter meridian.

The dimensions of the Earth no longer have the same significance to-day as they had before the invention of the steam engine. Their development in meaning is seen to be even greater if modern ideas are compared with those of the Middle Ages before the discoveries of Columbus. Magellan's expedition took three years to circumnavigate the Earth. To-day the journey can easily be done in two or three months. Given a land route all the way, a modern express travelling at 40

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[1] Lived at Alexandria about 200 B.C.

miles an hour would circle the Earth in less than a month. Given a direct, unobstructed sea route all the way, a modern transatlantic liner would sail round it in forty-five days.

The area of even limited portions of the Earth's surface is enormous in comparison with that of the maps which represent it. Every map is a plan, a model reduced in size. The reduction is called the *scale.*

The scale is expressed by a fraction whose numerator is invariably 1. In a map whose scale is 1 : 1,000,000, one inch represents a million inches (about 15¾ miles), and one millimetre represents a million millimetres, i.e., one kilometre. The Ordnance Survey publishes maps of the British Isles on various scales. The map used for military purposes is on a scale of 1 : 63,360 ; in which 1 inch represents one mile. The corresponding French map, known as the Staff Map, is on a scale of 1 : 80,000. On it one millimetre represents 80 metres, and one kilometre is represented by 12.5 millimetres.[1] The more populous of the United States are mapped on a scale of 1 : 62,500. When a map does not contain this numerical index of its scale, it has a line scale showing lengths that correspond to distances of 1 or 10 or 100 miles or kilometres.

The scale of a map is said to be large or small according to the value of the fraction which expresses the scale. A scale of 1 : 80,000 is large, but 1 : 1,000,000 is small. Even with a scale of 1 : 80,000 it is impossible for a map to show all the windings of streams, all the bends in the coastlines. Hence, maps always simplify topographical features, and simplification increases with the reduction of the scale. The value of a map as a representation of the truth depends therefore on its scale, and the first question that a geographer should ask about a map is "What is its scale ?" The number of people who are unable to answer is a proof of the grave neglect of education in geography. From the beginning the student should be familiarised with the meaning of scales by being shown the same area on different scales.

The Earth in the Solar System. The position of our globe in the solar system is as important as the shape of the Earth, if the general character of the distribution of climate is to be explained. Whether the apparent movement of the heavenly bodies, in which the sun itself joins, is real—as was long thought

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[1] The new Staff Map is on a scale of 1 : 50,000.—Tr.

—or whether the movement results from the rotation of the Earth on the polar axis, the effect on climate is the same. The alternation of day and night causes a sort of regular pulsation in life at the surface of the Earth Air, soil, and water grow warm and cold alternately. Out of these changes there arise in the mountains or on the sea-coasts winds which are alternately cool or stifling, and which cause masses of clouds or disperse them. In extreme climates the rocks disintegrate under the influence of nocturnal frost or burning noons. Sleep which comes over animals corresponds to certain phases in the growth of plants.

If day and night were always of the same length, the balance would be established between the loss of heat at night and the gain of it by day ; hence, the temperature would remain the same from one end of the year to the other at all places in the same latitude. It would decrease regularly from the equator to the poles. The seasons would be unknown, the climatic belts but slightly marked. The varying length of day and night is one of those familiar phenomena whose effects are not realised except by an effort of mind. It causes the seasons by disturbing the balance between the gain and loss of heat ; the loss increases as the days shorten, whilst air and earth both grow warm as the days lengthen. These variations are due to the relative positions of the Earth and the Sun.

The Earth revolves round the Sun, describing a vast ellipse in the space of 365 days. If the polar axis were perpendicular to the plane of this ellipse, the length of day and night would be equal all through the year all over the surface of the globe, as is shown in Fig. 3A. But actually, the polar axis is inclined to the plane of the orbit at an angle of 66° 33′. As a result the distribution of light and heat changes from day to day according to latitude. Fig. 3, in which extreme cases are shown, illustrates this clearly. Twice a year, at an interval of six months (September 23 and March 21), the Earth is in position A with respect to the Sun. Rotation then brings every place successively into the sunlit portion, and day and night are of equal duration everywhere; hence the name *equinox*. Twice a year, at intervals of six months (June 21 and December 21), the straight edge of the sunlit portion makes an angle of 23½° with the polar axis, the complement of the angle of inclination to the plane of the Earth's orbit (Fig. 3, B and C). These moments are called *solstices*. At the summer solstice (June 21), the sunlit portion touches at C and D′ the parallels CD and C′D′, which are termed the Arctic and Antarctic Circles respectively. In this position the rotation of the Earth cannot bring every part of the surface either into the circle of light or into the circle of darkness. Fig. 3 B shows that no place in the polar cap CPD will have an interval of darkness, whilst no place in the polar cap C′P′D′ will see the daylight. The rest of the globe will have day and night of very unequal length according to latitude. It is seen that the equator is the only parallel which is bisected by the line separating night from day and that consequently the equator alone has day and night of twelve hours each. From the equator to the Arctic Circle the length of day will continue to increase until it reaches 24 hours. From the equator to the Antarctic Circle it will continue to decrease until it reaches zero. The exact figures for the maximum length of day in different latitudes are as follows :—

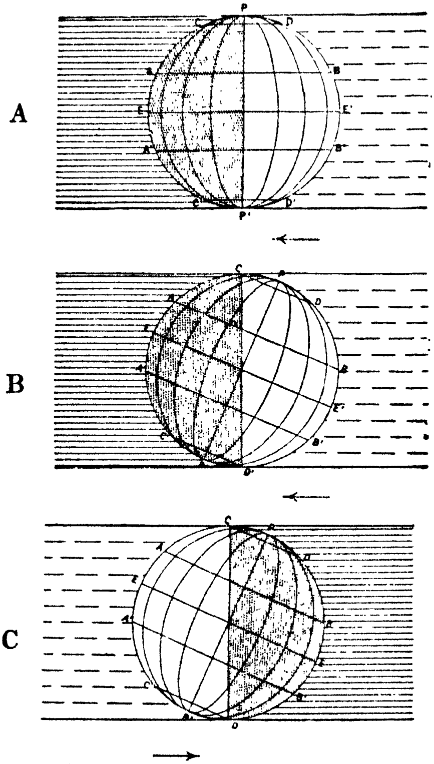

Fig. 3.—Showing the causes of the varying length of day and night.

Position A shows the autumnal equinox ; B, the summer solstice ; C, the winter solstice. The broken lines show the direction of the Sun's rays.

Latitude.	*Northern Hemisphere.*	*Southern H.*
Arctic (Antarctic) Circle.	24 hrs.	0 hr.
50	16 „ 18 min.	7 hrs. 42 min.
40	14 „ 52 „	9 „ 8 „
30	13 „ 56 „	10 „ 4 „
20	13 „ 12 „	10 „ 48 „
Equator		12 hrs.

At the winter solstice the conditions are exactly the reverse. This will be understood sufficiently from Fig. 3 C, and there is no need to go over the argument. The figures given for the maximum length of day are the same as at the summer solstice, but the figures for the northern hemisphere become those for the southern and *vice versa.* Between the equinoxes and the solstices there is a gradual transition, so that from the autumnal equinox to the spring equinox the days are always longer than the nights in the northern hemisphere. The conditions are reversed in the interval between the spring and the autumnal equinoxes.

The causes of the seasons and the significance of the great climatic belts can now be understood. The period of long nights is always the cold season, the period of long days the warm season. The unequal length of day and consequently the annual variation in temperature increase from the equator to the poles. Around the equator lies a belt which receives most heat and where there is least variation in temperature. It is bounded by the parallels for 23½° N. and S., which are termed *tropics.* The polar caps, bounded by the parallels for 66½°, which are called respectively the Arctic and Antarctic Circles, have the longest nights and the most intense cold. The temperate belts extend between the tropical belt and the polar caps.

To understand some of the terms used in the foregoing paragraphs, it must be remembered that the explanation of the varying length of day and night and the causes of the seasons was discovered before the revolution of the Earth round the Sun was known, and that the terminology was invented at a time when the apparent movement of the Sun was thought to be real. The premises supplied by the old theory lead to the same conclusions as do the facts as they are now understood. The old theory was arrived at by observing that the Sun neither rises nor sets in the same place every day, then by marking the position at sunrise and sunset on the celestial sphere, and by concluding from this that the Sun moves round the Earth on a plane, termed the *ecliptic,* which is inclined to the celestial equator at an angle of 23½°. The equinoxes are the points at which this plane cuts the equator; the solstices are the points at which the Sun is farthest from it and at which it checks (*sol stat*) its forward movement. The parallels passing through the solstitial points are the tropics, because they mark the turning point of the Sun's movement. The northern tropic was called the Tropic of Cancer, because when these ideas were first brought to light the solstitial point was observed to lie within the constellation of Cancer; the southern tropic was called the Tropic of Capricorn for a similar reason.

III. THE THREE ELEMENTS

Our globe consists of an envelope of gas, the *atmosphere*; of a solid mass which may be called by analogy the *lithosphere*; and of a liquid film or *hydrosphere*. Geographical phenomena cannot be understood without a knowledge of the physical properties of these three elements and of the effects produced by their contact with each other.

The Atmosphere. The atmosphere is a compound of oxygen and nitrogen with a varying proportion of water vapour, together with several other elements, of which the most important are carbonic acid gas and argon. In dry air—that is, in air from which all water vapour has been removed—the proportions are as follows:—Nitrogen, 78 per cent; oxygen, 21 per cent; argon, 0.94 per cent; carbonic acid gas, 0.03 per cent. A change in these proportions might have incalculable effects on life at the Earth's surface, for the atmosphere acts as a sort of reservoir for retaining solar heat. A greater proportion of carbonic acid gas, for instance, or of water vapour, would lead to a complete change in the climatic system.

The exact height of the atmosphere above the Earth's surface is not known. The density of the air decreases rapidly with altitude, and the summit of Mont Blanc, which is 15,781 feet above sea level, is above two-fifths of the whole atmosphere. The upper layers, however, though very rarified, can still be observed at an altitude of 20 miles.

Water vapour is almost entirely confined to the dense lower layers. Half of it is below 6,500 feet; three-quarters below 13,000 feet. Hence, the whole cycle through which water vapour passes in the atmosphere, with all its various phenomena, such as the formation of clouds, thunderstorms, rain, and snow, occurs in a layer of air whose greatest altitude is between 9,000 and 18,000 feet. Variations in temperature are also most marked in this layer, and, as the great inequalities of the Earth's surface also occur in it, the variable nature of the physical conditions of the atmosphere here will be easily understood.

Distribution of Land and Water. While the atmosphere envelops the whole Earth, the liquid element, being denser and heavier, accumulates at the bottom of depressions in the lithosphere. Hence, the atmosphere is in contact at one time with water and at another with the land. From this fact arise all the differences in climate which do not depend on the position of the Earth in the solar system. Land grows cold and warms up nearly twice as quickly as water. Besides, the latter, as it evaporates, introduces water vapour into the lower layers of the atmosphere and reduces the conductivity of the air. At every step forward in our knowledge of the mechanism of climate, we shall come across the results of the difference in heating and cooling of the land on the one hand and the water on the other. The most accurate calculations of the distribution of land and water in various latitudes have been made by meteorologists. The percentage of water surface in the two hemispheres is as follows :—

Latitude.	*N. Hemisphere.*	*S. Hemisphere.*
0–10	77·46	76·40
10–20	78·77	78·00
20–30	62·51	76·83
30–40	57·72	88·65
40–50	48·93	96·92
50–60	43·61	99·18
60–70	29·80	(85)
70–80	70·70	(27)
80–90	(95)	(0)

This table shows that the land masses are of greatest extent about Lat. 65° N. This is just where the greatest extremes of temperature and the most marked differences in climate occur, and here, too, atmospheric disturbances are most frequent and most irregular. The northern hemisphere has long been known to contain a greater proportion of land (59.6 per cent) than the southern. The discovery of the Antarctic Continent in an area which was formerly assumed to be covered with water has indeed reduced the percentage of water surface known to exist in the southern hemisphere, but it has not brought it below 81 per cent. As early as the beginning of the 17th century, Bacon noticed the tapering of the continents towards the south and their proximity in the north.

The Earth can be divided into hemispheres by another great circle besides the equator, in such a way that nearly all the land masses are grouped into one hemisphere, whilst the other hemisphere consists almost entirely of water surface. The centre of the land hemisphere would lie in Europe somewhere near London.

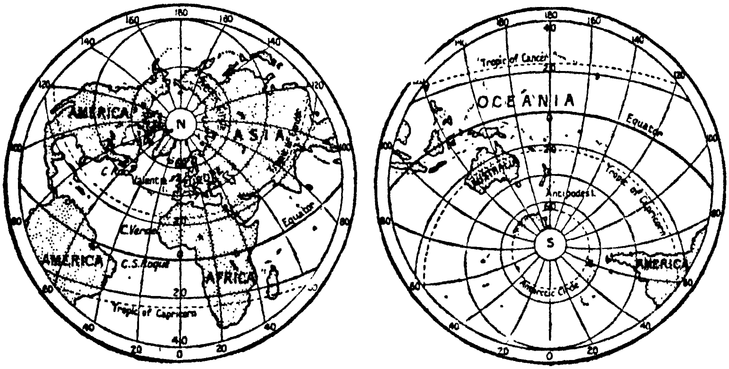

FIG. 4.—Land and water hemispheres.

Certainly it must not be concluded from this fact that Europe is predestined to be the home of civilisation or that London is permanently the centre of that civilisation. But the grouping of land masses in the northern hemisphere and especially in high latitudes is none the less a fact of almost equal importance with the shape of the Earth and is one which has affected the whole course of the history of the human race. At the present day all the great civilised areas are in the northern hemisphere outside the tropics, and are due to the mingling and interbreeding of races. Such intercourse was hardly possible in the southern hemisphere. The settlement of North America would have occurred earlier if the narrowest part of the North Atlantic across which the Norsemen passed to reach Labrador in the 10th century had been situated further south, within reach of the ancient civilisations of southern Europe. The common origin of the primitive tribes that dwell on the fringes of the habitable world in America, Europe, and Asia bears witness to the fact that migration from one continent to the other was easily possible. Throughout the great forest belt of the northern hemisphere the trees are of the same kinds, oaks, pines, firs, and larches ; and the zoologist finds the same species of animals. No such evidence of close intercourse exists in the southern hemisphere.

Relief of the Land and of the Ocean Floor. The unequal distribution of land and water is due to the unevenness of the surface of the lithosphere. Taking the sea level as the basis for comparison, the highest mountain peaks (in the Himalayas) rise to an altitude of 29,000 feet ; whilst the deepest depressions (near the Ladrones Islands in the Pacific) descend to 31,614 feet. The difference is the range of the inequalities of the lithosphere, nearly 11½ miles. However, the inequalities are insignificant as compared with the size of the Earth, the radius of which is 333 times greater ; and their insignificance is all the greater as the ocean deeps as well as the high mountain regions occupy only a very small area. The proportionate areas of the continents and oceans with corresponding altitudes and depths is as follows :—

Altitude or Depth.	*Land Area.*	*Ocean Area.*
Feet.	(Percentages of Total.)	
0—600	24.0	5.6
600—1,500	28.8	3.4
1,500—3,000	18.2	2.4
3,000—6,000	17.6	4.4
6,000—10,000	6.8	11.4
10,000—15,000	2.6	37.4
15,000—20,000	1.8	33.2
Over 20,000	.2	.6
	100.0	100.0

The mean height of the land is about 2,400 feet, and the mean depth of the sea about 12,000 feet. Hence, most of the land surface is comparatively low-lying, whilst in the oceans by far the greater part of the floor lies at a depth of between 10,000 and 20,000 feet. Submarine relief is, however, comparatively uniform, whilst the relief of the land is strikingly varied. The average depth of the Pacific is 12,700 feet; that of the Atlantic 10,800 feet; and that of the Indian Ocean 11,800 feet. In Europe the mean height of the land above sea level is 1,100 feet, and three-fourths of the surface is below 1,600 feet. The mean height of the land in Africa is 2,200 feet above sea level, and one-third of the land surface is between 1,600 and 5,000 feet. The vast continent of Asia has a mean altitude of 3,300 feet, yet 35 per cent. of its surface is below 3,300 feet. A comparison between a cross-section drawn through Asia and one through the best known ocean (see Fig. 5) illustrates still more clearly the fundamental difference between submarine and land relief. The irregularities which are so noticeable in the relief of land surface are due to erosion, which tends to reduce the level of elevated areas; and the uniformity of submarine relief is due to the accumulation of sediment in the depressions.

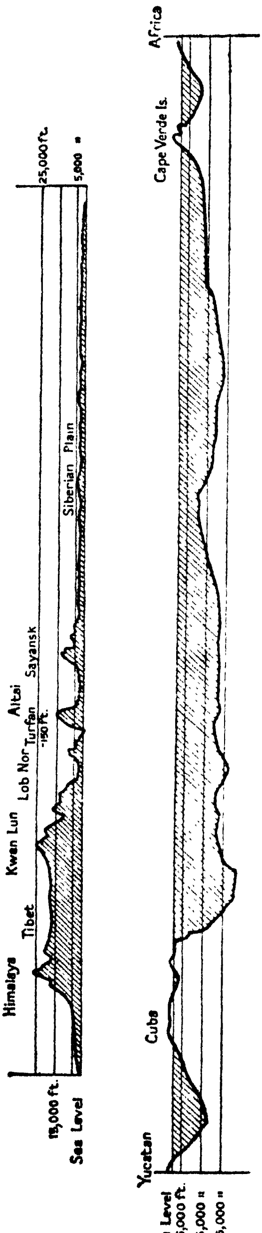

FIG. 5.—Cross-sections of Asia (along the 87° E. Long.) and the North Atlantic (along the Equator), contrasting the height of the land with the depth of the oceans. Vertical scale exaggerated 50 times.

Close examination of a good map reveals another remarkable fact, namely, that far from occupying the centre of the oceans, the great ocean deeps are usually near the coasts and form troughs skirting the foot of lofty coast ranges. De Lapparent has laid great stress on this asymmetry of terrestrial relief, and it is indeed one of the most important features of the inequalities of the lithosphere.

The study of earthquakes has shown that they affect especially those regions where great differences of level occur. This is evidence of the fact that the principal inequalities of the surface of the lithosphere are due to movements in the Earth's crust, which indicate a certain amount of activity in the interior.

Movements of the Earth's Crust. The rigidity of what we call the solid earth is indeed only apparent. *Seismographs,* which are instruments designed to register earthquakes, show frequent tremors even in regions where these phenomena seem to be unknown. In countries of great seismic activity the disasters caused by earthquakes are innumerable. In Japan and Southern Italy not a year passes without violent shocks in one part or other, and every inhabitant of these regions has felt several during the course of his life. The valley of Crati in Calabria has an average of 86 shocks a year. In fact, it may be said that no matter when one visits this district one is certain to experience an earthquake.

Another violent form of activity in the earth's crust is represented by the volcano. Catastrophes like that of Krakatoa, which caused two-thirds of an island of 13 square miles to disappear, and which hurled into the air four cubic miles of *débris,* are imposing displays. But besides these there is the incessant, if less destructive, activity of certain volcanoes which emit gas and give forth dull roars.

The Earth is known to be a source of heat without which all form of life would become impossible at the surface owing to the loss of heat at night. Beyond a certain depth the superficial changes in temperature are no longer felt; but below this the temperature of the crust is observed to increase progressively. The boring of the Simplon Tunnel was greatly hindered by this internal heat, which rose in places to 140° F. The rise in temperature averages 2.75° F. for every 200 feet of descent, though the rate varies with the nature of the rock and the proximity of centres of volcanic activity. The great uplifts and subsidences of the Earth's surface are probably due to the high temperatures of the interior.

Movements of the Hydrosphere. The water which has accumulated in the depressions of the lithosphere is not a source of heat and has no activity of itself; but the fluidity of the liquid element and its sensitiveness to impulses derived either from movements of the atmosphere or from the attraction of heavenly bodies give it a striking semblance of activity. The phenomenon of the tides which raise the surface of the sea some 50 feet and cause the shore line to oscillate over some 12 miles in extreme cases is known to all; and the waves which erode coasts formed of the hardest rock are equally familiar as evidence of the activity of the hydrosphere. Ocean currents, though less known, are more important owing to their geographical effects. The Gulf Stream has a far-reaching influence on the climate of the Atlantic coasts and pushes forward the limit of cultivation in Europe right up to the Arctic Circle.

Contact of the Three Elements. Each of the three elements has its own form of activity and movement. But their contact produces results which cause most of the physical changes on the Earth's surface, and which, therefore, will be fully dealt with from the geographical point of view in this book. The line of contact between the continents and the oceans is marked by a strip of low ground which is continued for some distance under the sea as a shallow coastal margin known as the *continental shelf.* Most of the rapid changes in coastal topography occur here. The cliffs of Normandy, for instance, are being undermined by the sea, and are retreating near Havre at an average rate of 7 inches a year. On the Yorkshire coast of England the annual advance of the sea into the land is as much as 13 feet. In other places the *débris* and sediment brought down by the rivers from the land modifies the sea floor so rapidly that hydrographic surveys have to be constantly revised. Careful study of deltaic growth has brought to light some striking figures. For instance, the Po has wrested 140 square miles from the sea since the 16th century, and the chief mouth of the Mississippi advances 330 feet a year.

The most important changes in the land itself are due to the passage of running water over the surface. The progress of erosion, in spite of its ceaselessness, is often gradual and imperceptible. But it is not always so. The meanders of great rivers are sometimes cut off during floods, and in mountain regions violent spates, land slides, or falls of rock are frequently caused by heavy rains which soak the ground and melt the snow. The summer of 1905 alone saw the following incidents in the French Alps :—July 28 : a destructive flood caused by the Griaz torrent, and the flooding of Modane by the Saint-Antoine on the same day ; August 7 : an avalanche from Mont Velan into the Dranse, which diverted the stream over 1½ miles from its former course ; August 10 : the subsidence of Mont Roche Noire, near St. Jean-de-Maurienne, and a fall of rock from Mont Trois-Chateaux above Pont-en-Royans ; etc.

The movements of the atmosphere may cause rapid changes even on land surfaces. Thus, the wind is responsible for the formation of dunes. The sandhills of Gascony advanced inland at a rate of 30 feet a year, until their further progress was checked by Bremontier. There is little need to recall the part played by the wind in causing waves and hence in coastal erosion.

The reaction of the elements on each other is made more complex by their intermingling in the zone of contact. Thus, the atmosphere is nowhere pure near the ground, but is always more or less laden with dust from the land surface. This dust sometimes gives a red or yellow tinge to the rain. Water which is constantly evaporating from the surface of the sea and damp land areas is the cause of incessant storms and disturbances in the lower levels of the atmosphere. Even outside the coastal margin the sea contains solid matter. The salts which it bears in solution come from the land, as is proved by the high salinity of lakes in dry regions of inland drainage. The atmosphere penetrates to the bottom of the ocean, for organic life would be impossible there but for the presence of a little oxygen. Hence, the complexity of physical conditions on the Earth's surface should be constantly borne in mind by the geographer.

Aim and Branches of Physical Geography. We are now able to understand fully the meaning of the definition given above[1]

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[1] Page 1

of physical geography, and to supplement it by saying that *physical geography is the science which studies the physical phenomena that occur on the Earth's surface and which treats especially of their reaction on each other and of their distribution.* In order to explain these reactions and this distribution, it must use the data of the sciences which study each element by itself; but it keeps its individuality by continually seeking to analyse the complex relations between the elements and to discover the causes of their geographical distribution.

The limits of a treatise on physical geography are naturally determined by the peculiar characteristics of these three elements. The phenomena of the atmosphere are observed, and their processes explained by the meteorologist, while the geographer covers the same ground in relation to its distribution, calling this part of his study *Climatology*. The oceans and river systems, which are studied from the same point of view by the engineer and the oceanographer as well as the meteorologist, also interest the geographer, who gives this branch of his subject the name of *Hydrography*. The analysis of the relief of the land, the representation of which is the work of the topographer and the explanation of which is subordinated to a knowledge of the principles of geology, is the most delicate part of physical geography, and is known as Morphology or *Geomorphology*. Biological geography, or *Biogeography*, of which we shall try to give an outline, studies facts which are still more complex, since it treats of forms of organic life and their distribution. The field of human geography is still greater and even more difficult to understand; but in any case it is certainly impossible to cover the field without having acquired an understanding of the phenomena of physical geography which impose rigid limits on man's activities. If, amidst the historical changes which many a time seem to have brought about a revolution in political and economic conditions, one tries to find what is permanent in the distribution and forms of human activity, success can only be achieved with the aid of the laws of physical and biological geography.

APPENDIX

TO THE INTRODUCTION

I. Suggestions for Further Reading :—

The following papers should be consulted on the definition and method of Geography :—

- P. VIDAL DE LA BLACHE : *Leçon d'ouverture du cours de géographie* (Annales de géographie 1899, p. 97) ; and *Des caractères distinctifs de la géographie*, (ibid., 1913, p. 289).
- EMM. DE MARTONNE : *Le développement et l'avenir de la géographie moderne*, in *Revue de l'Université de Bruxelles*, 1913.
- W. M. DAVIS : *An Inductive Study on the Content of Geography.* (Assoc. of American Geographers, 1905.)

All questions touched upon in this introduction are treated in greater detail in the author's *Traité de géographie physique*, pp. 1–103 (4th edition), pub. Armand Colin, Paris.

II. Practical Exercises :—

A. MOVEMENT OF HEAVENLY BODIES, LATITUDE AND LONGITUDE.

Those who wish to have a really intelligent grasp of the science should lose no opportunity of basing their ideas and theories on the results of personal experiments. To assist in this, some suggestions are given below on certain astronomical questions closely connected with Geography.

Observe the Sun's change of position according to the season ; note the point on the horizon at which it rises and sets every week, and notice that the rising and setting are farther south in winter than in summer ; note also the height of the Sun above the horizon at noon and at other times near midday, by observing the length of your shadow, and compare the length of your shadow at the same hours in summer and winter.

If you travel north or south for any distance, note at the beginning and end of your journey the length of your shadow at noon (the difference is appreciable between London and Edinburgh, Paris and Perpignan, New York and Charleston). If you travel towards the equator, the length will decrease; it will increase if you go towards the pole.

You can calculate the difference in latitude between the two places, so long as you are sure you know the exact moment of noon, when the shadow is shortest at any given place. The difference in latitude is equal to the difference in the height of the Sun above the horizon—or to put it another way, to the difference between the angles formed on your departure and on your arrival by a perfectly horizontal ground and the line joining the top of your head to the end of your shadow. Draw a diagram to verify this.

It is suggested that the experiment should be performed by students in Aberdeen and London, Glasgow and Exeter, Edinburgh and Eastbourne, or Boston and New Orleans, etc., the shadows measured being those of students of the same height or of an upright rod four or five feet long.

Any quick journey westwards or eastwards enables one to verify the difference in longitude by observing the earlier or later rising and setting of the Sun. As the legal time all over France is that of Greenwich Observatory, a student who spends his holidays in the French Alps or in Savoy or on the Riviera and one who stays in England can, if they compare notes on the exact hour of sunset on, say April 15 or July 24, discover an appreciable difference.

Such an experiment could be organised by post, and, although it would not be accurate enough for a practical measurement of longitude, yet it would illustrate the relation between longitude and clock time and give a good idea of the basis of accurate measurement.

B. MAP PROJECTIONS.

The construction of some of the more common projections, e.g., Mercator's, Mollweide's, the orthographic and the stereographic, is recommended. The following table gives the necessary figures. Column 1 gives the distance apart of parallels, or rather their distance from the equator, for Mercator's projection. Column 2 gives for Mollweide's projection the distance of the parallels from the equator proportionate to the radius of the projection, which is taken as 100. Column 3 gives the true length of a degree of latitude at various distances from the equator and is also meant for use in constructing Mollweide's projection. Column 4 gives the radii of concentric circles representing the parallels in the normal orthographic projection, expressed as a percentage of the radius of the Earth.

Latitude.	1	2	3	4
0°	0	0	111·31	100·00
5°	553·5	6·85	110·89	99·62
10°	1,111·4	13·68	109·63	98·48
15°	1,678.0	20·47	107·54	96·59
20°	2,258·2	27·20	104·63	93·97
25°	2,857·4	33·85	100·94	90·631
30°	3,481·8	40·40	96·47	86·603
35°	4,139·0	46·82	91·28	81·914
40°	4,838·0	53·10	85·38	76·603
45°	5,590·7	59·20	78·84	70·711
50°	6,412·9	65·11	71·69	64·279
55°	7,326·1	70·80	63·99	57·358
60°	8,361·8	76·24	55·79	50·0
65°	9,568·6	81·83	47·17	42·262
70°	11,027·3	86·19	38·18	34·202
75°	12,889·6	90·60	28·90	25·882
80°	15,494·9	94·54	10·39	17·365
85°	19,927·1	97·84	9·73	7·716
90°	∞	100·00	0	0

The only instruments necessary are a well sharpened pencil. a flat ruler, a set square, a pair of compasses, and a protractor, In every case the construction begins with the drawing of a horizontal and a vertical axis cutting each other at the centre of the paper.

For Mercator's projection, mark off along the horizontal axis the length of the circumference on the scale chosen; mark off on this line the degrees of longitude and through the divisions draw perpendiculars representing the meridians; divide the vertical axis in the proportions given in column 1 of the table and according to the scale chosen; then draw through the divisions lines parallel to the horizontal axis and of the same length, to represent the parallels of latitude.[1]

For Mollweide's projection, mark off along the horizontal axis the length of the Earth's circumference on the scale adopted and divide it as for Mercator's projection; mark off along the vertical axis a length equal to half that of the Earth's circumference on the same scale; divide this length according to

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[1] *Example:* If the map is to be drawn on a scale of 1 : 100,000,000 and if the graticule is to show parallels and meridians at intervals of 5°, produce the horizontal axis to a length of 200 mm. on each side of the vertical axis; divide the 400 mm. which thus represent the equator into 72 $\left(\frac{360}{5} = 72\right)$ equal parts (400 + 72 = 5.5 mm.); draw parallels through the vertical axis on both sides of the equator at the following distances apart, starting from the equator: 55.5 mm., 111.1 mm., 167.8 mm., 225.8 mm., 285.7 mm., 348.18 mm., etc.

the proportions given in column 2; then draw through the divisions lines parallel to the equator.[1]

Produce these parallels to the lengths given in column 3 (the lengths given are for an interval of 1° between parallels and meridians, and they must, therefore, be multiplied for greater intervals). Join the points of division to obtain curves representing the meridians.[2]

The normal orthographic projection is carried out on the plane of the equator and gives the representation of a hemisphere with the pole as centre. To construct it, mark off on both axes the length of the diameter of the Earth on the chosen scale and divide the radius in the proportions given in column 4; through the points marked off describe circles with the point of intersection of the two axes as centre. These are the parallels of latitude. The meridians are radii and can easily be drawn with the help of a protractor at intervals of 5° or 10°.

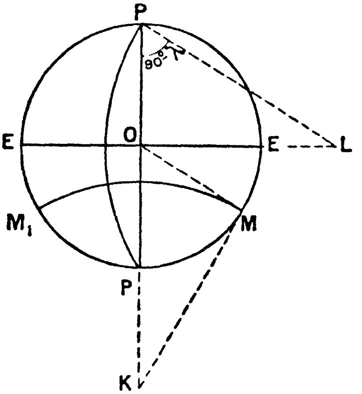

FIG. 6.—Construction of the transversal stereographic projection.

The transversal stereographic projection is used in atlases to represent the globe divided into two hemispheres on the plane of a meridian.

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[1] *Example:* On a scale of 1 : 200,000,000 and with parallels and meridians at intervals of 5°, produce the vertical axis on each side of the horizontal axis to a length of 50 mm.; on it mark off divisions at the following distances, starting from the equator:

$$50 \times .0685 = 3.425 \text{ mm.}$$
$$50 \times .136 = 6.84 \text{ mm., etc.}$$

[2] *Example:* On a scale of 1 : 200,000,000 and with parallels and meridians at intervals of 5°, mark off along the parallel for 5° the following length 36 times:

$$\frac{110.89 \times 5}{200,000,000} = 2.77 \text{ mm}$$

Similarly, along the parallel for 10° mark off lengths of:

$$\frac{109.63 \times 5}{200,000,000} = 2.72 \text{ mm.}$$

And along the parallel for 15° the lengths:

$$\frac{107.54 \times 5}{200,000,000} = 2.67 \text{ mm.}$$

and so on.

The projection is arrived at by a simple graphic construction (see Fig. 6). Produce one of the two axes to the length of the diameter of the Earth on the chosen scale (PP′) and describe a circle with this axis as diameter and the point of intersection of the two axes as centre (O). The meridians are arcs of circles passing through both poles (P and P′), and having their centres on the horizontal axis. The centre of meridian $\lambda°$ of longitude is a point L placed so that $\angle$OPL $= 90° - \lambda$. Hence, for meridian 5° of longitude draw PL with the help of a protractor making $\angle$OPL $= 85°$, and so on. The parallels are arcs of circles having their centres on the vertical axis. The centre of parallel $\varkappa°$ (EM $= \varkappa°$) is the point of intersection of the vertical axis with MK drawn perpendicular to the radius OM. The radius OM can be drawn with the aid of a protractor.

Once the graticule has been drawn, the outlines of continents can be sketched in. This will show the distortions and exaggerations involved by each method.

PART I

CLIMATE

CHAPTER I

TEMPERATURE

Definition of Climate. Climate has been defined as " the sum total of meteorological conditions which constitute the average state of the atmosphere at a given point on the Earth's surface." Three points in this definition should be borne in mind :—

1. " The state of the atmosphere at a given point *on the Earth's surface.*" That is, climatology deals particularly with the belt of contact between the atmosphere on the one hand and the solid land and liquid ocean on the other, and it is this belt which would seem to be essentially the field of geographical observation.

2. " The *average* state of the atmosphere." As climatic conditions are in a constant state of change, climatology is based on the study of averages deduced from observations made over a considerable period.

3. Climate is the *sum total of conditions* which cannot be separated from each other. Temperature, wind, humidity, rain are closely related and give to each region a character which is accurately reflected by the vegetation. The object of climatology is to recognise and bring to light the nature of their complex relations.

To achieve this end, a knowledge of the laws of meteorology is evidently indispensable. We shall try to review the chief principles on which those laws are based by analysing the essential elements of climate, namely, temperature, wind, and rainfall.

The Temperature of Western Europe. An examination of charts showing the distribution of mean temperature in Western Europe (see Figs. 7 and 8) will illustrate by a definite instance the laws which regulate the distribution of heat on the Earth's surface.

The wavy lines traced on these charts are known as *isotherms*, and are drawn through places which have the same mean temperature. The averages shown by them are calculated from observations made over a great number of years. Since temperature falls with height above sea level, all mountainous regions, like the Alps, the Pyrenees, the Central Highlands of France, etc., would appear as isolated areas of cold, if our

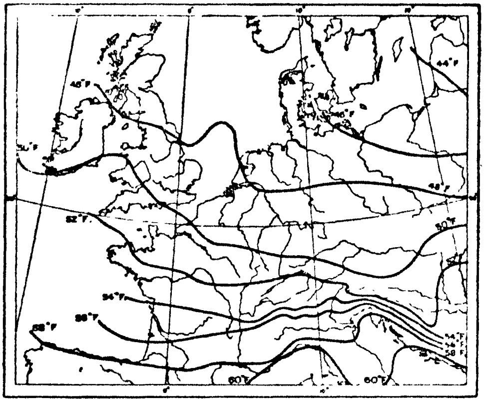

FIG. 7.—Isotherms showing mean annual temperature in Western Europe.

isotherms were not drawn according to temperatures reduced to sea level value. This principle is always applied in the construction of isotherm charts, otherwise the charts would merely be poor reproductions of relief maps.

Let us examine the distribution of mean annual temperature (see Fig. 7). The predominant influence in this case seems to be latitude. Temperature decreases from south to north, as one would expect if one remembers that the Earth is round, and that, consequently, the Sun's rays strike the surface more and more obliquely as one passes further from the equator. But the path followed by the isotherms is far from being the same as that of the parallels of latitude. Irregularities are observed, especially near the coasts (e.g., the north end of the Adriatic and the Gulf of Genoa). This does not surprise us, as we know that land and water do not absorb heat at the same rate (see above, p. 13). In the north we notice a tendency in the isotherms to follow a N.W.—S.E. direction, which shows that the coasts of the Atlantic are warmer than similar latitudes in Germany and Poland. These facts become clearer and more easily understood if we consider the averages for the months of January and July (see Fig. 8), in which we see the extreme conditions of winter and summer.

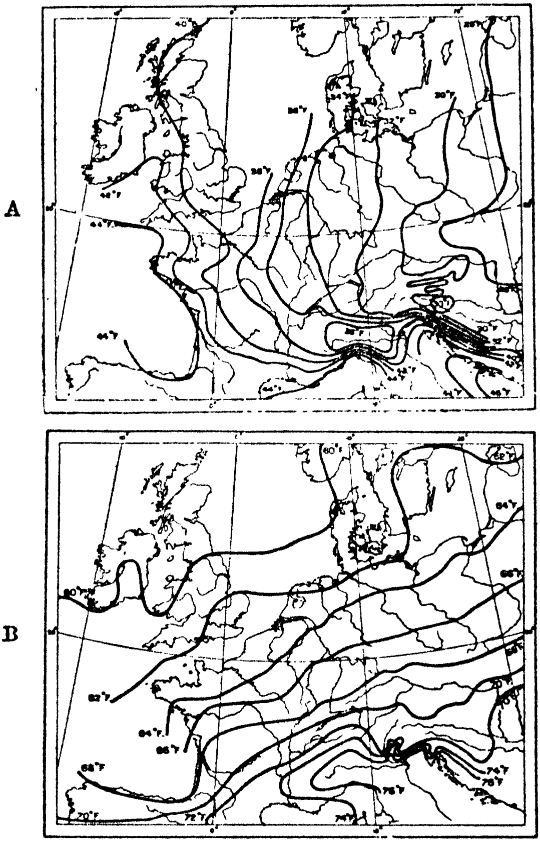

Fig. 8.—Isotherms for Western Europe.
A shows January, B July means.

In July the temperature falls with fair regularity from south to north in this chart also, but the influence of the sea is very marked on the coasts of France and England. Plymouth is 2° F. cooler than London, Finistère 5.4° F. cooler than the district round Paris, and similar differences are noticed between Bordeaux and Lyon, Dunkirk and Cologne, Fort William and Aberdeen. In January, on the other hand, the interior is colder than the coast. Plymouth is 3° F. warmer than London, while Brest is 6.2° F. warmer than Paris. The contrast is so marked that the distribution of temperature seems to be completely free from the influence of latitude. The isotherms show a general N.—S. direction, and in their minor curves follow the contours of the land. We find the same temperature at Brest, Perpignan, Genoa, Trieste, Avignon, Rennes, and Liverpool.

The explanation of these figures lies wholly in the fact that the oceans are warmed more slowly than the land and conversely that the sea loses its heat more slowly than the land. The seasons are behind time on the sea; hence, the coasts are warmer in winter and cooler in summer.[1] The wind system accentuates the contrasts in western Europe, since the prevailing winds there, as will be seen later, blow from the west. As these winds are most frequent in winter, the influence of the sea reaches its greatest extent at that season.

Another interesting anomaly deserves notice. The valley of the Po is noticeably colder than the surrounding regions in winter. On the slope of the eastern Alps, the isotherm for 30° F. shows irregularities which indicate phenomena like those which occur also in the valleys of the Mur and the Drava. On the other hand, the valley of the Po is warmer in summer than the surrounding regions, and this peculiarity extends to the lower valley of the Adige. Relief of surface has, therefore, an influence on temperature, even when all observations are uniformly reduced to sea level value. Depressions are colder in winter, warmer in summer—in other words they are more continental in climate —than open plains. The explanation is that they are sheltered by the surrounding heights from winds off the sea. The air is to a certain extent isolated in the depression and grows warm and cold alternately through contact with the surface.

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[1] An apparent exception should be noted: the Mediterranean coasts are warmer than the interior at every season. The explanation is that the Mediterranean is not a great ocean, but only an inland sea partly surrounded by deserts, and that its waters are exceptionally warm (cp. Part II, Chap. VII).

The following laws emerge from what has been said above :—

1. Temperature decreases, generally speaking, from the equator to the poles.

2. Maritime regions are warmer in winter and cooler in summer than continental regions.

3. Depressions surrounded by mountains are continental in character.

It will be interesting to see if we can apply these laws to the Earth as a whole.

General Causes of the Distribution of Temperature : Mean Annual Temperature. The annual isotherms clearly show the influence of latitude (see Fig. 9). Various peculiarities are noticed, however : the regions of greatest heat are not at the equator, but slightly to the north of it, on the extensive land masses of the northern hemisphere. In this area is to be found a confirmation of the second law stated above.

Closer examination of the isotherms shows that at times they follow the coast lines (e.g., in Africa and South America) and that they always change their direction as they pass from the land on to the sea, turning in high latitudes towards the pole and in low latitudes towards the equator. The best illustrations of this are the isotherms for 40° and 80° in the northern hemisphere and 70° in the southern. Thus, the sea not only lessens the annual variation in temperature at a given place, but also tends to remove differences between one place and another. In the Atlantic the temperature falls only 45° from the equator to the Arctic Circle ; while in Asia there is a fall of more than 70° over the same latitudes.

It should be noted, however, that the influence of the sea in this respect is not felt everywhere to the same extent. It is most marked on the west coasts of continents. Thus, Aberdeen is 27° warmer than Nain in Labrador, and the temperature is 7.2° lower at the mouth of the Congo than at Cape San Rocas in Brazil. The system of prevailing winds and ocean currents is the cause of this peculiarity. The Westerlies which prevail in high latitudes carry the influence of the sea over the western coasts of the continents, but not over their eastern coasts. It will be seen later that the surface of the oceans is

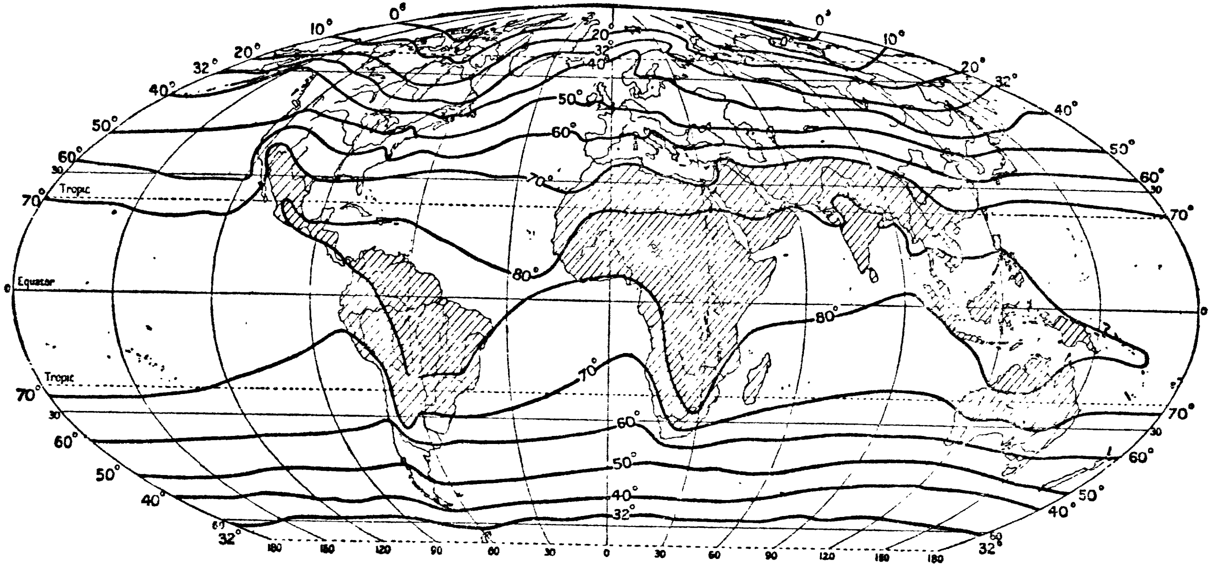

FIG. 9.—Mean annual isotherms. (After Hann.)

stirred by a circulation of the water, which gives rise to a cycle of currents in each hemisphere. From this results a flow of warm equatorial waters towards the western coasts of continents in high latitudes, whilst cold streams flow along the same coasts in the tropics. The Gulf Stream and the Canaries Current are the best known examples of this.

Distribution of Mean Temperature in January and July. Let us now examine the maps (Figs. 10 and 11) showing the distribution of temperature in the two extreme months. To understand them one must remember that the seasons occur at opposite times in the two hemispheres ; that January is the midsummer month in the southern hemisphere and July the midwinter.

The line (known as the *thermal equator*) which passes through places with the highest mean temperature oscillates with the seasons through 50° of latitude. Theoretically, it should not go beyond the tropics. But the presence of vast land masses in the northern hemisphere makes its influence felt. Mean temperatures of 90° F. are found on the continents only. They are observed particularly in desert regions, i.e., the Sahara, Arabia, Turkestan, Central Asia, Mexico, and California in the northern hemisphere ; and the Kalahari and Australia in the southern. In this fact is seen a clear indication of the relation between temperature and vegetation. The bare soil of the deserts is parched by the heat of the sun, the effects of insolation being increased by the fact that the extremely dry air allows the sun's rays to pass through it without much loss of heat. The burning sands, over which a temperature of more than 140° F. has been observed in the Sahara, are proof enough of the heat received.

The coldest, as well as the hottest, regions are found on the continents, and especially in the northern hemisphere. The *cold pole* lies at Verkhoyansk in Siberia. There extreme cold is favoured by the dryness and calmness of the air, which factors also cause low temperatures to be less noticeable. When the sky is clear and the sun pale, even though it is unobscured by clouds, man can exist in temperatures which freeze water as it is in the act of being poured out, which crack the soil, and which enable glass window-panes to be replaced by slabs of ice.

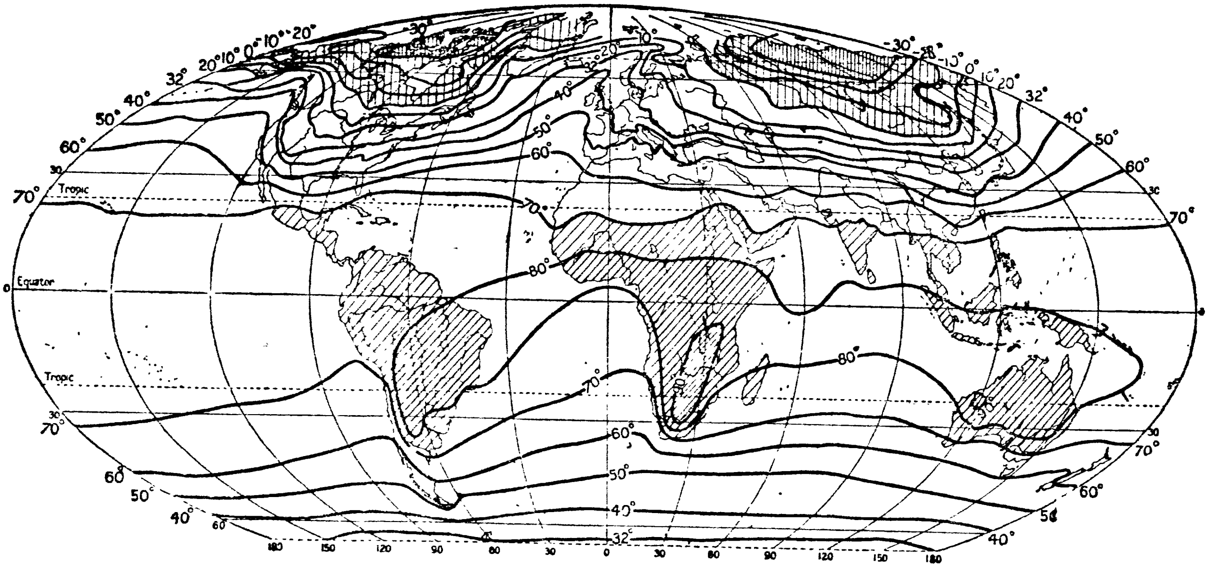

Fig. 10.—Mean isotherms for January. (After Hann.)

The moderating influence of the sea is still more evident than in the map showing mean annual temperature. The bends in the isotherms are explained in the same way, and it is not surprising that they should be particularly striking in the northern hemisphere in January, when the isotherm for 32° F. bends northwards through 30° of latitude. The contrast between the western and eastern coasts of continents is seen once again, but in an exaggerated form; the latter being less affected by the influence of the sea, the former enjoying a remarkable uniformity of climate. From Cape Verde to the North Cape, the temperature does not fall more than 36° F. in winter, whilst in America one need go no farther than from Florida to New York to find the same amount of difference. Perhaps these conditions give a certain advantage to the modern peoples of the New World. The zones of vegetation are packed closely together on the Atlantic coast of the United States; the most varied products are ranged together at short intervals; the cotton of Carolina and the bananas of Florida are within easy reach of the inhabitants of New England, where the climate and crops are the same as in Scotland.

It is evident, therefore, that the principal factor in the distribution of temperature is the difference between the continents and the oceans. The land hemisphere is the richest in contrasts, the hottest and the coldest. The Old World, being of greater extent than the New, offers examples of more marked extremes. Finally, the largest continent, Asia, shows the greatest annual range: in July nearly three-quarters of its surface has a temperature of over 68° F., whilst in January one-third has a temperature of below 50° F. We shall see that this great change of temperature according to season has incalculable effects on the system of winds and rainfall, as well as on vegetation and human life.

Belts of Temperature. The annual range and the duration of high or low temperatures are the elements of what is called the *thermal system* of a given place. From the maps just discussed it may be concluded that the range depends on latitude, on the distribution of land and water, on the surface relief, and lastly on the vegetation. It has been seen that the

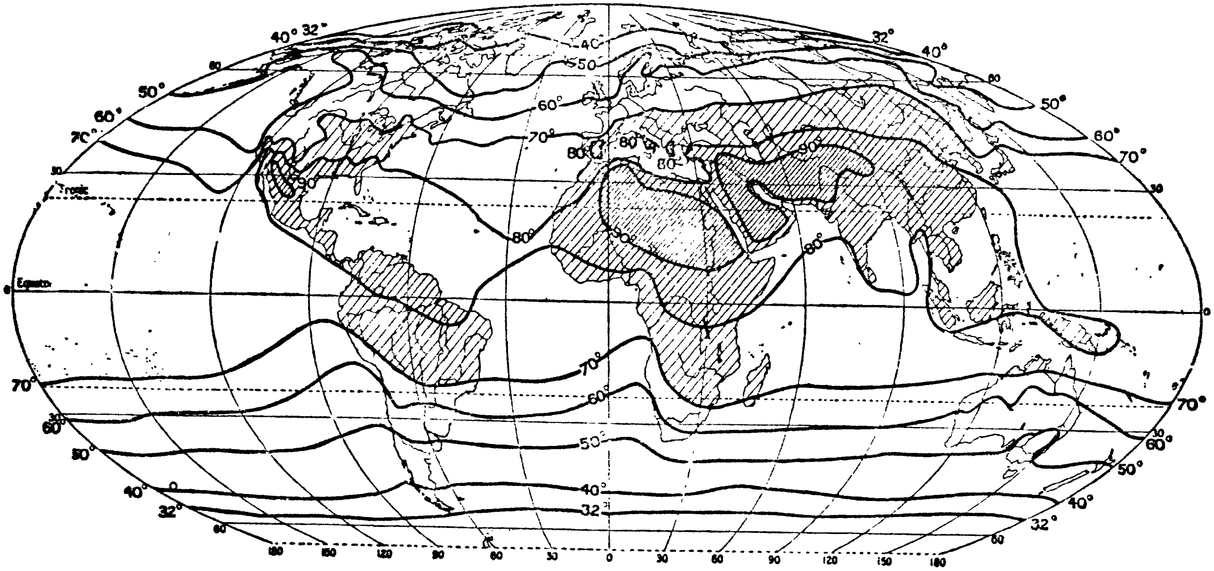

FIG. 11.—Mean isotherms for July. (After Hann.)

range increases from the equator to the poles, that it is great on the continents, in depressions, and in deserts. It is also more marked on eastern than on western coasts of continents in the same latitude, since the eastern coasts are less influenced by the sea. Thus, the range is 54.9° F. at Nain in Labrador and 20.5° F. at Aberdeen.

On his observation of the duration of temperatures, Köppen divided the Earth's surface into belts, which clearly express the thermal characteristics of the climate in each :—

1. *The tropical belt,* characterised by the almost complete absence of variation, no month having a lower temperature than 68° F.
2. *The sub-tropical belt,* in which the mean temperature is lower than 68° during a period of from one to eight months; the maximum is higher than in the tropical belt; the range varies between 12.6° and 32.4° F., increasing with latitude and distance from the sea.
3. *The temperate belt,* in which for eight months or less the temperature is below 68° F. There is a winter season, which is more or less marked according to latitude and to continental or maritime position; spring and autumn are clearly marked, especially in coast regions, where, moreover, winter and summer are late or of shorter duration.
4. *The cold belt,* in which there is no real summer and where only four months have a temperature of over 50° F.
5. *The polar belt,* in which the temperature is below 50° F. throughout the year.

The last two zones are found on mountains even near the equator, as well as in high latitudes.

Köppen's Belts are of great geographical importance. Botanists agree that they coincide with the main divisions of the vegetable kingdom, while ethnographers notice that certain races seem to be restricted to certain definite belts of climate, and that even civilised races are not independent of these zones. The European, for instance, cannot settle permanently in the tropical belt, as his system is weakened by the climate. The cause of this would seem to be the absence of a cold season.

The most densely peopled regions in the world lie chiefly within the temperate belt. Civilisation and economic power, though they had their beginning in the subtropical belt, are tending more and more to become centred in temperate regions ; and, furthermore, after having long flourished in the subdivision of the temperate belt which has mild winters (Mediterranean civilisations), they seem to be concentrating in the subdivision of the zone which has pronounced winters.

CHAPTER II

WIND

WIND is an essential element of climate. From earliest times names have been given to local winds whose violence or whose effect on temperature, rainfall, and vegetation strike the imagination. Such are the Etesian Winds, the Sirocco, the Bora, the Simoon, the Mistral, the Tramontano, and the Föhn. It is, however, less than a century since the causes of wind have been known, and its relations with the changes in atmospheric pressure clearly defined.[1] A glance at the distribution of pressure and movement of air during the two months of extremes, January and July (see Figs. 12 and 13), shows the most significant facts in respect of their relation to each other.

Distribution of Pressure and Wind. Figs. 12 and 13 show the distribution of pressure by means of lines known as *isobars*, which join places of equal mean pressure. Like the figures expressing temperature and for the same reason, pressure readings are reduced to sea-level. The mean direction of the wind is indicated by arrows.

Great changes take place between winter and summer, but one feature remains constant, viz., a belt of low pressure at the equator corresponding to the belt of high temperature mentioned in the previous chapter. On both sides of this low pressure region the wind is observed to blow from the N.E. in the northern hemisphere and from the S.E. in the southern hemisphere. These regular winds have long been known as

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[1] As a result of his study of the storms of 1850–1860, Le Verrier was the first to show clearly the possibility of forecasting weather by observing the centres of low pressure. The law defining the relation between wind and atmospheric pressure was first formulated by the Dutchman Buys Ballot in 1860. Buchan, an English physicist, conceived the notion of *gradient* in 1865.

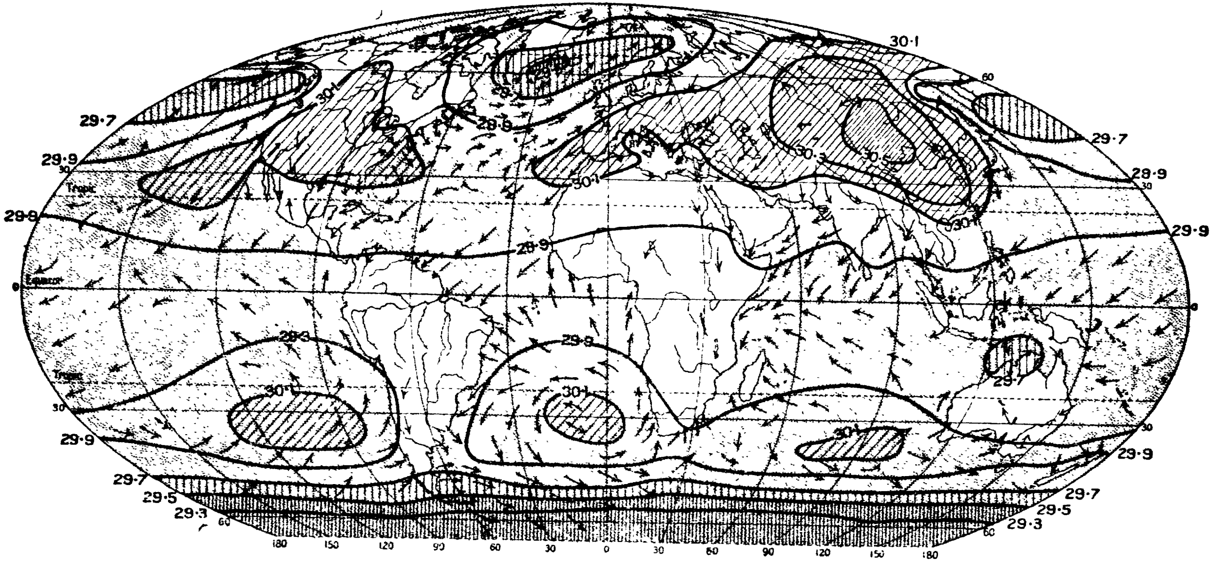

Fig. 12.—Isobars and winds for January. (After Hann and the oceanographical atlas of the *Deutsche Seewarte.*)

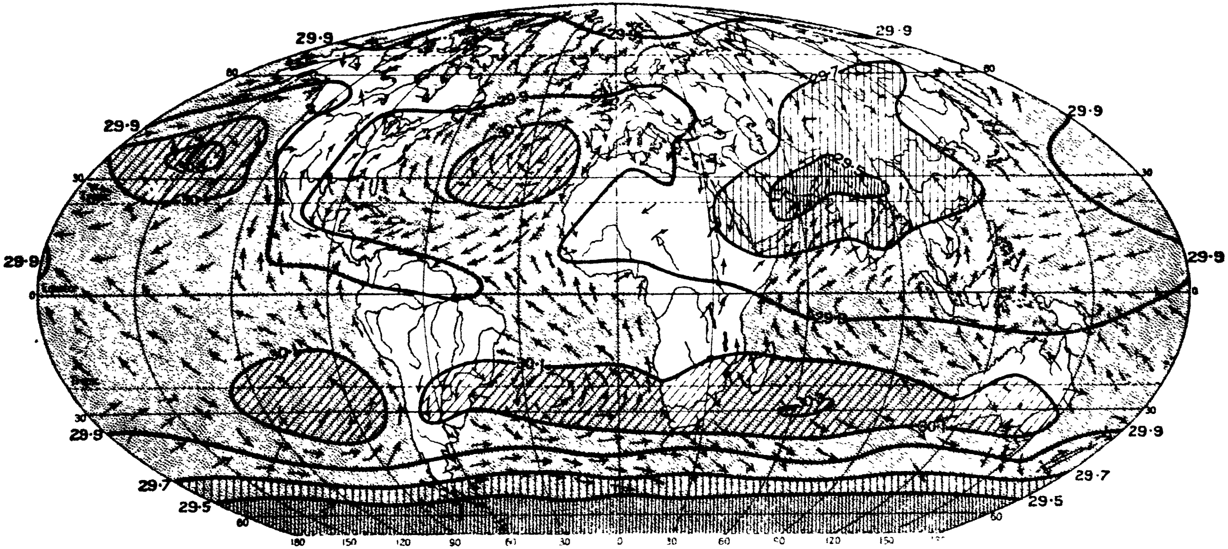

FIG. 13.—Isobars and winds for July. (From the same sources as Fig 12.

the *Trade Winds*. Their explanation was the first problem to be approached by oceanography and meteorology. It is evident that they are caused by the low pressure area at the equator, where the calms, so well known to sailors and so feared by them before the introduction of steamships, occur. The equatorial areas of low pressure have been explained by Hadley as due to the rising of the air, owing to its expansion by the great heat of the region; the Trade Winds flow in to occupy the space vacated by the rising air.

Beyond the Trade Wind belts are found areas of high pressure, then areas of low pressure which extend to the Arctic and Antarctic Circles. The arrangements of these areas in belts is far more irregular in the northern hemisphere than in the southern, which is mainly occupied by the sea. This simple statement indicates that the distribution of land and sea has great influence on the system of atmospheric circulation. A comparison of charts showing isobars with those showing isotherms furnishes quite a simple explanation:—The area of high pressure which covers Asia in winter corresponds to the region of extreme cold which has already been mentioned; the low pressure area observed to the south of that continent in summer extends over one of the hottest regions in the world under the present distribution of temperature. The area of low pressure in the north of the Atlantic coincides with the poleward bend of the isotherms; the low pressure is more intense in winter when the isotherms are most irregular. These facts seem, therefore, to confirm the theory that low pressures are due to overheating and high pressures to cooling. In any case it seems that low pressure areas draw the winds towards them from all sides, whilst high pressures send the air outwards in all directions.

But it is noticed that, whether in moving towards a centre of low pressure or away from a centre of high pressure, the course of the wind is deflected. Hence there result circular systems of winds which are centripetal or centrifugal according as the centre is one of low or high pressure. Whenever the arrangement of pressure changes, the winds change also. Hence, the system of winds is far more irregular in the northern than in the southern hemisphere.

To sum up, it seems clear that wind is caused by differences in atmospheric pressure and blows with a more or less marked deflection from areas of high to areas of low pressure. It is found, moreover, that pressure is often highest in abnormally cold regions and lowest in abnormally hot areas. But one important fact remains unexplained, namely, the existence of high pressure areas in middle latitudes forming an almost continuous belt in the southern hemisphere. One would naturally expect to find that pressure increases regularly from the equator to the poles. In order to understand fully the actual facts of atmospheric circulation, one must appeal to the teaching of physics.

Theory of Wind. Meteorologists give the name *cyclone* or *cyclonic area* to regions of low pressure or barometric minima, and the name *anticyclone* or *anticyclonic areas* to centres of high pressure or barometric maxima. The force and direction of the wind depend on the shape of the isobars and the interval between them. The *gradient* expresses the force which acts perpendicularly to the isobars and which draws the air towards cyclonic centres and expels it from anticyclonic centres. But the direction of the wind never corresponds with the gradient. The Trade Winds furnish sufficient proof that there is a deflection to the right in the northern hemisphere and to the left in the southern, right and left being understood in the same sense as when applied to the banks of a river.

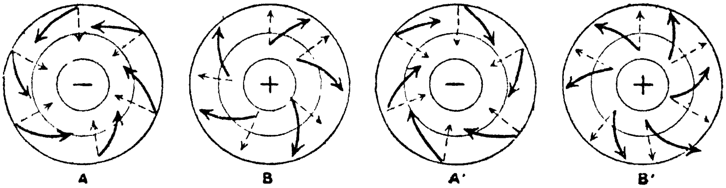

FIG. 14.—Cyclonic (A, A') and anti-cyclonic (B and B') systems. A and B are in the northern hemisphere, A' and B' in the southern.

The result is a circular movement which is centripetal in cyclones and centrifugal in anticyclones. The circular movement is in opposite directions in the two hemispheres, as is shown in Fig. 14. They are called cyclonic and anticyclonic systems. Clearly, the observer with his back to the wind always has the low pressure centre on his left in the northern hemisphere and on his right in the southern[1]—a fact of great importance to sailors.

The deflection is due to the rotation of the Earth. It does not depend upon the direction of the gradient, but is proportionate to the speed of the wind and to latitude. It has been shown that all movements on the surface of the Earth are similarly affected.[2]

One point, the cause of deflection, has now been cleared up. It remains to explain the relation between abnormal distribution of temperature, differences of pressure, and wind. Let us imagine that we could separate by a partition two columns of air, one of which is warmer than the other. As the warmer air will expand, the same pressure will be found everywhere at a greater height on the warmer side than on the cooler (see Fig. 15A). If the partition is removed, the actual conditions of the atmosphere are obtained (see Fig. 15B). As the pressure extends higher up in the upper layers of air on the warmer side, the air there tends to flow towards the cooler area. The isobaric planes are inclined in the direction of this movement, which continues as long as there is a difference of temperature. Hence, the air is accumulated in the cooler area, where it is forced into a descending movement. Meanwhile, as it is constantly escaping from the warmer area, it imparts to this area an ascending movement. Consequently, the lower part of the warmer column will soon tend to become empty, whilst the accumulation of air in the cooler column will cause

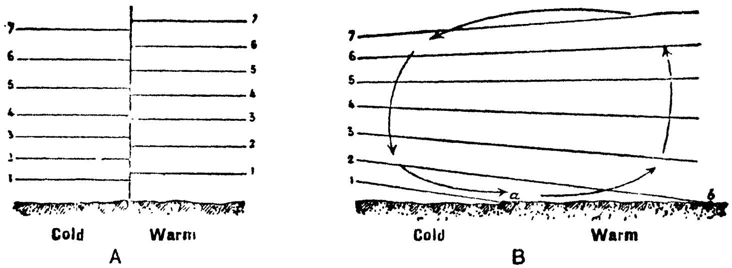

FIG. 15.—Theory of convection currents as a cause of wind.
1, 2, 3, 4, etc., are sections of isobaric planes, i.e., planes on which the pressure is everywhere the same.

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[1] This is known as Buys Ballot's law. Tr.

[2] Ferrel's law is that "every moving body on the Earth's surface tends to be deflected to the right in the northern hemisphere and to the left in the southern." Tr.

the lower layers here to become denser. The isobaric planes will therefore be inclined in opposite directions in the upper and lower layers of air in the two columns, and a movement of the air from the cooler column to the warmer will soon begin at the bottom of the columns. The meteorological facts thus analysed show what actually takes place in the lower regions of the atmosphere where the air is in contact with the Earth's surface. Hence it is that areas of low pressure correspond to regions of high temperature and wind flows into such regions, whilst high pressures correspond to cold regions whence the air moves outwards.

The fact that the upper layers of the atmosphere move in the opposite direction to the lower layers has been established by experiment. The Trade Winds, which are explained by the theory of convection currents, are felt only to a height of about 6,500 feet. Above that a movement of the air towards the N.E. has been observed, and this meteorologists call the *counter-trade wind.* This observation was made long ago at the summits in the equatorial belt, especially on the Peak of Tenerife (11,057 feet). The ashes ejected in volcanic eruptions in the West Indies have always been carried N.E. From St. Vincent the ashes were carried in 1812 and 1902 to Barbados; from Coseguina in Nicaragua to Jamaica in 1835. Observations made recently near the Azores by means of kites fitted with self-recording instruments have produced results which agree with the foregoing. The same conclusions have been reached in the temperate regions by means of balloon ascents and kites flown regularly from various observatories.

Regarded as a whole, the typical cyclonic movement may be pictured as a whirlwind in which the air ascends spirally and into which the air flows at the base and escapes at the top; while in the anticyclonic movement the air moves spirally downwards in the swirl, entering at the top and escaping at the base.

It is now possible to understand the main outlines of atmospheric circulation. The impulse is given by the intense heat of the equatorial belt, which causes an ascending movement of air. In the upper regions of the atmosphere the currents which have risen tend to flow towards the poles (counter-trade wind). But this movement is affected by the rotation of the Earth, which causes the flow of air to be deflected to the right in the northern hemisphere and to the left in the southern. Since the deflection increases with latitude, the counter-trade wind cannot pass beyond middle latitudes. Hence, the air accumulates at this point, and the mere accumulation thus formed up to a great height is sufficient to cause very high pressure at sea-level. Moreover, high latitude regions are for the same reason understocked with air; in other words, the atmosphere will be less dense in these places. Consequently, the pressure at ground level is far lower than it is round the tropics of Cancer and Capricorn.

Wind Systems. We can now hope to understand the principal types of wind systems, and we shall proceed to examine these systems in equatorial regions, in middle and in high latitudes, and in monsoon areas.

The area controlled by the equatorial system comprises the belt of low pressure round the equator together with the zone of the Trade Winds. As there is little variation in temperature in these regions, pressure also varies but slightly, and the wind system is very regular. The belt of maximum temperature moves north and south, according as the midday Sun is at its zenith N. of the equator (May to September) or S. of the equator (October to April). The belt of equatorial calms follows this movement. There is consequently a belt of 10° or 12° of latitude wide in which the direction of the Trade Winds is reversed according to the season. This is the only variation in the equatorial system.

Between latitudes 30° and 70° the wind system is far less regular. The data given on maps should be regarded merely as averages, which are very different from the extremes which are sometimes observed. The positions of cyclones are especially variable; they move on from day to day. The changes in weather which are notoriously frequent on the west coast of Europe are connected with these disturbances. The irregularity and instability of the systems are all the greater when the surface is divided between land and water, since the unequal rate of heating and cooling of these elements favours the formation of local maxima and minima of temperature. In the southern hemisphere the belt of high pressure is almost continuous in winter (July), and in summer (January) resolves itself into several oceanic anticyclones from which originate the cold winds that dry up and cool the coasts of Chile, Australia, and Africa.

In the northern hemisphere the areas of maximum and minimum pressure exist as centres of high or low pressure at every season, and never form continuous belts. In winter (January) the oceans between 45° and 65° of latitude are regions of extreme low pressure (the centres are Iceland and the Aleutian Isles), which coincide with regions of abnormally high temperature. The cyclonic movement causes a system of winds from the west, south-west, or north-west. The continents are, on the other hand, regions of maximum pressure (Siberia, North America), coinciding with regions of abnormally low temperatures. The oceanic centres of high pressure about the tropic of Cancer (i.e., at the Azores and California) diminish and retreat south, since the excessive heat of the continents in these latitudes is less marked than in summer. This withdrawal allows the west wind system to prevail farther south in winter than in summer.

In summer (July) the differences in temperature between land and sea decrease from latitudes 45° northwards, but increase towards the tropics. Hence, the anticyclones of Siberia and America disappear and the oceanic cyclones in high latitudes almost pass out of existence, whilst the high pressure centres round the Azores and off California spread out towards the north. Between latitudes 40° and 60° they give rise to winds from the west and south-west.

Only by keeping in mind these data can one hope to understand the mechanism of climate in the temperate zone and the changes of weather shown by the daily weather charts published in France by the Office National Météorologique, in England by the Meteorological Department of the Air Ministry, and in the United States by the Weather Bureau in Washington. The rise and fall of temperature, rain, sunshine, and fog depend on the direction of the wind, which is itself determined by the temporary location of cyclones and anticyclones. These centres of low and high pressure have, therefore, been aptly termed by Teisserenc de Bort "the main centres of atmospheric activity."

Cold winters in Western Europe are always due to the extension of the Siberian anticyclone. On the other hand, the contraction of this high pressure area allows the southward spread of the Icelandic centre of low pressure and the inflow of west winds, which raise the temperature and bring rain.[1]

The Monsoon System. Monsoons are seasonal winds which blow alternately from the land to the sea and *vice versa.* In summer the great land masses undergo a marked rise in temperature, and consequently cyclonic centres are formed on them, sucking in the air from over the sea. In winter they are colder than the adjacent oceans and anticyclones are formed in them, giving rise to land winds that blow outwards in all directions. The monsoon wind which blows from the sea tends to lower the temperature; it is damp and rain-bearing. The monsoon wind which originates on the land is, on the other hand, essentially dry and sometimes very warm. The most favourable conditions for monsoons are found in the belt where pressure is most steady; hence their predominance in the equatorial zone.

The coasts of the most extensive continent (i.e., Asia) and of the ocean which is the most closely surrounded by warm lands (i.e.. the Indian Ocean) are the principal monsoon areas. In winter the centre of high pressure in Siberia causes the monsoon, which rises as far north as 35° N. and reinforces the N.E. Trades. The centre of low pressure which occupies southern Asia in July is the cause of the summer monsoon, which seems to carry the S.E. Trades into the northern hemisphere and brings the eagerly expected rains on the coasts of Africa, Arabia, India and Indo-China. It is during the change in the monsoons that the typhoons which ravage the shores of the Indian Ocean and of the China Seas spring up.

[1] See Appendix at the end of this Part, p. 84.

CHAPTER III

RAINFALL

Rainfall in Western Europe. Let us begin the subject of rainfall by examining a particular case. The map given in Fig. 16 shows the distribution of rainfall in Western Europe by means of curved lines and of shading, which is darkened in proportion to the depth of the sheet of water that would remain on the surface of the ground at the end of a year, if the rain stayed where it fell without percolating into the ground or being evaporated. The results shown are the mean totals for a year, and are arrived at by adding together the amounts of rainfall recorded by daily observation.

It is seen at a glance that the object here has not been, as it is in the charts showing isotherms and isobars, to reduce the observations to sea-level value. The influence of surface relief is especially striking, and, to understand a chart showing rainfall, one must place it side by side with a relief map in a good atlas. Clearly, rainfall increases with altitude. All the highlands—the Alps, the Pyrenees, Central Highlands of France, the Apennines, the Highlands of Scotland—have an abundant rainfall. Great height is not necessary to cause precipitation ; the hills of Brittany and Normandy receive twice as much rain as the neighbourhood of Paris ; the hills of Devonshire twice as much as the London district. The Argonne, the Plateau de Langres and Morvan are also comparatively rainy, and so are the Harz Mountains and the Thuringerwald in Germany.

Lowland is always relatively dry, and it is the more so the more closely it is surrounded by heights, which, by attracting much rain themselves, seem to protect the lowland. The plain of Alsace, the plain of the Saône, the basins of the Forez and Limagne in the Central Highlands are striking examples. Even in the Alps there are relatively dry valleys, like those of the Inn and the Durance. Lowlands, though open on one side, may be sheltered from heavy rains, provided they are protected

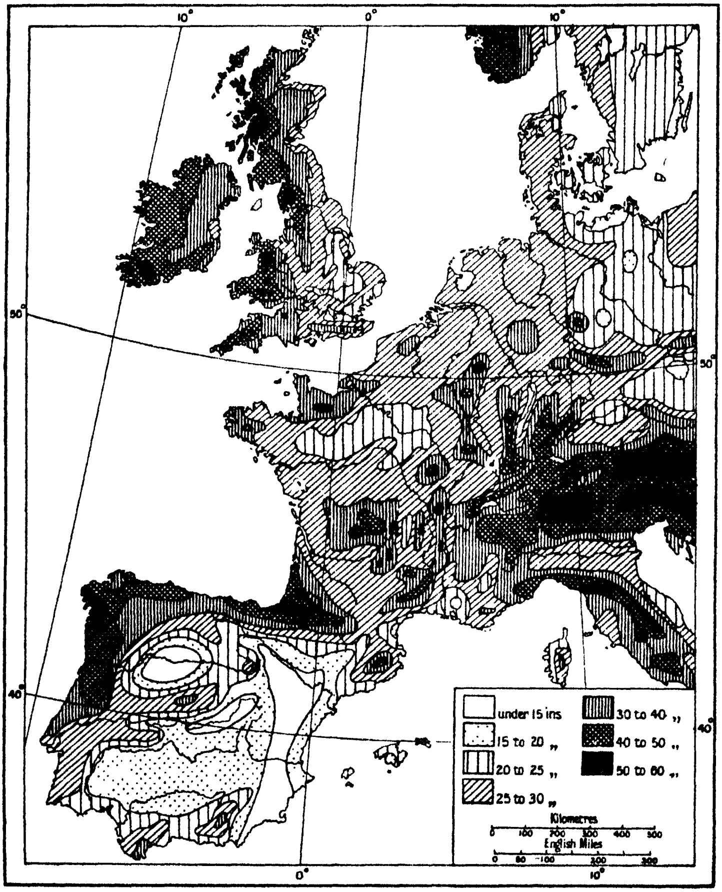

FIG. 16.—Mean annual rainfall in Western Europe. (After Angot.)

on the west by highlands; e.g., the Midland plain of England, the basin of the Ebro and upper Castile in Spain, Southern Languedoc and Provence in France, and the plain of Lombardy in Italy. It is to be presumed, therefore, that it is the Westerlies which bring rain to Western Europe.

This conclusion is confirmed by an examination of the Atlantic shores, which are always found to have a greater rainfall than the interior, even if their relief is insignificant, as is the case in the Landes of Gascony. It seems then that there is some connexion between rainfall and the distribution of land and sea. Apart from regions of very marked relief, rainfall decreases from west to east (the British Isles, Holland, Sweden, North Germany). In Spain and in the British Isles the contrast is striking between the west and east coasts.

The connexion of rainfall with relief and nearness to the sea will cause no surprise to anyone who has seen clouds collect round mountain tops and has noticed how when the wind changes to the west, it almost always brings rain. It is natural for such an observer to conclude that the surface of the ocean is the origin of the vapour which falls as rain and that the mountains, by stopping the clouds as they move eastwards, bring down heavy falls of rain on their slopes. But before trying to understand more exactly the mechanism of this phenomenon, let us see if an examination of the distribution of rainfall over the whole surface of the Earth confirms the relations observed in Western Europe and reveals others.

World Distribution of Rainfall. The influence of relief, which seems predominant in a limited area, is still noticeable when the Earth is examined as a whole; but other and more important factors appear. The Himalayas, the ranges of Alaska, the Australian Alps, the Andes of Southern Chile and Patagonia have a plentiful rainfall; but the plains of the Amazon basin have four or five times as much rain as the summit of the Andes in Peru and Bolivia, though the latter rise to a height of more than 13,000 feet. Again, the valley of the lower Mississipi and Eastern China are much damper than the mountain ranges of California and Iran.

The most marked general feature of the distribution of rainfall on the Earth's surface is the existence of a belt of great humidity at the equator. The most extensive areas of heavy rainfall occur in low latitudes. As a general rule, precipitation seems to decrease from the equator to the poles. But on the more extensive land masses there appear belts of minimum rainfall

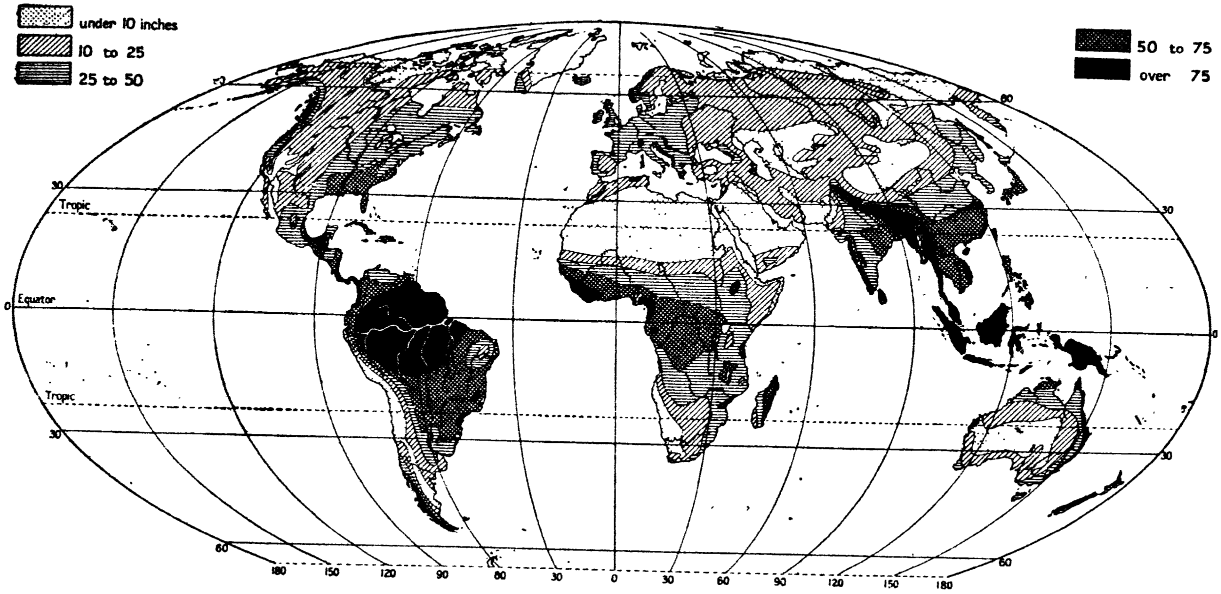

FIG. 17.—Distribution of mean annual rainfall on the land surfaces. (After Supan.)

at the tropics (e.g., Sahara, Arabia, Turkestan), and traces of the same phenomenon are found in the narrower continental areas of the southern hemisphere (Kalahari, Australia, Chile, Argentine). From these facts it may be concluded that rainfall is directly connected with temperature. Its decrease in high latitudes corresponds with the decrease in evaporation, which itself depends on the amount of heat, and with the decrease in the proportion of water vapour in the lower layers of the atmosphere.

But the connexion between the distribution of rainfall and the distribution of pressure is even closer. A comparison between the chart showing rainfall and that showing isobars (see Figs. 12 and 13) indicates that the heavy equatorial rains coincide with the belt over which swings the zone of equatorial calms, and that, apart from mountainous regions, rainfall maxima are found in or near areas either of constant low pressure, as in Iceland and Alaska, or of periodic low pressure, like that in Southern Asia, which gives rise to the summer monsoon. Precipitation is particularly abundant when the winds caused by cyclonic depressions approach the land, as in Ireland, Scotland, Norway, Alaska and British Columbia, the Western Ghats, Annam, China, and Japan, especially when they strike against a region of high relief, like the Himalayas. Thus the connexion of rainfall with relief, direction of wind, and distribution of land and water is confirmed; but the connexion with barometric pressure seems to be even more important. Rain appears to be caused by the ascending movement of air caused in cyclonic areas. To understand the reason one must have recourse to the meteorological theories which explain the cycle of water in the atmosphere.

Theory of Precipitation. The liquid element does indeed pass through a regular cycle. Evaporated from the surface of the sea or moist earth, water remains suspended in the air in the form of vapour till it condenses into clouds or falls as rain; then it flows along the surface of the ground or percolates into the soil to reappear in springs; lastly, it evaporates once more.

The amount of water contained in the air may be expressed by the weight of water vapour contained in a cubic foot of air.

This is known as *absolute humidity* and is measured, like the density of the atmosphere, by the pressure it exerts on the barometer. This pressure cannot exceed a certain amount for a given temperature. When the limit is reached, the air is said to be *saturated* ; if the pressure is then lowered, the air is forced to reject some of its water-vapour, and *condensation* takes place. *Relative humidity* is the relation between the absolute humidity at a given temperature and the maximum pressure of water vapour at the same temperature. It shows how far actual conditions are from the saturation point.

Condensation causes fogs and clouds. Saturated air rejects its surplus moisture in the form of tiny droplets, which remain in suspension as long as their volume, and consequently their weight, is not too great. Since condensation is due to cooling, every cause which brings about a fall in the temperature of the air may lead to the formation of clouds ; and everything that increases the volume of the droplets of water of which these are composed causes rain.

Cooling is most often caused by the rising of air, which results in expansion. No surprise can, therefore, be felt at the heavy rainfall on mountains and in the centre of low pressure systems, for it is known that high ground forces the wind to rise and that centres of low pressure cause the air to move spirally upwards. As a result, clouds are formed, and sooner or later these bring rain either by the slow continuation of condensation or through thunderstorms, the electric discharges of which cause precipitation.

The influence of the distribution of land and water is as easily explained. Since evaporation is more active at the surface of the sea, the absolute humidity is usually higher there. The air which passes thence on to the land has a sufficiently great relative humidity for the slightest cooling to bring about condensation. Since friction is greater on the solid land than on the water, which yields to the force of the wind, this alone is enough to cause the air to rise when it is impeded by the land. Hence, it is natural for the coasts to have a heavy rainfall, especially when the wind reaches them from the sea.

The exceptionally heavy rainfall in the hot belt is really due, as may be suspected, to the great evaporation which constantly renews the supply of water vapour in the air and makes the absolute humidity always very great. If this moisture does not fall as rain round the tropics of Cancer and Capricorn, it is because conditions are not favourable to condensation. The absolute humidity is often very great in the Sahara, Arabia, and in deserts generally; but the relative humidity remains far from the point of saturation. It is the same wherever the air is not driven upwards by the relief or by convection currents, and particularly where it is, on the contrary, caused to descend, as in anticyclonic systems.

Rainfall Systems. The principles which have been brought to light by the foregoing study of the distribution of annual precipitation will enable us to understand the differences observed in the rainfall systems, that is, the variations in the amount of rain that falls throughout the year. These variations are shown by the mean depth of the layer of water that falls as rain each month. To give an idea of their importance it may be mentioned that at Bombay, where the annual rainfall is 74.41 inches, only .39 inches fall between December and May; that Jerusalem receives only .71 inches between May and October and 24.37 inches during the other six months.

The influence of these variations on all forms of physical and organic life is felt especially in hot countries, where each rainfall system corresponds to a certain type of vegetation, of definite plant and animal association, and sometimes even of human society. In Africa the equatorial system of rainfall corresponds to the virgin forest with its primitive races; the subequatorial system to parkland with an agricultural and settled population which has a rudimentary political organisation; the tropical system to the savana which shades off gradually into steppe; and the desert system to the home of warlike pastoral tribes (Hamites, Wahuma, Peuhls) and to the zone of the Sudanese states.

The Tropical Belt. It is here that the study of rainfall systems is of greatest interest. In the absence of marked variations of temperature, rainfall depends almost exclusively on latitude. Rain is caused in fact by the ascending movement of air which occurs in the belt of equatorial calms and follows the swing of this belt from north to south. The period of greatest rainfall almost coincides with the moment when the midday sun is at its zenith and shoots its rays vertically down on to the Earth's surface.

The midday Sun is at its zenith twice a year at the equator with an interval of six months. The two zenithal periods follow each other more closely as latitude increases, until at the tropics themselves the periods become one. Consequently, at the tropics there is one period of great rainfall, and at the equator two. According as the two periods of rain are separated by a greater or smaller interval, they are distinguished from each other by one or two periods of drought which correspond to the season when the Sun is lowest at midday.

Hence, there is an equatorial system with no dry season, but with two periods of maximum rainfall at an interval of six months; a subequatorial system with two dry seasons, the longer of which becomes more and more prolonged with latitude; and a tropical system with one long dry season and a single period of violent rains, which lasts from three to six months.

The Mediterranean System. The Mediterranean system is marked by winter rains and a period of drought in summer. The annual swing of the high pressure belts at the tropics is the cause of this. In summer, the Mediterranean region is brought within their sphere of influence, but in winter they retreat towards the equator, the pressure decreases, and the Westerlies prevail in the region. The influence of these rain-bearing winds does not, however, reach the interior of great land masses like those of the Old World. That is why the Mediterranean system is restricted to the west coast, while the region is continued eastward by a belt of desert areas. The same effect is produced by a chain of coastal mountains which stop the rain-bearing winds, e.g., the Andes in Chile and the Sierra Nevada in California. Hence the Mediterranean and the desert systems are everywhere seen side by side.

The Desert System. The desert system of rainfall is, therefore, the result of a kind of impoverishment of either the Mediterranean or the tropical system. In the northern Sahara the infrequent showers of rain fall in winter; in the southern part they fall in summer.

The High Latitude System. The system which prevails in high altitudes is regulated by entirely different causes. Generally speaking, there is nowhere a really dry season; there are only seasons which are more or less rainy and whose time of year is determined by essentially geographical causes, viz., the distribution of land and water and the direction of the coast-line and of the mountain ranges. The normal type is the continental system, which is marked by a period of maximum rainfall in summer, owing to the weakening of the high pressure centres (e.g., the Siberian area of high pressure). In the maritime system the period of greatest rainfall occurs perhaps in winter, on account of the frequency of cyclonic disturbances which come up from the west in that season.

The Monsoon System. The monsoon winds give rise to a system of rainfall which is similar to that of the tropics. The anticyclonic monsoon which blows from off the continents in winter is naturally dry; the cyclonic monsoon which comes from over the sea in summer is, on the contrary, always rain-bearing. Nowhere is the contrast between the wet and dry seasons so clearly marked or their influence more evident on vegetation and economic life than in monsoon countries.

In Southern Arabia the monsoon has caused a fertile strip where coffee has long been a source of wealth. This is the only part of Arabia where rain is not prayed for. In Western India the rain-bearing monsoon is anxiously expected; if it comes too late or too early, it destroys the crops and causes those terrible famines which are often followed by epidemics and in one way or the other kill off three-quarters of the population of a province. Certain crops, like coffee, tea, and rice, long remained the monopoly of monsoon regions and are still the chief crops in them.

TYPES OF RAINFALL.

A^1 = equatorial, **A^2** = subequatorial, **A^3** = tropical, **B** = monsoon, **C** = Mediterranean, **D^1** = temperate continental, **D^2** = western continental (maritime temperate). The rainfall is expressed in inches.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total.
A^1 Jaluit (Marshall Is.) ..	11·46	11·81	17·87	14·13	20·20	15·71	15·43	13·58	13·46	11·57	14·25	17·48	176·95
A^2 Port-au-Prince (West Indies)	1·10	2·44	2·95	6·65	10·77	3·94	3·07	6·06	7·36	6·10	3·03	1·65	55·12
A^3 Gorée (West Africa) ..	·00	·04	·00	·00	·00	·95	3·58	9·88	5·24	·71	·12	·00	20·52
B Bombay	·16	·00	·00	·00	·43	21·89	28·82	17·36	12·60	2·52	·20	·04	84·02
C Jerusalem	6·30	5·75	3·58	1·73	·28	·00	·00	·00	·04	·39	2·05	5·34	25·46
D^1 Cracow	1·06	·98	1·38	1·73	2·80	3·58	3·46	3·50	2·36	1·97	1·54	1·46	25·83
D^2 Valentia (Ireland) ..	5·80	5·20	4·40	3·80	3·10	3·50	3·90	4·80	4·30	5·70	5·40	6·40	56·30

CHAPTER IV

CHIEF TYPES OF CLIMATE

Principle of Classification. An infinite variety of climates result from the combination of the meteorological factors whose laws we have studied and whose complex relations we have pointed out. It is, however, both desirable and possible to distinguish a certain number of types which are found wherever the same main factors predominate. We shall now try to do this without entering into a detailed account of each variety. One need only think of the shape of the Earth and the distribution of land and water to realise that the same combination of factors must recur in several places. The main belts of temperature are found in each hemisphere, while the alternation of areas of land and water causes the climatic contrasts between maritime and continental regions to occur several times on a single parallel of latitude. Consequently, the map given in Fig. 18 often shows the same type of climate repeated as many as four or five times. At first glance five main groups of climates are distinguishable : hot, temperate, and cold climates, desert climates, and monsoon climates.

The Group of Hot Climates is characterised by a mean annual temperature of more than 68° F. ; moreover, no month has a mean temperature below this average, and the annual range does not exceed 9° F. On the other hand, the diurnal range is very great. The absence of a cold season is certainly an important factor in the physical and psychical character of the human races that inhabit this zone and is the cause of the inability of Europeans to become acclimatised in it. Luxuriance of vegetable and animal life seems to develop at the expense of human activity.

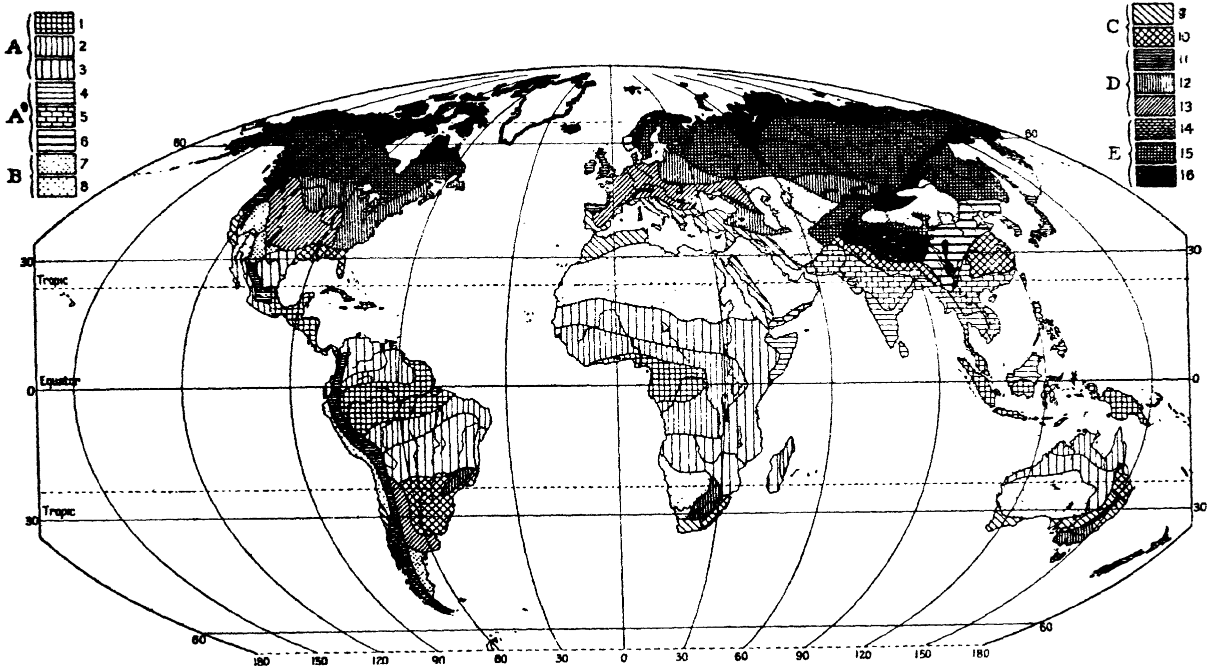

FIG. 18.—Distribution of the chief types of climate.

FIG. 18. DISTRIBUTION OF THE CHIEF TYPES OF CLIMATE.

A. Hot climates	1. Equatorial or Amazonian. 2. Subequatorial or Sudanese. 3. Tropical or Senegalese.
A^1. Monsoon climates	4. Bengali type. 5. Hindu type. 6. Manchurian type.
B. Desert climates	7. Cold deserts. 8. Hot deserts.
C. Subtropical climates	9. Mediterranean. 10. Chinese.
D. Temperate climates	11. Maritime or western 12. Continental or extreme. 13. Transitional.
E. Cold climates	14. Cold maritime. 15. Cold continental. 16. Arctic.

The centres of economic power tend to become more and more concentrated in the temperate belts and civilisation is focused in them. The mean annual temperature is below 68° F., and several months have an even lower mean temperature, but the cold season does not exceed eight months. The annual range of temperature is very great throughout the belts. Consequently, there is a seasonal change which is not found in hot climates and which influences plant life sufficiently to cause a complete change in the appearance of regions according to season. On the other hand, hot climates usually have seasonal change in rainfall. The character of the vegetation and the conditions of human life are regulated by the variation in the total annual rainfall and by the occurrence of more or less clearly marked dry seasons. The annual variation of temperature enables the temperate belts to be subdivided into climates which have a cold season lasting four or five months and those which have no cold season. Cold climates have no temperate season.

So far our main climatic regions are very like Köppen's belts of temperature. But our classification differs from his in distinguishing also a desert climate and a monsoon climate. The former is marked by drought (i.e., a mean annual rainfall of less than 10 inches, and a dry season of more than ten months), by the clearness of the atmosphere, and by a great range of temperature. It occurs in the temperate as well as in the hot belt. The monsoon climate is caused by the special system of wind which has been described above and by the rainfall cycle dependent on that system.

Hot Climates in Africa. No continent has such a vast expanse of land surface in the hot belt as Africa has, and the principles of differentiation between hot climates are illustrated there better than anywhere else. Except in the deserts and the Mediterranean countries, cold is quite unknown. The mean annual temperature is everywhere over 68° F., though at Gorée in the Senegal the month of February has a recorded mean of slightly below that figure (65.7° F.). In extreme cases the annual range of temperature is less than 18° F. (at Gorée it is 16.2°), and all seasonal change depends on rainfall, as the vegetation clearly shows.

The whole coast of Guinea and a part of the Congo basin are covered with virgin forest. The air is always moist and the sky cloudy or misty. The total rainfall for the year exceeds 79 inches (in the Cameroons 163.6 inches) ; at two periods of the year a violent thunderstorm occurs every day, beginning in the afternoon and causing a deluge of rain. During the month of June alone the Cameroons have more rain than London or Paris during the whole year. The sky clears and the thunderstorms are less frequent during the months when the Sun is approaching the tropics, but, in spite of intense evaporation, there is hardly what may be termed a dry season. This is the *continental equatorial climate.*

As one ascends the affluents of the Congo northwards or southwards, one sees a rapid change. The forest thins out and is confined to damp valleys ; the temperature is still high ; the sky often misty ; and during part of the year the rains are as violent as in the climate just described. But there is, nevertheless, a season when the sky clears, the storms are less frequent, the earth dries up and vegetation languishes. During four months in the year Togoland receives a rainfall of less than 2 inches, although the total annual fall almost reaches 59 inches. At the mouth of the Congo there is a true dry season, from June to October, when the rainfall is hardly 0.79 inches. This is the *subequatorial climate.*

As one goes north, one reaches the *tropical climate* which is found in the Senegal and on the whole southern border of the Sahara. The range of temperature has now become greater, and the dry season extends over a period of months, drying up ponds and minor streams and causing the leaves of the trees to fall. At Gorée from November to June only 0.16 inches of rain are recorded ; at Bathurst, where the total annual rainfall is more than double, the same months give only 0.83 inches.

We know the causes of the gradual change from the equatorial to the tropical climate. It is all explained by the position of the Earth in the solar system and by the apparent motion of the Sun (see page 57). The relief of Africa is not sufficiently varied or its coasts sufficiently indented to give rise to any important modifying tendency. The east coast of tropical and equatorial Africa, which is influenced by monsoons, is the only part of the continent that is relatively drier and has more extreme seasonal changes. If it was desirable to give local names to the different types of hot climate, Africa would supply appropriate names : one might find thus, *Senegalese*, for the tropical climate, and *Sudanese* for the subequatorial. The equatorial climate is best represented in South America, where it extends over nearly all the basin of the Amazon. hence, one might term this the *Amazonian climate.*

Temperate Climates with no Cold Season, or Subtropical Climates. The variety of the temperate climates greatly exceeds that of the hot climates. Geographical influences, e.g., the distribution of land and water, surface relief, aspect, are of ever-increasing importance, while atmospheric disturbances are frequent and of great effect. These characteristics are at once noticed, though slightly, as one passes from the tropical climate into the belt of temperate regions with no cold climate, or subtropical regions, as they are also called. The mean annual temperature is everywhere found to be below 68° F. But the number of months during which the mean temperature falls below 50° F. never exceeds four. The best known variety of this type of climate is the *Mediterranean.* Its seasonal changes of temperature are like those of the tropical climates, but they have a greater range. It is, however, distinguished from the tropical climate by its system of rains, which fall during the cold season on account of the cyclones that come up from the west. Hence the Mediterranean region, which is an extension of the tropical desert belt in summer, becomes attached in winter to the maritime temperate region in which the prevailing winds are the Westerlies, and where atmospheric disturbances originating over the Atlantic regulate the nature of the weather. In such circumstances, it will be easily understood that a gradual transition from the Mediterranean region is observed, on the one hand to the desert belt. and on the other to the cold temperate belt.

On the Atlantic coast and throughout the northern part of the western basin of the Mediterranean, the range of temperature is relatively small (at Lisbon 19.8° F.) ; the rainy season is early and gives much rain. The wettest month in most places is October, e.g., in Provence, and Central Italy.

In Algeria, Sicily, and Greece, the influence of the sea is less, the range of temperature is greater (at Athens 34.2° F.), and the rainy season is later and shorter. Clear, bright skies, which are characteristic of the Mediterranean region, also become more and more noticeable. From Algiers to Athens and Jerusalem this change leads gradually but progressively to a sub-desert climate, which is clearly marked in the interior of Syria and in Iran. The same atmospheric conditions also occur on the coasts of California and Chile. But the Mediterranean climate is confined to a narrow coastal strip. In California the Sierra Nevada stops the rain-bearing winds, and on the plateau of the Great Basin the climate has already changed to the desert type. The ranges of the Andes play a part similar to that of the Sierra Nevada and limit the Mediterranean climate to a narrow strip on the coast of Chile. South Africa and Australia reach just far enough south for the regions about the Cape and about Adelaide to have a climate and vegetation like those of Provence.

If the desert type of climate replaces the Mediterranean in the centre of great land masses, the influence of the monsoon changes the character of the latter type on the east coasts. The *Chinese climate* (e.g., at Shanghai) has, generally speaking, no dry season. Perhaps a slight decrease in rainfall is noticeable in winter. The greatest fall occurs in summer or in spring; in fact, the summer monsoon brings the heaviest rains. But the cyclones which form in winter on the outskirts of the Siberian high pressure centre and move towards the north-east also bring an appreciable amount of rain. The combination of winterless temperate climate with a rainfall that is distributed throughout the year gives to the woodlands that peculiar beauty which strikes every visitor in Southern China. The Chinese climate occurs also in the United States along the shores of the Gulf of Mexico and the southern Atlantic coast (e.g., New Orleans and Charleston). The influence of the monsoons is felt particularly in the southern Atlantic coast, since the anticyclone which centres round Manitoba plays the same part here as the high pressure centre plays in Siberia.

Desert Climates. The desert belt spreads over both the hot and the temperate belts of Köppen's system and manifests throughout the following characteristics: total annual rainfall less than 10 inches, ill defined and irregular periods of rainfall, very great range of temperature. In the hot belt these features are very striking on account of their contrast with those of the normal varieties of climate. Hence, hot deserts are the best known, and the Sahara is the classic instance.

Outside the hot belt deserts are usually restricted to the interiors of great land masses in the northern hemisphere. The fact that they coincide with regions of inland drainage, lofty plateaux in Asia and America, or basins whose lowest parts are below sea level, such as the basin of the Aral and Caspian Seas, proves that surface relief is really a factor in producing a desert climate. The mountains that encircle these depressions form an effectual screen which stops all precipitation. But the anticyclonic conditions that prevail in these regions have no less importance. Rain is not so completely lacking as in tropical deserts, and, when the soil allows it, steppes often replace the desert. But range of temperature tends to accentuate the effects of drought. Burning summers cause temperatures which sometimes exceed those of the Sahara, while the winters are unusually cold. This type of climate is of greatest geographical extent in the continent of Eurasia. It prevails over the whole depression of the Aral and Caspian Seas—whence the name *Aralic* has been given to the type—and extends over the plateaux of the interior which are enclosed between the lofty mountain ranges of Central Asia from the Tarim to the source of the Amur. The type also occurs in the Great Basin of the United States and on the Plateau of Oregon.

The Aralic climate, like that of the Sahara, is not entirely hostile to human life. The deserts and steppes of Central Asia are the ranging grounds of warlike tribes and were in the past the starting point of those great racial migrations which changed the face of Europe. In them, as in the Sahara, irrigation gives rise to oases. At the foot of the vast mountain regions of Central Asia the traces of a comparatively advanced civilisation of bygone days have been discovered in the Ferghana.

Monsoon Climates in Asia. The largest of the continents is also the one in which the influence of the monsoons is most extensive. Wherever these prevail, the year is clearly divided into a dry season, which is often very long, even in equatorial lands, and a period of torrential rains. The drought is increased by the continental and anticyclonic character of the winds which blow during the early part of the year; the abundance of the rainfall is increased by the passage of winds from the ocean on to the land and their collision with lofty highlands. Hence, the mean annual rainfall is almost always more than 40 inches. The transition period between the two seasons is marked by violent atmospheric disturbances: thunderstorms, cloudbursts, and typhoons. These features of the climate are found from Arabia to Manchuria and in the countries between them, including India, Indo-China, China, and Japan. But a number of sub-types are caused by surface relief, by the direction of the coastline, and by the extension of the monsoon system into the temperate zone.

Near the equator (e.g., in the Deccan, Bengal, and Cochin China), the temperature varies but slightly (at Rangoon the range is 9° F., at Bombay 19.8° F.), and the striking feature of the climate is the contrast between the wet and dry seasons. The latter season is always clearly marked, even at the foot of the Himalayas, where the mean annual rainfall exceeds 394 inches (at Cherrapunji it is 472 inches).

As one advances northwards from the coast, the annual range of temperature increases. It reaches 59° F. in Central India, where the end of the dry season is intolerable. For example, Nagpur has a temperature of 94° F. in May. At the same time the amount of rain decreases, the drought is prolonged, and the climate approaches the desert type. A true Saharan *erg*[1] extends along the Indus, and the river reaches the sea with a diminished volume. Irrigation alone has made the agricultural development of the Upper Punjab possible. A similar climate occurs on the coasts of Arabia and Somaliland.

The direction of the coastline may cause a difference in the period at which the wet season occurs. Thus, in Annam the winter monsoon, which strikes the coastal ranges after crossing the South China Sea, brings the rainy season.

As it intrudes into the temperate belt the monsoon climate is still more modified in character. The Chinese climate has already been shown to be the result of the occurrence of monsoons

[1] See p. 226.

in a subtropical region. But monsoons are felt as far north as Manchuria. At Peking the year is divided into two seasons, one dry and cold, the other hot and wet. In winter the land winds from the north-west, which are caused by the centre of high pressure in Siberia, give rise to snowstorms or sandstorms. In summer the south-east and east winds from off the ocean bring rain, but do not moderate the high temperature. January has a mean temperature of 23.5° F. and a rainfall of 0.12 inches. The rainfall is 8.39 inches in July, when the mean temperature is as high as 79° F.

Asia does not monopolise the monsoons. Their influence is felt on the east coast of Africa, in Madagascar, in Australia, and in America, where they produce climates like those prevailing in Asia in corresponding latitudes.

Temperate Climates with a Cold Season. The extent of this type is far from being as great as one might think from the expanse of the continents in middle latitudes, in the northern hemisphere especially. Lofty mountain ranges and vast deserts encroach on its domains in Asia. The type is best developed in Europe, and its various sub-types, which are due to geographical influences, can be most clearly distinguished there.

Nowhere else is the difference between maritime and continental climates so marked. The British Isles and Poland may be taken as examples wherewith to illustrate the contrast. In the former the temperature is equable and the constant rain is favourable to vegetation. The year is divided into four seasons: a very mild winter (Valentia in S.W. Ireland has a mean January temperature of 45° F.), when the sky is constantly veiled in mist and rain often falls in prolonged showers of drizzle; a comparatively cool spring with frequent squalls; a late summer with moderate temperature (at Valentia the mean July temperature is 59° F.) and often with a good deal of rain; a fine autumn with mildly sunny days and spells of warmth which ripen the fruits. Snow is almost unknown and frost is rare.

In Poland and Russia, on the other hand, snow covers the ground in winter, often for several months; the sky is clear, the sun bright; the still air makes one able to bear temperatures whose mean falls in January to 26.6° F. (e.g., at Cracow) and even lower (e.g., Moscow with 12.2° F.). Spring comes on suddenly, melting the snow, soaking the ground, making the roads impassable and swelling the rivers, which sweep down masses of broken ice. By May the temperature exceeds that of the Atlantic coasts. At the same time the sky becomes overcast; summer is wet and hot, and thunderstorms alternate with fine weather and a baking sun. The mean temperature for July is close on 68° F. or even higher. Autumn comes on as suddenly as spring. With the shorter days the temperature falls rapidly, the ground freezes during the night, and the leaves fall two months earlier than in the south of England.

These contrasts, the cause of which we know, gradually become less marked as we move away from the Atlantic coast, and we actually pass by an imperceptible transition from the maritime climate of England to the continental climate of Poland. The area over which the maritime climate extends is limited and hardly goes beyond a narrow coast strip, even in England. It is difficult to say where the continental climate begins. The further east one goes, the greater becomes the annual range of temperature, the colder and finer is the winter, and the earlier and warmer the summer. At the same time the total annual rainfall decreases, and autumn assumes more and more the character of a dry season. In the south of Russia, the average fall is less than 20 inches, and of this 65 per cent falls during the summer months. Forest gives way here to the grassy plains of the steppes. Still further east one comes upon the desert climate of the Aral region.

In America, the transition is peculiarly abrupt. The maritime climate is confined to a coast strip at the foot of the Rocky Mountains in British Columbia. The high relief of these mountains greatly increases the rainfall, but it does so at the expense of the plateaux situated to leeward, where the Aralic climate consequently prevails. Similarly, in South America the southern coast of Chile enjoys an extremely moderate and wet climate, but in the east among the Cordilleras there prevails a region of extreme drought.

Cold Climates. The polar limits of cereals, trees, and human habitation lie within the belt of cold climates. However, a considerable portion of this zone is full of intense life, namely, those parts where a moderate season of four months or less occurs. Here the influence of the sea causes contrasts as striking as those which occur in temperate climates. The maritime sub-type, characterised by a mild winter, a late spring and a warm autumn (October being warmer than May), and a comparatively cool summer, prevails in islands like Iceland, the Faeroes, and the Shetlands, whose shores are washed by warm currents, and also along the whole of the coast of Norway. The Baltic coast of South Sweden is sufficiently protected by intervening land from sea influences and feels them far less. Thus, at Stockholm the annual range is over 36° F.

The continental sub-type is of far greater extent: it covers a wide belt running from one end of the continent of Eurasia to the other. The mean annual temperature lies between 23° and 41° F. The range increases gradually from west to east, from Russia to Eastern Siberia. At Moscow it is 54° F., at Barnaul and Irkutsk nearly 72° F. Rainfall gradually decreases, and winter becomes almost a real dry season in Siberia. All Canada north of the Great Lakes has the same climate, which, though rigorous, does not prevent the growth of plant life.

The limit of trees is almost the same as that of cold climates with a temperate season. Wherever the four warmest months do not reach a mean of 50° F., life is impossible. The ground is covered with snow during the greater part of the year, and all water is covered with ice. Elevated land always gives rise to glaciers, which descend to the sea. Only the continental variety of this type of climate is well known. It prevails over all the lands round the north pole and is, therefore, termed Arctic. Upernivik, in Greenland, represents the average conditions; Spitsbergen, with an annual range of temperature of 36° F., represents the sub-type in which maritime influence is felt; while Verkhoyansk, with a range of 120° F., is the most extreme continental instance.

Summary. A few general remarks are suggested by the chart showing the distribution of climate (Fig. 18). There is a remarkable difference between the two hemispheres. The northern hemisphere offers the greatest variety of types and the greatest contrasts, and, generally speaking, all the extreme continental types are found there.

The systematic difference between east and west coasts is equally marked in all climatic belts and on the shores of both the Atlantic and Pacific oceans. It is observed that true maritime climates with their small range of temperature, their irregular and variable systems of pressure, are restricted to the west coasts of continents, whilst the east coasts in the corresponding latitudes are always influenced by continental conditions and even share in the monsoons (e.g., Manchuria). On the other hand, in the winterless subdivision of the temperate zone the west coasts have a dry period (Mediterranean climate) which is unknown on east coasts (Chinese climate). At and around the tropics of Cancer and Capricorn the west coasts of continents have a desert climate, whilst the east coasts escape this drought owing to the monsoons. Generally speaking, the influence of the monsoon is confined to east coasts.

Each ocean influences the land in a different way. The Indian Ocean, owing to its equatorial position in the midst of the largest continents, is the focus of the monsoons. The influence of the sea is greatest on the shores of the Pacific, though it is restricted in area, on account of the girdle of mountain chains; on the Atlantic coasts it is less pronounced but affects a greater area. The transition from maritime to desert climate is gradual in Europe, but sudden in America. Hence, the two main continental groups have their own peculiarities, and the distribution of the various types of temperate climate is not the same in the Old and New Worlds.

CHAPTER V

MOUNTAIN CLIMATES

WHEREVER they occur, mountainous regions are distinguished from the surrounding lowlands as much by climate as by relief. Meteorological phenomena of temperature, humidity, rain, and wind, all assume peculiar forms and have a far greater effect there than elsewhere on all kinds of physical and organic life. Not only are the frequent and capricious changes of weather reflected in the distribution of plants and in the sites of man's dwelling-places and the forms of his economic activity, but the nature of the relief itself owes its peculiar features to the special processes of rock disintegration and erosion which are due to the meteorological conditions existing in mountain regions. Hence, few branches of his science are more suggestive to the geographer.

Temperature. The fall in temperature which accompanies a rise in altitude is one of the best known and most important features of mountain climates. It is caused by the rarefaction of the atmosphere, the capacity of which for retaining heat varies with its density. The fall has been calculated to be, on the average, 1° F. for every 325 feet of ascent. But the rate varies according to season, being greatest in summer. A comparison of observations made at the summit and at the base of the Eiffel Tower shows a difference of 1° F. for every 290 feet in summer and for every 360 feet in winter—which gives an annual mean of 1° F. for every 325 feet. On lofty mountains the rate of fall depends on topographical conditions. In the Eastern Alps, it is known to be more rapid on southern slopes than on northern, and the average rate of fall for every 325 feet is considerably less in valleys like those of Carinthia, which have a continental climate. Thus:—

FALL OF TEMPERATURE FOR A RISE OF 325 FEET

Means for	Year	Winter	Spring	Summer	Autumn
Northern slopes	.92° F.	.63°	1.08°	1.10°	.84°
Southern slopes	1.08° F.	.9°	1.18°	1.2°	1.02°
Enclosed valleys (Carinthia)	.82° F.	.46°	1.02°	.9°	.75°

Since the rarefied air of elevated regions absorbs less heat than air at lower levels, it loses less during periods of cooling. Hence, thermometrical variations are less in such regions. At Toulouse the annual range is 29.52° F.; on the Pic du Midi it is 25.2° F. An even greater difference is shown by Catania (29.16° F.) and the summit of Etna (19.44° F.). But the range of temperature does not decrease regularly right up to mountain-tops. Valleys at high altitudes often have a more extreme climate than the plains below. Thus, the diurnal range at Geneva is 20.88° F., at Chamonix 25.56° F., while it is only 6.3° F. at the summit of Mont Blanc. This is not surprising, since depressions have been shown to have continental climates (see Chap. I, pp. 32-33).

In mountain regions it sometimes happens that during the cold season the temperature decreases, not from the valleys to the summits, but from the summits to the valleys. This is known as *inversion of temperature*. The following incident affords a typical illustration: On December 26, 1879, a temperature of 3.56° F. was observed at 6 a.m. at Clermont-Ferrand, a town situated on the borders of the plain of Limagne, while at the same moment a temperature of 39.92° F. was recorded at Puy de Dôme, an isolated volcanic peak rising to a height of 4,800 feet. Inversion of temperature is the rule in sheltered valleys and basins in the Eastern Alps. So often does it occur there that, in the valley of Klagenfurt, even mean winter temperatures show traces of its presence. Thus, according to Hann, the mean temperature observed at an elevation of 1,500 feet is 24° F.; at 1,800 feet, 25° F.; at 2,300 feet, 25.5°; at 3,600 feet, 25.5°; at 4,600 feet, 25°; at 7,500 feet, 20.7°. Thus, an ascent of 3,100 feet, instead of causing a fall in temperature, involves a rise of 1° F.

This seeming paradox is easily understood if the conditions under which inversion occurs are considered. Inversion depends both on the general state of the atmosphere and on topography, for it is observed most often in narrow valleys, in enclosed basins, and in plains adjacent to isolated peaks. It always appears in times of calm, clear weather with high barometric pressure. Even in Paris the observations on the Eiffel Tower have shown it to be a normal occurrence. When the atmosphere is quite calm, the cold layers descend by their own weight to ground level and in mountain regions flow down, as it were, to the bottom of valleys, which thus become colder and colder. Since radiation by night is always cooling the layers of air near the ground and thus preventing these from mingling with the upper layers, a steady fall in temperature is brought about in depressions. This process stops as soon as definite winds spring up and the layers of air are forced to mingle.

Inversion of temperature is a phenomenon of the utmost importance to life in mountain regions. It partly explains why villages and isolated dwellings avoid valley bottoms and choose a site on the alluvial fans of torrents or on terraces, and even climb the hill slopes when the gradient is not too steep. Wherever the phenomenon occurs, cultivation, even outside mountain regions, prefers hill slopes and elevated places. In the Alleghanies, for instance, it prefers the warm zone above the valley bottoms, which is rarely touched by the severe cold of winter. This zone of cultivation is known as the *thermal belt.* In the provinces of Sao Paulo in Brazil, the coffee plantations prefer the high gound. For the same reason the vineyards of Alsace and Switzerland are spread over the high ground, and those of Valais in France occupy rocky hillsides rising to 3,000 feet in preference to the valley bottom.

The advantage slopes have over valley bottoms is explained partly by insolation. Insolation increases with altitude, since the heat which is not absorbed by the air reaches the ground directly. It is also affected by the average slope of the ground, since the amount of heat received on a given surface is proportionate to the angle of incidence of the Sun's rays (see Fig. 19). The difference between slopes facing away from the Sun and those which receive the rays is expressed in the French Alps by the terms *ubac*, or the wrong side, and *adret*, or the right side. In England every gardener knows the effect of different *aspects* on his plants. Differences of aspect are particularly striking in valleys running east and west.

Rainfall. The variability of mountain climates is best illustrated by the conditions of atmospheric humidity. Sometimes mist covers one slope of a hill, whilst the sun shines on the other; in one place sleet and hail may fall with unusual violence, whilst a hundred yards away the sky may be clear, etc. One well-known fact stands out, viz., the increase of rainfall with altitude. However, its irregularity precludes any attempt at quoting a definite rate of increase, even approximately. The following figures, which give the means for a large number of stations in Germany (outside the Alps), will give some idea of the conditions in a continental temperate climate :

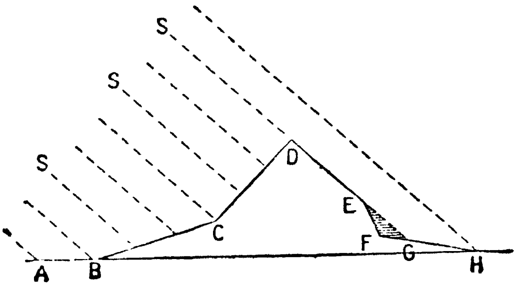

FIG. 19.—Causes of differences in insolation.

The same amount of heat derived from the Sun from equal bands of rays (SS) is distributed over a greater area on flat ground (AB) or on a gentle slope (BC) than on a steep slope (CD). But in the reverse slope, a gentle slope (GH) is sufficient to diminish considerably the amount of heat received ; a slope equal to the inclination of the Sun's rays reduces it to the minimum (DE) ; while a steeper slope (EF) removes the effect of the rays altogether. (EFG is in the shade.)

Altitude in feet	0–600	600–1000	1300–1600	1600–2300	2300–3300
Rainfall in inches	22.88	25.65	30.71	33.47	39.38

Very seldom do the two slopes of the same mountain range have the same amount of rainfall at the same altitude. The contrast is all the greater when the direction of the rain-bearing winds is almost at right angles to the axis of the range. Thus, there is little difference in rainfall between the northern and southern slopes of the Eastern Alps, whilst the contrast between the two slopes of the Vosges is very marked, thus—

	Western slope.				Eastern slope.		
Stations—	Nancy	Mirecourt	Epinal	Le Syndicat	Wesserling	Thann	Colmar
Altitude in feet	656	915	1108	2034	1433	780	656
Rainfall in inches	30.94	35.04	37.40	54.09	47.56	36.69	18.86

The most striking instances are afforded by the Himalayas and the Rocky Mountains, which separate deserts from the wettest regions in the world. This is one of the reasons why mountain ranges are often climatic boundaries and important barriers in bio-geography.

The Snow Line. At great elevations rainfall often assumes the form of an accumulation of snow, which the heat of summer is insufficient to melt completely. The limit of eternal snow, or snowline, is one of the most important boundaries in the geography of mountain regions. It separates two worlds which are as different from the physical as from the biological point of view. Its height depends chiefly on temperature. Theoretically, it corresponds to the zone within which the mean summer temperature remains below 32° F.; hence, it becomes lower as it passes from the equator to the poles. Actually, its greatest mean altitude is near the tropics of Cancer and Capricorn. This fact by itself indicates that rainfall plays almost as great a part in determining its height as temperature does. The influence exerted by these two factors is clearly seen when the mean altitudes of the snow line is compared with the mean temperature and rainfall in different latitudes (see Fig. 20). The influence of rainfall often seems to be the dominating

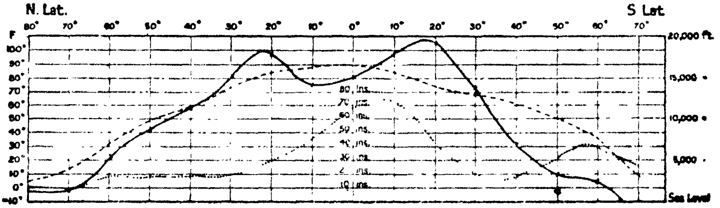

FIG. 20.—Showing variations of latitude of:—

(a) ———— snow line.
(b) - - - - - - mean annual temperature.
(c) .... mean annual rainfall.

factor when the area examined is a mountain mass. The wettest slope always has the lowest snow line, even when this slope is the warmest. Thus, the snow line descends to 15,000 feet on the southern slope of the Himalayas, which is exposed to the monsoon rains, but to only 19,000 feet on the northern slope, which faces the deserts of Central Asia. In the Western Caucasus, the limit of snow lies at 9,500 feet on the southern slope, but at 11,200 feet on the northern. In the Western Alps the snow line is lower than in the Eastern Alps, which are drier. The same difference is seen to exist between the outer and inner Alpine ranges, the former having a greater rainfall than the latter.

Mountain and Valley Breezes. Not only does great elevation modify the character of atmospheric circulation, but it also gives rise to local winds. Such are the *mountain and valley breezes*, which in calm weather alternate as regularly as land and sea breezes. The mountain breeze, a cold wind which seems to bring with it the icy air of the region of eternal snow, springs up about 9 p.m. It lasts all night, but stops in the morning. Between 9 and 11 a.m. there springs up in the opposite direction a wind which moves along the valley towards the mountain, increasing in force during the whole afternoon, but dying away at sunset. This is a warm, damp wind and brings a train of clouds which wrap the peaks in mist.

Local names indicate the importance attached by mountaineers to these regular winds. On the Italian lakes at the foot of the Alps the valley breeze is termed the *Breva,* while the mountain breeze is known as the *Tivano.* These breezes drive the boats from one shore to the other alternately. In the Tyrol the same winds are known as the *Oberwind* and the *Unterwind.* In the French department of Drôme the *Pontias* is a cold, dry wind which issues from the gorges of the mountain streams.

The cause of mountain and valley breezes is the same as that of land and sea breezes. During the day the warming up of the atmosphere causes greater air expansion in the plains, where the atmospheric column is denser, than on the heights, where it is rarer. Consequently, the pressure is greater at a given height over the valley than over the mountain at the same altitude, the planes of equal pressure are, therefore, inclined towards the mountain, and the air flows in that direction. Night causes the phenomenon to be reversed : the cooling and contraction of the atmospheric column is greater over the plain and hence there is a flow of air from the heights towards the lowlands.

The Föhn. In the valleys of Switzerland and the Tyrol the name Föhn is given to a warm, dry wind which blows from the mountains for several days with increasing violence. The wind often follows at the beginning of spring on a period of severe cold, calm weather, during which inversion of temperature occurs and mist covers the lowland. Its arrival is announced by the disappearance of mist and the appearance of an ideally clear sky. Soon avalanches begin to thunder down, and torrents rush down headlong, swollen by the melting snow. The Alpine hamlet retires within its doors, the flocks and herds are hastily driven in, and fires are extinguished—for the air is so dry that a spark might cause a conflagration. The Föhn has good effects, for by hastening the melting of the snow, it opens the pastures at an early date to the flocks and herds ; and the peasants say that one day of Föhn is equal to a fortnight's sunshine. In narrow valleys which receive but little insolation, the Föhn makes agriculture possible ; but when the wind is late, the crops are endangered. Moreover, at the end of autumn the Föhn ripens the grapes in the canton of Grisons and the maize in Vorarlberg.[1]

It is recognised that this wind always coincides with a period when high pressure reigns over the Mediterranean region and at the same time low pressure prevails over North-west Europe. The Föhn is, therefore, only a current of air caused by the relative positions of the great centres of atmospheric activity, but modified by the influence of surface relief. Violence is a characteristic which the Föhn shares with all winds that blow across elevated regions (e.g., the Bora, the Mistral, the *vent d'autan*). A kind of stagnation of air is produced behind the mountain range, but the wind rushes in furious swirls down the

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[1] To get an exact idea of the influence of the Föhn on the atmospheric conditions, one must remember that the thermometer has been seen to rise to 67° F. on February 1 at Bludenz and the relative humidity to decrease to 14 per cent, a proportion which is ordinarily recorded in deserts only.

other side, like the current of a river when obstructed by narrows and rapids. The descent of the Föhn on the Swiss slopes is very like a kind of cascade. The drought and high temperature which accompany the Föhn will be understood if the relation between the clear, dry weather which prevails on the Swiss slopes and the periods of heavy rain and very cloudy weather on the Italian slopes is fully realised. The temperature is, moreover, far lower on the southern slopes and decreases far more slowly on the northern slopes.

The accompanying diagram (Fig. 21) will help the reader to understand the process of the phenomenon. The air in moving upwards on the southern slopes is cooled more slowly than it warms up again on descending the northern slopes. In fact, as soon as it reaches an altitude OH_1, at which the water vapour with which it is laden begins to condense, it is warmed by condensation, which, as is known, sets free a great deal of latent heat,[1] so that it reaches the culminating point H_2 at a temperature of OT_2. On the northern slope the descending air no longer contains much moisture; it is warmed on descending, according to the law which regulated its cooling as it ascended, before condensation began. The curve of temperature is therefore represented by BT_3 parallel to AT. It is clear that the air will reach an altitude corresponding to that from which it started on the opposite slope, with a far higher temperature, i.e., OT_3 instead of OT. While the air is warmed on descending, it also becomes drier. The relative humidity, which is still very great at altitude OH_2, decreases more and more.

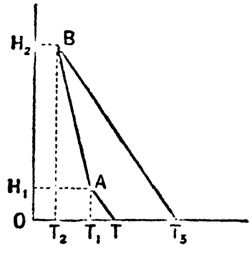

FIG. 21.—Theory of the Föhn effect.

TAB is a curve showing the temperature of the air in its ascent of the southern slopes of the Alps; BT_3 shows the temperature of the air as it descends the northern slopes.

Winds like the Föhn occur in every mountain range. The Indians of the Rocky Mountains give the name *Chinook* to a wind which brings a very great rainfall to the Pacific slopes, and on the other hand melts the snow on the eastern slopes. It has been known to cause a rise in the

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[1] About 600 calories per gramme of water. Tr.

thermometer from 14° F. to 68° F. Thanks to it, the polar limit of cereals, which in Eastern Canada lies in the latitude of Bordeaux, is pushed northwards as far as Lake Athabasca at the foot of the Rockies in latitude 60° N.

Chief Types of Mountain Climate. Anomalies due to altitude and surface relief are found in every climatic region, but the influence of latitude and geographical position is never entirely without effect. In hot climates the isotherm for 32° F., if not reduced to sea-level value, lies at a great height. Since the sun's rays are almost vertical at midday for a part of the year, the differences in insolation are comparatively slightly marked. Those which are due to the direction of the axis of the mountain range in relation to the rain-bearing winds are all the more striking. Rainfall systems are not changed by mere altitude; but the lower temperature gives elevated regions the character of a country with a maritime temperate climate. On the lofty tablelands of the Andes, Mexico, and Abyssinia there is a perpetual spring. It is to be noticed that these highlands attracted mankind from early times, and ancient civilisations grew up in Mexico, in Peru, and in Bolivia.

In the cold temperate belt mountain climate offers its most curious peculiarities. The obliqueness of the sun's rays accentuates differences due to insolation. According to the direction of their axis and the gradient of their slopes, two neighbouring valleys at the same altitude may have entirely different climates. Whilst the rain falls in torrents on the Rigi and the Säntis, and mist veils Lake Lucerne and the valley of the Reuss, Valais and the Upper Engadine are seen bathed in bright sunshine. Local winds are more marked in the temperate belt than in the hot. The Alpine valleys in which the Föhn blows can be recognised by their greater resemblance to the south of France: the chestnut and fruit trees, sometimes even the vine, are to be seen in them.

APPENDIX TO PART I

I. SUGGESTIONS FOR FURTHER READING :—

For a complete explanation of the laws of Meteorology, see A. ANGOT : *Traité de météorologie* (3rd edit. Paris, 1916, 415 pp.) It is clear and devoid of mathematical over-technicality. W. M. DAVIS' *Elementary Meteorology* (Ginn & Co., Boston, 1894) is an admirable text-book, while H. N. DICKSON'S *Meteorology* (Methuen, 1893), though out of print, is the best introductory work.

No student should be without *A Short Course in Elementary Meteorology* (1926), *The Weather Map* (1925), and *Meteorological Glossary* (1918), all published for the Meteorological Office of the Air Ministry by H.M. Stationery Office.

For a complete survey of climatology, see J. HANN : *Handbuch der Klimatologie* (3rd edit., Stuttgart, 1910-11, 3 vol., 8vo). Very lucid, with many tables of useful statistics. An English translation by R. de C. Ward has been published by Macmillan. KENDREW'S *Climates of the Continents* is also useful.

The most complete and most up-to-date meteorological atlas is J. BARTHOLOMEW'S *Physical Atlas, Vol. III, Meteorology* (Edinburgh, 1899).

The papers of A. ANGOT on *La température de la France* (*Annales de Géog.*, 1905, p. 296) and *Le régime pluviométrique de la France* (*Annales de Géog.*, 1917, pp. 255; 1919, p. 1; 1920, p. 12 ; 1921, pp. 32 and 111) are models of detailed study of the European climate and may be read with profit.

As examples of really geographical descriptions of the climate of a restricted area, see also the chapters devoted to climate in A. DEMANGEON'S *La Plaine Picarde* (Paris, 1905), A. VACHER'S *Le Berry* (Paris, 1908), EMM. DE MARTONNE'S *La Valachie* (Paris, 1902), and M. SORRE'S *Les Pyrénées Méditerranéennes* (Paris, 1913).

For a more general treatment of the details of climate, see Part II of *Traité de Géographie Physique* by EMM. DE MARTONNE, pp. 105-33 (4th edit.).

II. PRACTICAL EXERCISES :—

To acquire a practical understanding of the Laws of Meteorology, it is essential to study the weather charts published daily by the Air Ministry in Great Britain and by the Weather Bureau in Washington (U.S.A.). To make sure that you understand the principle on which isotherms are traced, draw the lines for yourself on a blank map from the temperature readings given for the various stations in the statistical lists that accompany the chart; observe the differences between your lines and those on the official chart and try to discover the reason for your mistakes.

Repeat the exercise for the isobars; then insert the direction of the wind at a number of points according to Buy Ballot's law.

Choose a period of weather which is remarkable for its peculiar character, so as to be able to seek for the explanation of it and to analyse completely the relation between pressure, wind, temperature, and rainfall. Thus, after a period of frost in winter, it is interesting to examine the charts for the coldest days. The same may be done after a remarkably mild month in winter. Observe if the conditions do not correspond more or less exactly with the following types.

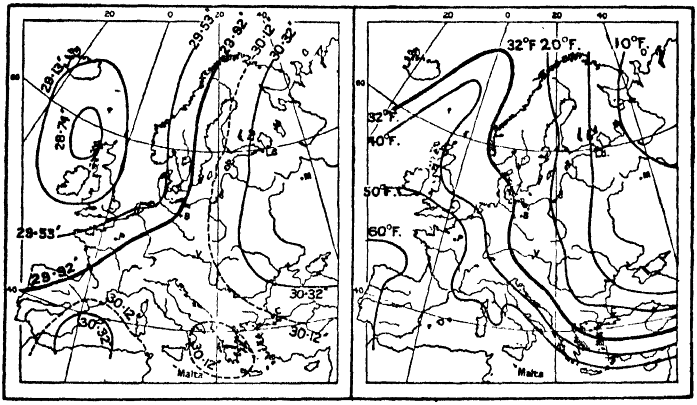

FIG. 22.—Pressure and temperature for February 19, 1880.

In February, 1880, the Siberian anticyclone spread widely over Russia, whilst a cyclone passed between the British Isles and Iceland (see Fig. 22). Winds from the south and southwest resulted, bringing over the whole of Western Europe up to and including the coast of Norway the moist, warm air from the ocean. Consequently, there was rain and mild temperature. On the other hand, in Eastern Europe, the calmness of the air assisted the process of cooling during the long nights, and the cold was severe. Notice the arrangement of the isotherms, which reminds us of the chart showing mean January temperature (see Fig. 8 A). In fact, we have before us the conditions which occur most often in European winters.

In December, 1879, on the other hand, we find abnormal conditions That winter was long remembered for its extreme cold. The isotherm chart shows that severe cold has settled over Central and Western Europe, whilst comparatively mild temperatures prevail in Russia. It is colder in London and Paris than in Leningrad. The isotherm for 32° F. passes through Moscow, Copenhagen, London, Bordeaux and Trieste. These extraordinary conditions are explained by the pressure chart. There an extensive area of anticyclone is seen covering the whole of Central and Western Europe from the British Isles to the Black Sea. Hence arise the south-westerly and westerly winds which blow over Scandinavia and Russia, so that the warm, damp air from the Atlantic penetrates into those countries; whilst north winds prevail over the Mediterranean, making the region colder than usual. Within the centre of high pressure the air is calm, the sky clear, and the temperature falls more and more every night, for the dryness and clearness of the atmosphere has been increased by falls of snow.

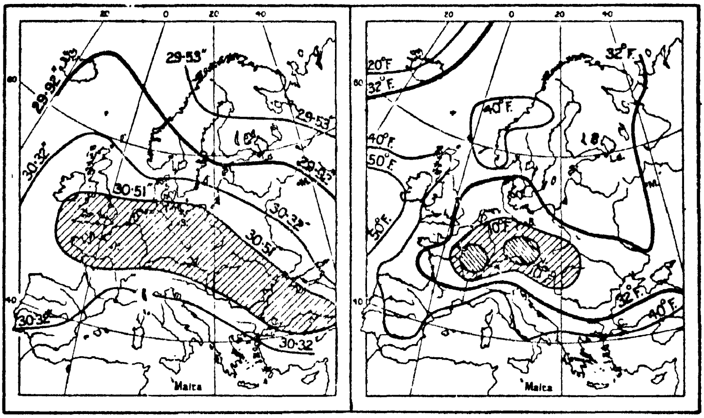

FIG. 23.—Pressure and temperature for December 17, 1879.

If it is desired to pursue this kind of exercise, consult the *Traité de Géographie Physique*, Part II, Chap. V., pp. 205-228 (4th edit.).

PART II

HYDROGRAPHY

CHAPTER VI

THE OCEANS

Nature of Submarine Relief. Modern oceanography[1] studies the shape of the ocean basins, the kind of sediment deposited on their bottoms, the chemical composition of sea water, the temperature and the various movements (waves, tides, and currents) of the oceans. These questions are all closely allied, but the most important is the first, since on it is based the claim of oceanography to be regarded as a branch of physical geography.

However imperfect our knowledge of submarine relief still may be, the general features are already fairly well established. The most important of these is the existence of a platform, roughly outlined by the isobath for 100 fathoms, which runs at varying distances round the coastline of all continents. This line encloses what is known as the *continental shelf.* The surface of the shelf is rather broken as compared with the monotonous evenness of the great ocean deeps, and in it are

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[1] The term *oceanography* in the sense of systematic study of the oceans occurs as early as the 17th century in the *Geographia Generalis* of Varenius, in which there are some general ideas that are still worthy of notice. In the 19th century oceanography definitely took its place as a physical and biological science (In this chapter only the physical side will be touched upon). Great research expeditions have methodically examined every ocean. In this work the English and Americans have naturally played the leading part. The cruise of the *Challenger* (1873–76) through all the oceans resulted in the publication of fifty big volumes; that of the *Tuscarora* (1874–76) was responsible for a great increase in our knowledge of the Pacific Nansen, Amundsen, Pettersen, and other Scandinavians have largely contributed to our knowledge of the Northern Seas, and Copenhagen is the headquarters of the "Permanent international council for the exploration of the ocean." The expeditions of the German ships *Gazelle* (1875–76) and *Valdivia* (1898–99) were very fruitful, and the maritime observatory at Hamburg has published the most complete oceanographical atlases. France, which began oceanographical research in the Mediterranean with Admiral Aimé in the 19th century and explored the Atlantic with the *Travailleur* (1881) and the *Talisman* (1883), can also boast of the work of the Prince of Monaco and the publication of the General Bathymetrical Chart of the Oceans on a scale of 1 : 10 M.

extensions of continental valleys and shallow areas, the direction of whose axis proves them to be continuations of the relief on dry land. The flatter the continent, the broader is the shelf that bounds it. Hence a slight movement would, in some cases, suffice to bring about an entire change in the outline of the coast. A negative movement[1] of 50 fathoms would turn Great Britain into a peninsula, the Baltic into a string of lakes and reduce the North Sea to a gulf. On the continental shelf and on the slope which separates it from the ocean deeps, the waste brought down from the land by the various agents of erosion accumulates to form terrigenous deposits.

If the isobath for 100 fathoms is followed, it is seen almost everywhere to run close to the isobath for 1,000 fathoms, and even to the isobath for 1,500 fathoms. That means that an abrupt slope separates the continental shelf from the ocean basins. These basins, which vary in depth from 2,500 to 4,500 fathoms, occupy most of the ocean floor. It is the scene of uniform deposits consisting of clayey muds composed of very fine particles, due to the chemical precipitation of matter held in solution by the sea water, and of the remains of organisms which live in the sea. The greatest depths form an abyssmal region which is as limited in area as the lofty mountains, and where the lead picks up only red clay of purely mineral origin, which seems to form a continuous layer of small depth.

Oceans and Seas. Oceans are distinguished from seas by a number of geographical differences. In oceans the deep areas are very extensive, whilst the continental shelf is comparatively small. The shores are formed by distinct continents at some distance from each other. There are few islands. Communication with other oceans is obtained by a broad expanse of sea. Hence, the oceans all have the same life, so to speak, and obey the same physical laws. The seas, on the other hand, always exist under abnormal conditions. Areas of considerable depth are limited in extent; not a few seas (e.g., the North Sea, the English Channel, the Baltic, etc.) are situated on a continental shelf. The shores are formed by

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[1] That is, a fall in the sea-level or an uplift of the continent.

a single continent with islands or peninsulas connected with it. Shoals, banks, and islands are numerous. Communication with the ocean is always more or less imperfect. It is often achieved through straits or over ridges whose depth does not allow of the direct exchange of bottom waters. Thus, each sea tends more or less to live its own life, and the circulation of water and the distribution of temperature and of salinity have peculiar features in each.

Marginal seas are to be distinguished from *continental seas.* The former are always situated on the edge of the great ocean basins and communicate with them over ridges and through straits which are sufficiently deep and sufficiently wide to allow the seas to share the life of the ocean basins to some extent, e.g., the China Seas, the Sea of Japan, the Caribbean, the North Sea, etc. Continental seas penetrate more deeply into the continents and communicate with the oceans through a narrow opening of little depth, e.g., the Baltic, the Mediterranean, the Black Sea, etc. The influence of the climate of the surrounding continent and the rivers which discharge into these seas sometimes stamps them with very peculiar characteristics. *Inland seas,* like the Caspian and Aral, are hardly distinguishable from lakes.

The principal laws which regulate the distribution of temperature, the density of the water, and the movements, are applicable to the oceans alone. The study of seas will form the subject of a separate chapter.

Surface Temperature of the Oceans. A knowledge of the distribution of heat at the surface of oceans is of the greatest interest in the explanation of climate. On comparing the mean temperature of the air with that of the water in different latitudes, one finds that the sea is slightly warmer near the equator and loses this advantage on approaching the tropics of Cancer and Capricorn; from latitude 40° on it recovers its advantage and remains right up to the poles an important source of warmth.

Latitude ...	0°	10°	20°	30°	40°	50°	60°
Air ...	78.6° F.	78.4°	75.6°	66.9°	55.6°	42.7°	32.5° F.
Sea ...	79.3° F.	77.9°	73.4°	66.56°	57°	45.86°	34.2° F.

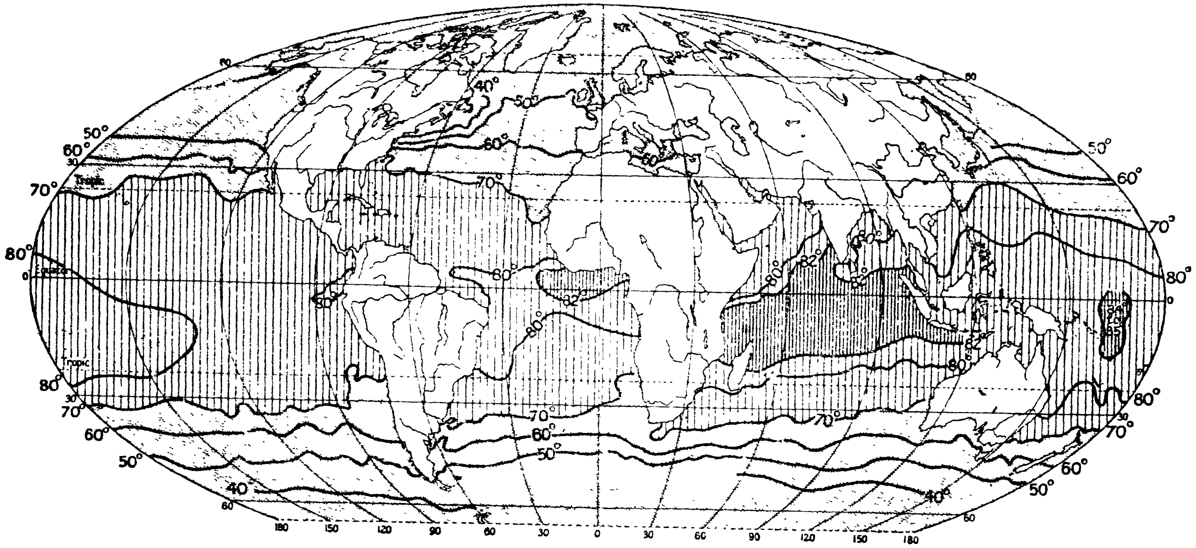

Fig. 24.—Isotherms showing the mean surface temperature of the ocean in February. (From the *Atlas of Temperature Charts*—Meteorological Office.)

A comparison of the isotherms showing the surface temperature of the sea and those showing the temperature of the air is particularly instructive (cp. Figs. 10 and 24, 11 and 25). In winter the sea is everywhere distinctly warmer than the air ; but the difference is most clearly marked in the North Atlantic. Figs. 10 and 24 show that the isotherm marking a temperature of 40° F. in the water follows the path of the isotherm for 32° F. of air temperature. In summer the sea is warmer only in the Indian Ocean and is notably cooler in the North Atlantic. Generally speaking, however, a striking agreement is noticed between the path of isotherms showing air temperature and those showing the temperature of the sea, in that they follow parallel sinuosities and show the same anomalies.

The causes of these anomalies are many, but the most important is the circulation of water which takes place in the oceans. The warm waters of the North Atlantic are carried from equatorial regions by the Gulf Stream. The cold waters off the coast of Africa and South America are due to currents flowing from the north or south and to ascending movements in the deeper layers of water caused by the rapid impulse given to the surface waters by the Trade Winds. But the shape of the ocean basins also exercises an influence which is easily recognised. However, most of the anomalies occur in the gulfs and marginal seas which do not communicate freely with the main oceans.

Marine Ice and Icebergs. The coincidence of very low air temperature with equally low temperature in the surface water of seas in high latitudes is bound to result in the more or less complete freezing of the surface of the sea. But the extent of ice-covered ocean is far greater than the area in which freezing takes place, for the sheets of ice (*ice-floes*), together with masses detached from the lower end of polar glaciers and known as *icebergs*, are swept by marine currents right down to the temperate zone. Polar ice is unknown in the North Pacific, and hence the surface temperature of the sea in that region is higher than at corresponding latitudes in the Atlantic. In the latter ocean polar ice spreads down the western shores and is carried by the Labrador and Greenland currents as far as Newfoundland. It is completely absent on the eastern shores

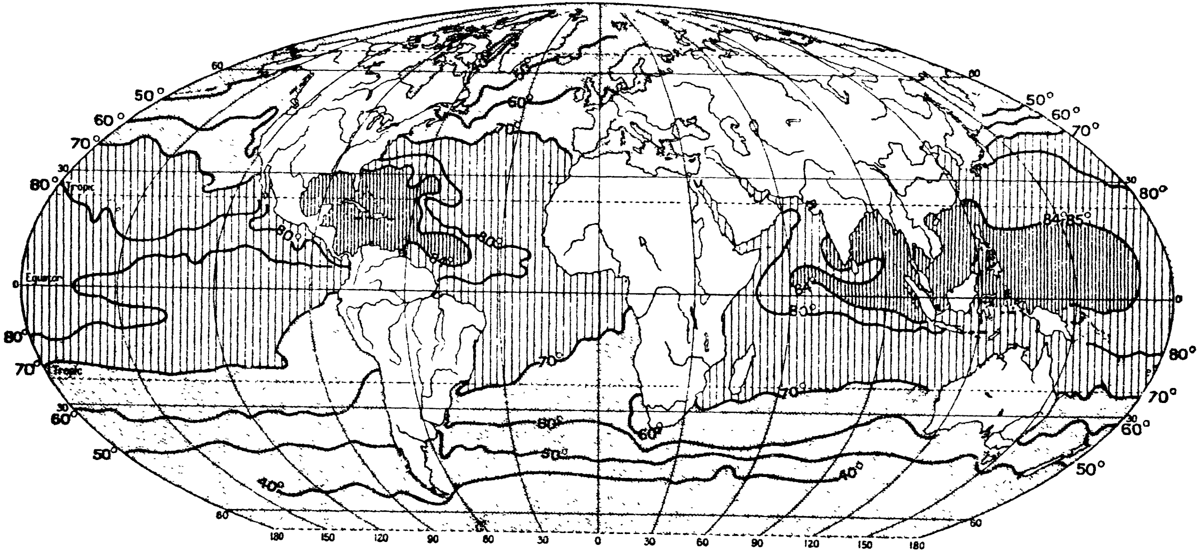

Fig. 25.—Isotherms showing the mean surface temperature of the ocean in August. (From the *Atlas of Temperature Charts*—Meteorological Office.)

which are warmed by the Gulf Stream. The areas covered by these currents, of which the western ones come from the polar regions and the eastern ones from the tropics, divide the Atlantic into two parts, one of which is abnormally cold and the other abnormally warm. The southern limit of floating ice advances or retreats according to the feebleness or strength and regularity of the westerly winds (see Fig. 26). Icebergs go much farther south than floe ice.

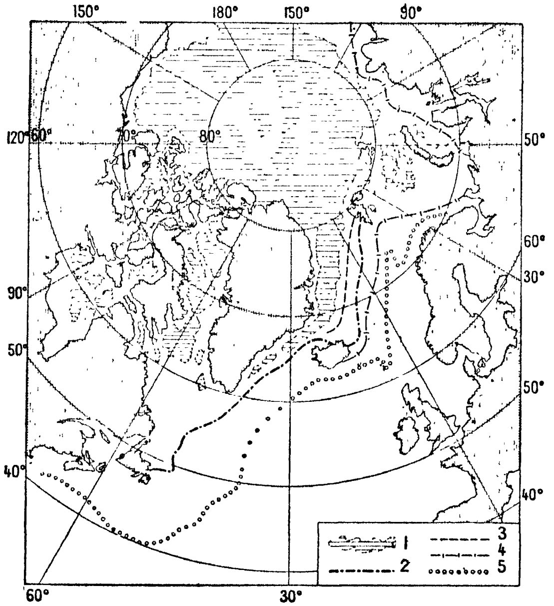

FIG. 26.—The Arctic Ocean, showing the variations in the extent of ocean surface covered by ice.

1 = permanently covered; 2 = mean limit of pack-ice; 3 = limit of minimum extension of area covered by pack-ice; 4 = limit of maximum extension; 5 = southern limit of icebergs.

Icebergs often reach a height of over 200 feet, and sometimes of over 300. Their submerged portion is anything from four to seven times greater than the part above water. Their horizontal dimensions depend on the glacier which gave birth to them: the gentler the gradient of the glacier the larger the berg. In the northern hemisphere, most of the icebergs originate in Greenland, hence they are unknown on the coast of Siberia and in the Pacific. The same currents which sweep along the floe

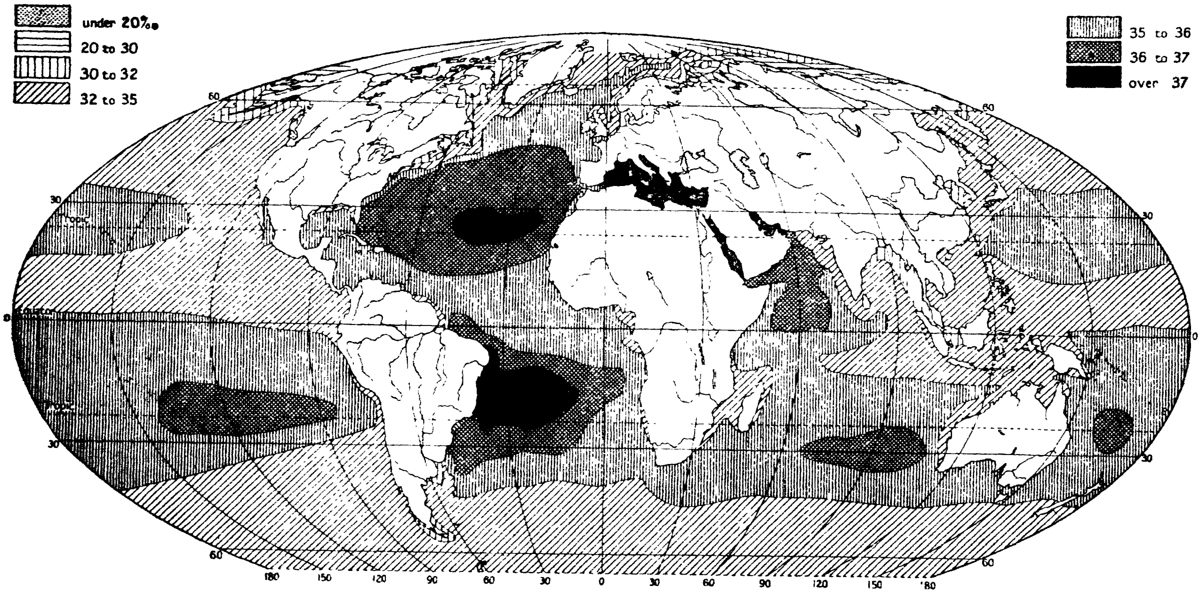

FIG 27.—Salinity of the surface water of the oceans (After Schott.)

ice carry the bergs as far south as and even beyond Newfoundland. Their frequent appearance in this region is rendered all the more dangerous by the thick fogs they cause. Every year they cause the loss of numerous fishing vessels, but they can also sink even the largest transatlantic liners (cp. the loss of the *Titanic* in April, 1912).

Salinity of the Surface of the Oceans. The variations in the salinity of sea water are important, as much on account of their influence on marine organisms as on account of the accuracy with which they reflect the nature of the climate of adjacent land. Although the salinity is fairly uniform in oceans which communicate freely with each other, a rather marked difference is observed between the polar zone, where the salinity falls to 3.2 per cent, and the hot belt, where it rises to 3.7 per cent. Salinity is not greatest at the equator, because the rainfall there is very great and the air is calm, but near the tropics of Cancer and Capricorn, where rain seldom falls and evaporation is assisted by the Trade Winds or the Westerlies. One might expect very high salinity in high latitudes, where there is little precipitation, but the effect of the inflow of the great rivers of the polar basin in Siberia and Canada and of the melting of icebergs must not be forgotten. The circulation of ocean waters produces certain anomalies. Thus, in the North Atlantic the similarity between lines showing surface salinity and the isotherms clearly indicates the flow of warm, salt water towards the coast of Europe and of the less salt, cold polar streams towards the coast of Greenland.

Temperature at Great Depths. What has already been said makes it clear that it is difficult to understand the geography of the surface waters of the ocean without a knowledge of their movements. The same conclusion is reached if one penetrates down to the greatest depths.

Generally speaking, temperature decreases from the surface to the bottom. At the same time variation lessens, becoming hardly appreciable at a depth of 200 fathoms. Local differences also gradually disappear: below 1,000 fathoms a temperature of less than 37° F. is observed almost everywhere, and this decreases slowly to close upon 32° F. Such uniformity

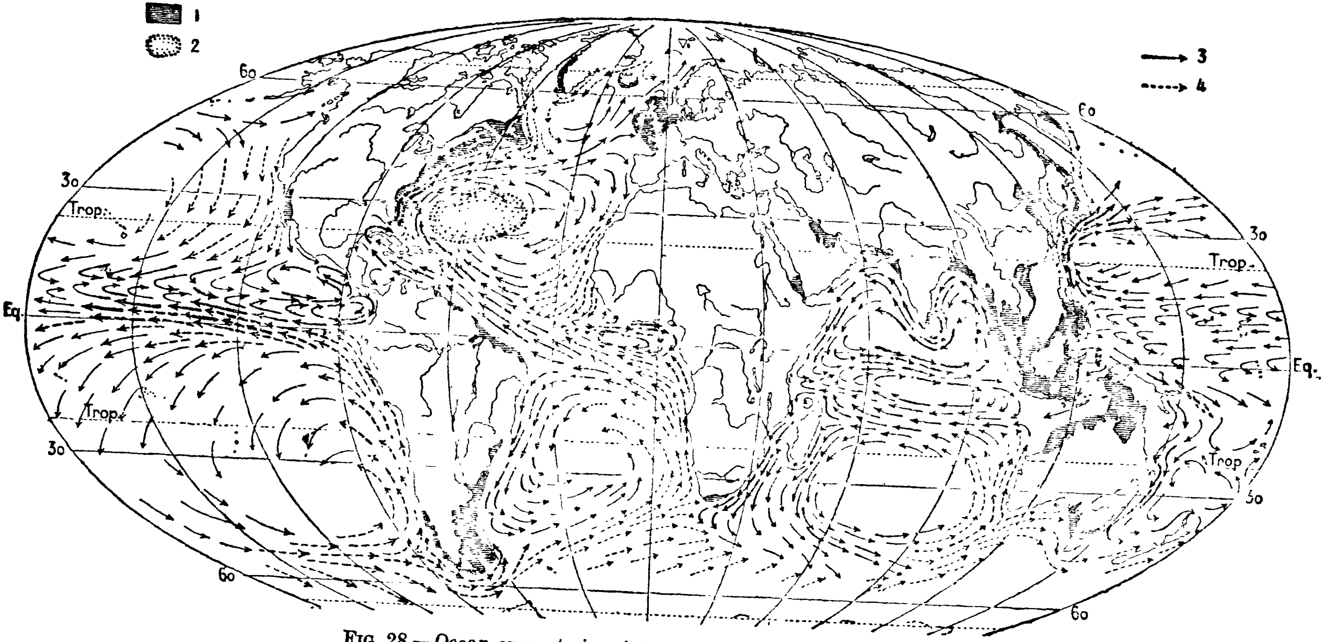

Fig. 28.—Ocean currents in winter. (From the *Deutsche Seewarte.*)
1 = zone of strong tides; 2 = the Sargasso Sea (an accumulation of floating seaweed in the centre of the North Atlantic system); 3 = warm currents; 4 = cold currents. The relative velocity of the currents is indicated by the thickness and number of the arrows.

is only to be explained on the theory of very free circulation at great depths. The temperature does not always fall constantly with the depth. In high latitudes a layer of cold water has been observed at a depth of between 50 and 150 fathoms. The lowest temperatures are found in the Antarctic regions, not only at the surface, but at almost every depth. If one remembers that it is just in that direction that all the oceans open out, one is led to suppose that the water at great depths, which is everywhere—even in the hot belt—of very low temperature, is constantly being renewed by a gradual underflow of water from the Antarctic.

Ocean Currents. Thus, everything points to the geographical importance of the circulation of ocean waters. This importance can only be suspected as far as the great deeps are concerned, but it can be seen at the surface, where the circulation takes the form of currents strong enough to carry ships out of their courses. Their average rate of flow is 3.28 feet per second, but in exceptional cases it rises to 8.2 feet per second, as in the Gulf Stream when it issues from Florida Strait. The velocity, however, decreases rapidly with depth and is rarely perceptible at 100 fathoms.

A map showing all the ocean currents makes it evident that they form separate systems of swirls in the different ocean basins in both hemispheres, and that the movement goes in opposite directions on each side of the equator. Hence, it may be concluded that the currents are influenced by (i) the shape of the ocean basins, and (ii) the rotation of the Earth, which, as has been shown already, deflects every moving body on the Earth's surface.

The currents of low and middle latitudes are sufficiently explained by the theory which attributes these surface movements of the oceans to the friction of the wind. The Trade Winds, which are the most constant of all winds, drive the water south-west and north-west; and the movement thus produced, being deflected towards the right in the northern hemisphere and towards the left in the southern, causes a flow of currents to the west. These are the Equatorial Currents, which are so strong in the Atlantic and Pacific. The place of the water thus driven away from the eastern shore of each ocean is filled by a counter current from the west, the one which flows in the Gulf of Guinea being particularly clearly defined. The general flow of equatorial waters towards the west has other results : checked by the land masses, the current tries to flow off north and south, but, since the deflection according to Ferrel's law increases with latitude. the movement ends in a swirl, which turns clockwise in the northern hemisphere and anti-clockwise in the southern. The shape of the Atlantic favours the swirl in the northern hemisphere at the expense of that in the southern. Cape San Rocas in Brazil divides the South Equatorial Current into two branches, one of which flows north to reinforce the North Equatorial Current. This explains the surprising strength of the current in the Caribbean Sea, where it is a veritable moving sea 180 miles in breadth and 100 to 150 fathoms deep.

One fact seems to prove that the friction of the Trade Winds is really the cause of these movements, viz., that the equatorial currents swing north or south according to the position of the equatorial belt of calms (see Fig. 29). In the Indian Ocean the reversal of the monsoon winds is actually accompanied by a complete reversal of oceanic circulation.

In high latitudes the conditions are more complex, and it does not seem possible to attribute the ocean currents there exclusively to the action of the winds. The Gulf Stream, which crosses the North Atlantic obliquely, follows the direction of the west-south-west winds that prevail in this belt—a fact that by itself is sufficient to prove that the current is not due to the friction of the winds, since the deflection due to the rotation of the Earth would, if that had been the case, have given the current a different course. It is probable that currents in high latitudes are chiefly due to differences in temperature and density of the water. In the North Atlantic the prevailing tendency is towards an exchange of the warm, salt water of low latitudes for the cold, less salt water of polar regions. The flow of water from the hot belt is towards the eastern shore of the ocean. thus forming the Gulf Stream. The polar waters are discharged on to the western side of the ocean, flowing along the coasts of Greenland and Labrador as far as and beyond Newfoundland. The influence of the rotation of the Earth helps in determining within narrow limits the course of these two currents, and, being both deflected to the right, one makes for the coast of Europe and warms it, while the other hugs the coast of America and makes it very cold. Hence, the warm waters of the Gulf Stream bathe the whole of the Irish coast and penetrate even into the fjords of Norway, keeping them always free from ice as far as the North Cape. The waters of the Labrador Current flow over the Newfoundland Banks and past them south-westwards to bathe the American coast as far as Boston and New York. There they come in contact with the Gulf Stream proper.

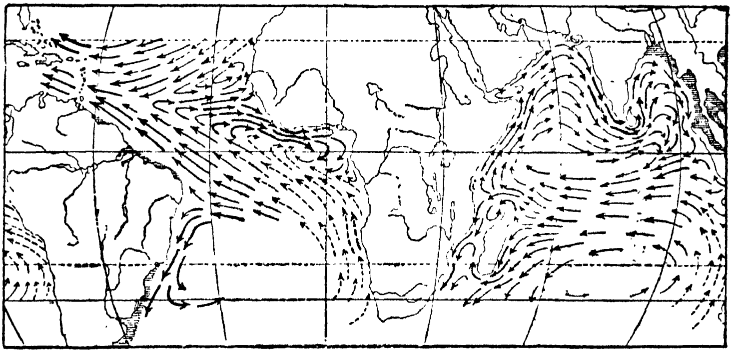

FIG. 29.—Changes which occur in the circulation of ocean currents in summer (August) in the Atlantic and Indian Oceans.

The struggle between the two currents has long been noticed by sailors. The name *cold wall* used to be given to the line of demarcation between the warm and the cold waters, a line which is often marked by a sudden jump of more than 18 or 20° F. in temperature and by the very colour of the water. The contact between the polar and the tropical streams has important results, not only from the physical, but also from the biological point of view. It hastens the melting of icebergs, which drop the solid matter they have been bearing along, and thus it causes the bottom of the sea to be raised by increasing the height of the Newfoundland Banks ; it gives rise to thick fogs and favours the formation of the cyclones which move eastwards to Europe. Lastly, it contributes to the development of animal life in the ocean and makes this region rich both in tropical and arctic plankton,[1] thus attracting fleets of fishing boats to these inhospitable shores.

Caused though they may be by differences in temperature and density, yet currents in high latitudes are not uninfluenced by the winds, the friction of which sometimes quickens and at other times slows down their rate of flow. Thus, the Gulf Stream is reinforced by the system of Westerlies, and checked by the north-west winds. The variations thus caused in the current have an effect on the climate of Western Europe, which owes its exceptionally temperate winters to this stream.

Waves. Although imperceptible to the eye, ocean currents have, nevertheless, a far greater geographical importance than the surface movements—waves and tides—which are visible to all.

Waves, which are the direct result of the friction of the wind, represent only an oscillatory movement like that produced by a stone thrown into a pond. The ripples which form round the place where the stone falls do not cause horizontal displacement of the floating leaves they lift in their passage. Similarly, the ocean *swell* reaches to great distances and causes the biggest ships to roll, but does not sweep them on as do the imperceptible currents. There is no real displacement except when the velocity of the wind suddenly increases and causes the wave crests to topple over, thus producing *white-horses*, or when the wave, as it approaches the shore and becomes retarded at its base owing to the lessening depth, breaks with the characteristic roar of the surf.

Waves are chiefly important in geography as agents of erosion. Their size is far less than one is led to suppose from mere impression. Apart from the breakers which often dash high on steep coasts, throwing spray to the tops of the cliffs, waves higher than 23 feet are rarely seen in the open sea. The undulating movement is sometimes felt down to more than 50 fathoms below the surface, but its erosive action hardly goes deeper than about 30 fathoms.

Tides. The phenomenon of the tides is particularly striking on low coasts, where a whole system of nomenclature has been

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[1] The term *plankton* denotes the whole collection of animal or vegetable organisms, mostly of microscopic size, which drift at the mercy of the surface currents (cp. Part IV, Chap. XX, p. 286).

invented to denote the chief aspects. Twice a day the sea advances up its shores like a river overflowing its banks, first working its way through the channels at a speed which is sometimes equal to that of a trotting horse, and then gradually covering the intermediate sand and mud. This is the *flow*, *flood*, or rising tide. Twice a day the *ebb*, or falling tide, carries the water back by the same paths. Sometimes a distance of more than six miles separates the *high water mark* from the *low water mark*. Everyone knows that the ebb and flow are due to a rise and fall of the whole surface of the sea. Ships are raised and lowered at the quayside, sometimes even left stranded at low tide, thus showing that the range of sea-level amounts to many feet. It is noticed, however, that the range varies from day to day. Its maximum, which recurs every fifteen days, is called the *spring tide*; whilst its minimum, which follows a week after the maximum, is known as the *neap tide*. It has long been recognised that this periodicity indicates evident connexion with a cosmic phenomenon whose cycle is also monthly, viz., the revolution of the Moon round the Earth. In early times the ancients had noticed the coincidence of the spring tide with certain phases of the Moon (*syzygies*).

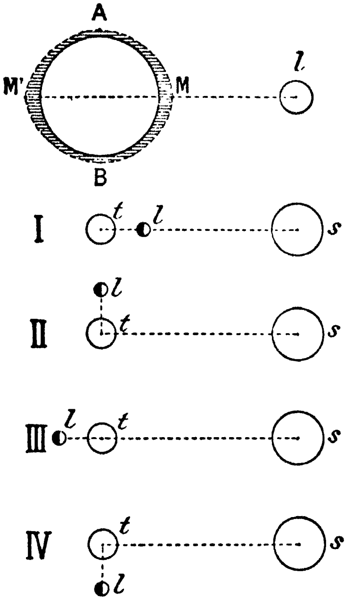

FIG. 30.—The theory of tides.

The effect of the moon is shown above Nos. I, II, III, and IV show the relative positions of the sun (*s* = *sol*), moon (*l* = *luna*), and earth (*t* = *terra*). I and III are syzygies; II and IV quadratures.

Fig. 30 shows the theory of tides as they would occur on a globe entirely covered over with water. The attraction exerted by the Moon on the film of ocean reaches its maximum at M and its minimum at M^1. Hence results a swelling of the water at these two points. The rotation of the Earth causes an apparent displacement of M and M^1, and sends a double wave round the globe daily. But the Moon is not the only influence at work: the Sun tends to produce the same effect, though, since it is much further away than the Moon, in spite of its greater mass it has less influence. When the two heavenly bodies are in the same straight line as the Earth (syzygies, I and III), their influence combines, and the height of the tidal wave reaches its maximum. This is the *spring tide*. In the intermediate positions, which are known as *quadratures* (II and IV), the influence of the Sun acts against that of the Moon, and the tidal wave is at its minimum. This is the *neap tide*.

On this, then, it has been calculated that the maximum range of the tides should be 35.4 inches. Actually, it is everywhere greater than this and varies considerably in different places. The cause of this discrepancy is that the surface of the Earth, unlike that of our theoretical globe, consists partly of land and partly of sea, and the latter varies in depth and contains islands and gulfs. The tidal wave, which affects the whole mass of ocean water, is greatly impeded in its progress, and rises all the more as its advance is hindered on approaching the coasts, just as ordinary waves do. In gulfs and marginal seas the tide is most impeded, and consequently its greatest range occurs in them; for example, there is a range of 46 feet in the Bay of Mont-Saint-Michel and of 59 feet in the Bay of Fundy in Nova Scotia. In certain channels the velocity of the currents at ebb and flow equals that of a torrent, and the water swirls and seethes as it races between small islands like the islets of Morbihan in France or the Lofoten Islands in Norway. In estuaries, when the velocity of the river reaches a certain degree, the rising tide sometimes causes the formation of a breaker which advances upstream. This has various names in different rivers: thus, in the Severn it is called a *bore*, in the Trent the *egre*, in the Seine *le mascaret*, in the Amazon the *pororoca*.

The action of ocean currents in sweeping away the sediment brought down by great rivers that discharge into the Atlantic causes the estuaries of these rivers to be useful for navigation and to afford shelter for great ports like London, New York, Liverpool, Hamburg, and Bordeaux, etc. Continental seas have almost imperceptible tides and therefore have no estuary ports.

CHAPTER VII

SEAS

Peculiarities in Seas. The general impression left by a study of the oceans is that their uniformity is remarkable. The great deeps have everywhere a temperature approaching 32° F., while three-fourths of the total volume of the oceans does not exceed 37.4° F. The salinity never departs to any extent from the average of 3 per cent. Variations in temperature even at the surface are, if not insignificant, at any rate always regular. This uniformity is due to a general circulation which is made possible by the great expanse of the ocean deeps and by the wide communication between all the great oceans. Seas, on the other hand, are by definition restricted basins and are more or less isolated. In them neither temperature nor salinity presents the same regularity and uniformity as in the oceans. Being more or less apart from the general circulation, seas are directly subject to the influence of local factors of climate and even of the factors controlling the climate of the whole continents in whose expanse they are more or less inset. All the anomalies found in the various seas are due to this fact, and the more isolated a sea is the more marked are its anomalies.

The surface water is always warmer and salter in low latitudes, colder and less salt in high latitudes than the surface waters of neighbouring oceans in the same latitudes ; and the annual range of temperature is always abnormally great.

The temperature of the deep waters is still more peculiar. Seas isolated by a sill, or ridge across the connecting strait, always keep the same temperature from the level of the sill down to their greatest depths. In technical language, homothermal conditions exist from the level of the sill downwards. The best known example of this phenomenon is the Mediterranean, whose waters keep the temperature of 55.0° F. from the level of the Gibraltar sill to the bottom. This is a direct proof that the low temperatures which prevail in the depths of the great oceans are really due to a slow underflow of polar waters. Protected by the sills which isolate them more or less completely, seas have abnormally high temperatures. It may even happen that the temperature of the bottom waters is higher than that of some of the upper layers. This is the same as the inversion of temperature which is found in isolated valleys (see above) and occurs regularly in all cold seas.

Like the thermal *régime*, the movements of the water in seas have special features. Tides are abnormal by reason of their greater range and, in marginal seas, of their periodicity, or else they are almost non-existent, as in continental seas. Currents take the form of circular systems independent of those of the oceans ; but anomalies of temperature and density very often cause swift outflowing streams. In fine, the circulation of water in seas depends chiefly on the factors of depth, shape of basin, and more or less free communication with the ocean. The more nearly complete the isolation, the more marked are the anomalies. Already noticeable in marginal seas, the anomalies become far greater in continental seas and end by giving enclosed seas the character of lakes. We shall try to illustrate this progressive falling away from the oceanic *régime* according to the more or less complete isolation of the sea by examining some of the best known examples.

East Indian Seas. Marginal seas are found chiefly round the coasts of the continent of Eurasia. They form a continuous line on the east coast of Asia : Bering Sea, the Sea of Okhotsk, the Sea of Japan, the China Seas, not to mention the maze of East Indian seas comprising the Sulu, Celébes, Java, Banda, and Arafura Seas. Western Europe can count among its marginal seas the North Sea, the English Channel, and the Irish Sea. The New World has only three true marginal seas, namely, the Caribbean, the Gulf of St. Lawrence, and the Gulf of California. The north polar basin should be placed in the category of marginal seas, although it approaches nearly to the character of a continental sea. In all these seas the surface waters communicate rather freely with the oceans, but the bottom waters are isolated by more or less elevated sills.

The East Indian Seas may be taken as an instance of warm marginal seas. They are all open on two or three sides, so that the tides penetrate into them through several straits. The surface waters are not much higher than the neighbouring ocean in either temperature or salinity, but the deep layers are abnormally warm. The deep waters of the seas are sufficiently well known to permit the law of homothermia to be verified. The homothermal layer is determined by the height of the sills. In the Banda Sea the temperature is 47.3° F. at a depth of 270 fathoms, and from a depth of 875 fathoms to the greatest known depths (3,550 fathoms) remains constantly at 37.9° F. Almost the same conditions exist in the Celébes Sea ; but the most striking example is seen in the Sulu Sea, in which a temperature of 50° F. prevails constantly from a depth of 400 fathoms to 2,500 fathoms. A homothermal layer of over 2,000 fathoms in depth with a constant temperature of 50° F. represents a considerable reserve of heat.

The Arctic Basin. This is a true marginal sea, divided by sills into several basins and almost separated from the Atlantic by a shallow ridge 550 fathoms deep running between Scotland and Iceland (see Fig. 31). This arrangement prevents the polar bottom waters from discharging into the Atlantic. Between the surface and a depth of 11 fathoms a layer of water of slight salinity (1.2 to 2.2 per cent) is observed, which comes from the melting of snow and ice. Its temperature, though usually about 32° F., varies considerably with the season. Between this layer and a depth of 130 fathoms is a cold layer, in which the salinity is less than 3.5 per cent on account of the inflow of the waters of the great Siberian rivers. Below this down to 550 fathoms is a warm and very salt layer. This consists of the waters of the Gulf Stream, which after having crossed the sills plunge by their weight below the surface waters, since the density of the latter is lessened by their slight salinity. Finally, below 550 fathoms right down to the bottom there is a mass of cold, heavy water whose temperature, high for the latitude, proves that the water escapes the influence of the surface layers and does not mingle with the upper layers. This water never issues from the polar basin, but remains there indefinitely, taking no part in the general circulation of the oceans.

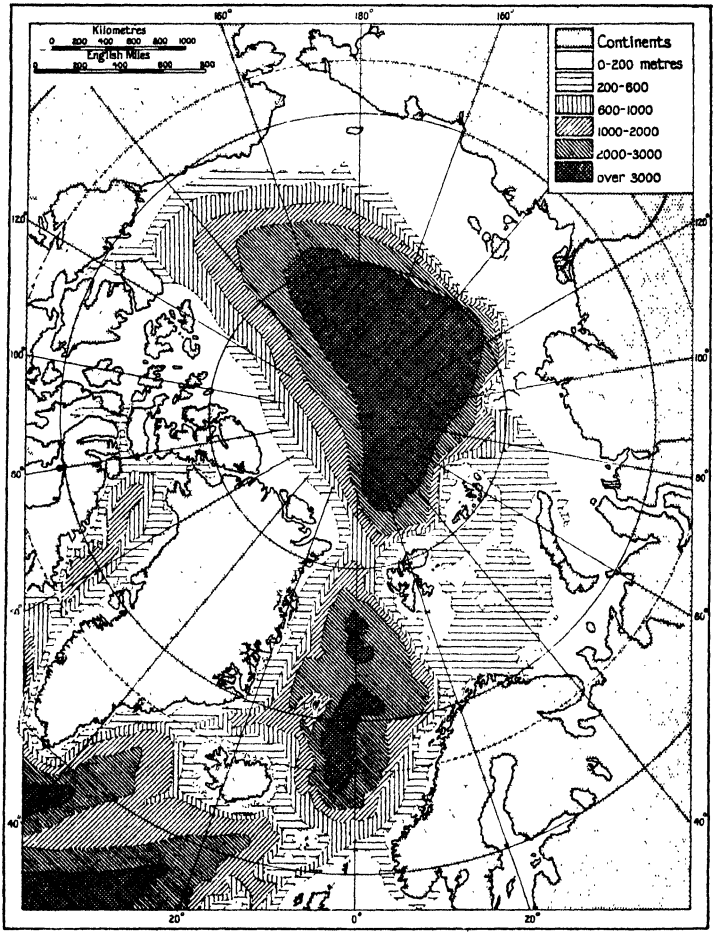

FIG. 31.—Map showing depths of the Arctic Ocean. (After Nansen.)

The whole circulation is therefore at the surface. A permanent cold current of extraordinary regularity carries the upper layers westwards. It was on this current that Nansen counted to drift his expedition to the pole; but his path has clearly shown that the current tends to move in a circle. On the other hand, some of its water escapes over the Spitsbergen sill and flows along the east coast of Greenland. The warm waters from the Gulf Stream form a circular current flowing below the surface and in the opposite direction to the upper circulation. Prevented from cooling by the surface layer which covers it over, they are unable to influence the climate.

The importance of submarine relief is here evident. If the sills were less elevated, more cold water would enter the basin, circulation would be greater, and the warmth of the surface be felt over a broader belt of the coast of Siberia; but, on the other hand, the polar bottom waters would be able to flow down into the North Atlantic and to reduce the temperature of that ocean. If, on the contrary, the sills were raised, the entry of warm water into the polar basin would be impeded and Novaya Zemlya and Barents Sea would suffer a corresponding reduction in temperature; but the North Atlantic would gain by the change. Owing to the abnormal character of its circulation and of its thermal conditions, as well as to the influence of the surrounding land, the Arctic basin is, under existing circumstances, almost a continental sea.

The Mediterranean. The Mediterranean represents the type of continental seas. It communicates with the Atlantic only through the Strait of Gibraltar, which has a depth of less than 100 fathoms. Submarine banks, which occur at the narrowing of the sea between Sicily and Africa, separate it into two basins. Branching peninsulas and large islands also mark off a number of subordinate seas, like the Tyrrhenian, the Adriatic, and the Ægean. Such a relief precludes the general mingling of the waters through active circulation, and the climate tends to accentuate the differences between the various parts of the basin. It has been shown above that the Mediterranean climate shades off gradually eastwards and southwards into a semi-desert climate with insufficient rainfall and intense evaporation.

The effects of the relief of the surrounding land must also be considered. The lofty chains of parallel ranges which come close to the shore do not permit the formation of great river basins. Insufficiently fed by rain, the Mediterranean receives a hardly more abundant supply of water from its rivers. Hence, evaporation is bound to cause an increase in density eastwards and southwards. At Gibraltar the percentage of salinity is 3.65 ; it reaches 3.77 near Nice, and 3.78 off the coasts of Spain ; and it exceeds 3.9 off the coasts of Tripoli and Egypt.

To counteract this increasing density, the Mediterranean calls in the aid of water from neighbouring seas which are less salt. The distribution of salinity in the Grecian Archipelago reveals the existence of a current of slight salinity which flows out of the Sea of Marmara. But the Atlantic is still more drawn upon: a double current passes through the Strait of Gibraltar, one consisting of a surface flow of lighter water from the Atlantic inwards, the other of the denser Mediterranean water moving along the bottom (see Fig. 32). This exchange of water affects only the surface layers. In the western basin of the Mediterranean the density of the water at a depth of 300 fathoms is found to be almost the same as that of the surface waters of the eastern basin. Near Monaco the percentage of salinity reaches 3.84 at a depth of 270 fathoms, at Pantellaria it reaches 3.94 at a depth of 220 fathoms.

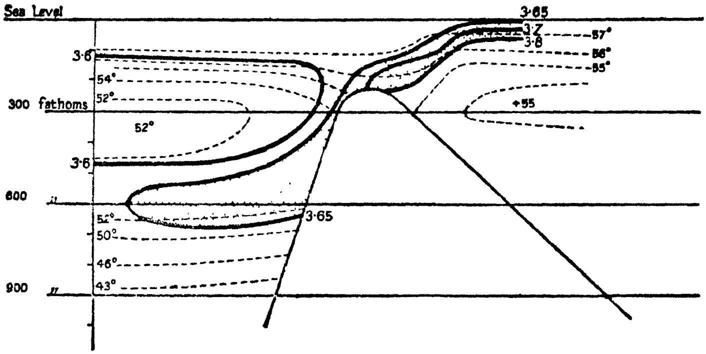

FIG. 32.—Section of the Straits of Gibraltar. The shaded portion shows the overflow from the Mediterranean of a stream of water with a high percentage of salinity. The double inversion of temperature thus caused is also seen.
Isotherms are shown by broken lines, while continuous black lines show surfaces of equal salinity. Temperatures are given in degrees Fahrenheit, salinity in percentages.

The stagnation of the bottom layers and the insufficient mingling with the waters of the ocean have the usual effects on the temperature of the Mediterranean. A homothermal layer with a temperature of about 55° F. extends downwards from the 200 fathom line; a depth which nearly corresponds to that of the Strait of Gibraltar. It approaches the surface off the coast of Spain, but is found only at a greater depth than the normal off the coast of Algeria, where the influence of the waters flowing from the Atlantic is most felt. If one thinks of the great depth of some parts and of the extent of the Mediterranean, one cannot but be struck by the vast reserve of heat which is stored up in the huge mass of water whose temperature remains fixed at 55° F. by the influence of local climate. The warmth of the deep layers certainly reacts on the surface layers by maintaining in them a high and relatively constant temperature.

Extreme Cases: the Red Sea and the Baltic. The Mediterranean is the type of moderate continental seas. The Red Sea, however, illustrates what a high degree of temperature and salinity can be produced by almost complete isolation in a hot climate. Stretched out between two desert lands from which no stream flows into it and communicating with the Indian Ocean through a narrow strait only 100 fathoms deep, this sea has a surface salinity of 4 per cent and a temperature of 87.8° F. The heat accumulated in the basin isolated by the sill of Bab-el-Mandeb is so great that the thermometer, on passing from a depth of 270 fathoms to the bottom, does not fall below 70.7° F.

The Baltic is an instance of the opposite extreme and shows how a sea, though almost isolated, may be almost fresh, if it is in a cold and rainy climate and receives the water of great rivers. The passages through the Danish islands are less than 11 fathoms deep. Through them the salt, dense waters of the Atlantic penetrate as an undercurrent, whilst the less dense waters of the Baltic flow out on the surface. But this exchange is not sufficient to make the salinity normal: the percentage is 3 in the Skagerrack, 2 in the Kattegat, 1.75 in the Great Belt; while at Bornholm it falls below 1 and in the Gulf of Bothnia below 0.5. It varies, however, with the season and with the discharge of water from the rivers.

The temperature of this sea also undergoes far greater variations than is observed in the ocean. Near Danzig it is between 60 and 65° F. in summer, whilst in winter the water is sometimes frozen over. Between Stockholm and Hangö in Finland the summer temperature of the water is from 57 to 59° F., though in winter the surface is often frozen. At Haparanda (65° N.) a temperature of 50° F. is found in summer, whilst in winter the sea is frozen for several months. These variations are confined to a surface layer 25 fathoms deep. The minimum temperature (33.3° F.) is reached at this depth of 25 fathoms. Below this the curve of temperature rises, as it does in the polar basin, owing to the stagnation of salt water from the Atlantic at the bottom.

Owing to its very slight and very variable degree of salinity and to its thermal system, the Baltic hardly deserves the name sea. Even its level is not constant, and there is always a difference of about 18 inches between the coasts of Denmark and East Prussia. The difference in level varies according to the influence of the wind and to the varying amount of water discharged by the rivers.

The Caspian and Aral Seas. The change from oceanic conditions is even more marked in enclosed seas like the Caspian and Aral. The water is brackish near the mouths of large rivers, whilst at places where no big stream discharges the density caused by salts in the water is sometimes so great as to cause the formation of saline crusts. If evaporation is greater than the supply of water brought in by rivers, the volume of water gradually diminishes, and, whilst even the most abnormal continental seas are kept by their communication with the ocean at more or less the same level as the oceans in general, the surface of enclosed seas rises and falls, and in the end gradually sinks. Thus, the Caspian Sea is at the moment 85 feet below the general level of the oceans. Its salinity is less than 1.4 per cent in the northern part; a fauna belonging to brackish water, and even some fresh water species, live off the coast near the deltas of the Volga and Ural Rivers. On the other hand, the salinity is extremely great on the east coast. In the Gulf of Karabogaz, which is separated from the rest of the sea by a bar 6½ feet deep, the density is so great as to kill the fish, and crusts of salt are deposited on the shore. On the whole, however, the Caspian is becoming less salt.

The Aral Sea is still more advanced in this process of evolution, which is bound sooner or later to turn into a lake every sheet of water which is separated from the main body of the ocean. Its mean salinity hardly reaches 1 per cent, whilst on the southern shores the water is quite fresh. The level, which rises or falls according to climatic variations, has been rising since the year 1900.

CHAPTER VIII

LAKES

LIMNOLOGY, or the science of lakes, is connected with oceanography, and has the same problems and employs the same methods. In it, however, an exact knowledge of depth is of special importance, for while the level of the ocean is more or less constant, that of lakes is liable to variations which depend on the shape of their basins and on certain other factors. The shape of the basins also exerts an influence on the system of temperature. Hence, the first step in the study of lakes is to determine the characteristic features of their topography and the peculiarities they owe to their mode of origin.

General Topographical Features. Fishermen on Lake Geneva know that a shallow ledge runs along the shore-line, even when this is abrupt. They call it the *beine.* It ends outwards in a bank, called the *mont,* which slopes steeply to great depths, where the bottom (known as the *plaine*) is remarkably uniform. The *beine,* which is caused by the erosive action of waves, the slope of the *mont* formed by the waste detached from the shore by erosion, and the plain, levelled by the deposition of fine sediment, are found in all fairly big lakes (see Fig. 33).

Lakes are usually fed by brooks or tributary streams, and their overflow runs off in one or sometimes more outflowing streams. But certain lakes have no outlet on the surface and discharge their water through subterranean channels. In such cases the variations in the surface level of the lake are far more irregular and may even become spasmodic. Lakes which have no outlet to the sea are still more sensitive to climatic influences. In hot regions they are liable to dry up completely after an intermediate stage, in which the water reaches a high degree of density owing to the amount of salt it contains in solution. The density is often great enough to cause the deposition of saline crusts on the shores. In cold countries, on the other hand, lakes are threatened with being silted up. In both regions their precarious existence is due to their isolation.

Origin of Lakes. The accumulation of water in an enclosed hollow is the cause of every kind of lake. The hollow may be entirely due to the natural structure of the Earth's crust, or it may result from the obstruction of a natural drainage channel. In the first case, the depth of the lake is usually greater and the permanence of the lake more assured than in the second. Movements of the Earth's crust, volcanic action, the peculiar effect of glacial action on the surface relief—these are the principal causes which sometimes lead to the formation of lakes in the natural hollows of the ground.

Many examples are known as *tectonic lakes*, i.e., those resulting from tectonic movement. They are usually caused by faulting and lowering of the surface. Such, for instance, are the lakes in Oregon, and those in East Africa which lie on either side of Lake Victoria along two large rift valleys (see Part III, Chap. XIV). Such lakes are sometimes very deep and large, and they are generally without any outlet to the sea and are greatly affected by climatic variations. The bottoms of their basins, and indeed in some cases even their surfaces, are sometimes below sea level.

In limestone countries enclosed hollows known as *poljes* are often occupied by lakes which usually have no outlet on the surface. Their origin is partly due to dislocation of the rock and partly to karstic erosion. The craters of extinct volcanoes contain circular lakes which are very deep and have no outlet. Numerous examples occur in the Central Highlands of France; e.g., Lake Pavin, Lake Bouchet, etc.

Glacial erosion sometimes hollows out basins in which water accumulates when the glacier has melted. In mountain valleys these basins have the characteristic elongated shape found in all Alpine lakes (see Fig. 33). They are generally very deep, being at times gouged out right down to below sea-level, as in the case of some of the lakes in Cumberland and of Lake Garda and

Lake Maggiore in Italy. Nearly all such lakes have an outlet on the surface.

Barrier lakes are all more or less temporary. The dam may be formed by landslides—as frequently happens high up in mountainous regions. There are many instances of this kind of lake, which have during historical times both been formed and actually passed out of existence once more. When the ice of a passing glacier forms the obstruction, the lake is hardly more long-lived. Such lakes are caused by the accumulation of water in a secondary valley at its point of confluence with a larger valley in which a glacier passes. The Märjelen See, which is dammed in by the Aletsch glacier, is the best known example. It occurs in the Bernese Alps (see Fig. 34).

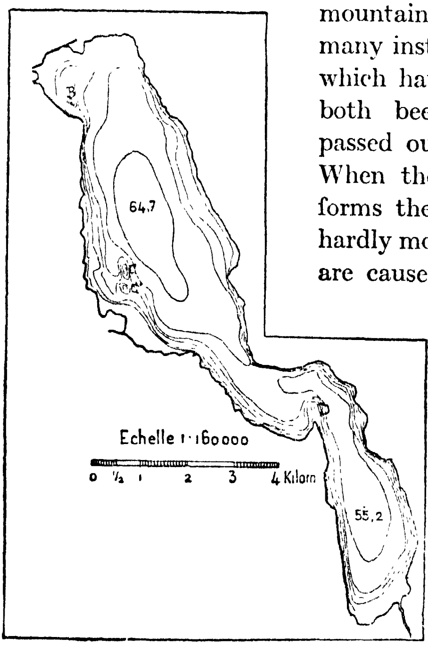

Fig. 33.—Map showing the underwater contours of Lake Annecy, a typical glacier lake.

Note (1) the extent of the *plaine* (flat bottom), and (2) the *beine* or shelf running round the shore and separated from the *plaine* by a steep slope.

A lava stream may produce the same result as a glacier. But the lake will continue to exist after the volcano has ceased to be active, so long as the dam has not been pierced by erosion. Lake Aydat in the Auvergne is a good instance of this phenomenon. In valleys through which glaciers formerly passed, the moraines left behind form dams behind which water accumulates. Lakes formed thus are shallow, unless a basin had been dug before by the glacier on the upper side of the dam, as often happens on the slopes of the Alps; e.g., Lake Geneva, Lake Constance; and in the English Lake District, as in Windermere and Ullswater.

Big rivers form lakes in their flood plains. Such lakes would be found in disused parts of the bed (e.g., an ox-bow or mortlake). or in hollows enclosed by natural dykes built up by alluvium on the banks of the main channel of the stream. They are known as *marigots* on the Niger, *bayoum* on the Mississippi, and *mayeh* on the Nile. Fed by the overflow from the river or by the infiltration of water through the dyke in times of flood, they almost disappear in the dry season each year.

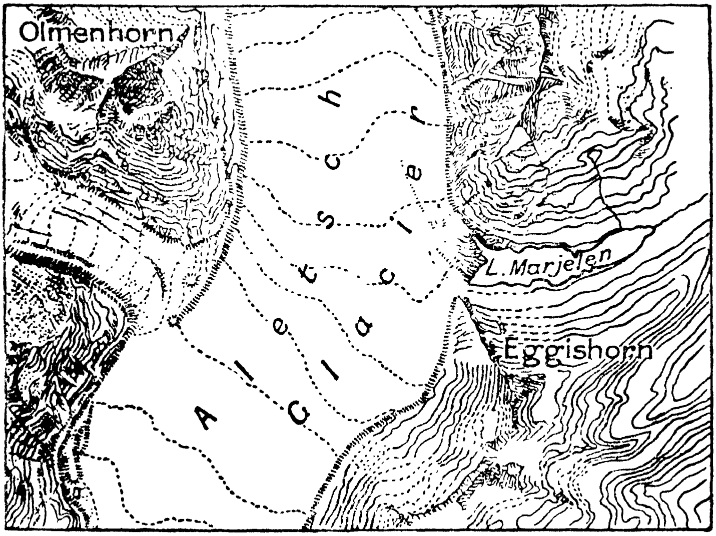

FIG. 34.—The Märjelen See, formed by the Aletsch glacier which passes across and blocks the end of a branch valley.

Scale 1 : 75,000. (After the official Swiss map on a scale of 1 : 50,000.)

The Temperature of Lake Waters. The thermal system in lakes differs essentially from that of seas, because the salinity of the water is so slight as to be negligible. The temperature of lakes is regulated by the insolation that occurs at their surfaces. Hence it decreases with depth, but great irregularities occur owing to the fact that the maximum density of fresh water is reached at 39.2° F. The stillness of lake water, which is not disturbed by great currents like those of the ocean, allows the denser layers of water to sink and the lighter ones to rise, and this leads to an abnormal distribution of temperature, In summer, only the surface layers undergo a rise in temperature, since the lightness of these layers prevents them from sinking and mingling with the layers below. In winter, on the other hand, the cooling of the surface layers causes them to sink as soon as they approach a temperature of 39.2° F., so that the whole body of water reaches a temperature of 39.2° F. If cooling continues, the renewal of the surface waters is no longer possible, because they have become lighter; hence, their temperature falls rapidly and freezing sets in almost at once, since the deeper water remains at a temperature of 39.2° F. Thus, the surface of lakes is liable to comparatively great variations of temperature, while the deep water escapes them. In summer the rise in temperature is not felt below a depth of some 40 feet. Within this surface layer a rapid decrease in temperature is observed, which sometimes attains the rate of .3° F. or more per foot of depth (see Fig. 35). In winter, on the contrary, there is a rapid increase of temperature from 32 to 39.2° F. within the same layer. Inversion of temperature is, therefore, the rule during this season.

The thermal system varies according to climate and to the topography of the basin of the lake. In hot countries lakes do not freeze, nor do they show inversion of temperature; but altitude may cause in them the same conditions as exist in colder climates.

The fall in temperature as the depth increases is more rapid in fairly large lake basins. Thus, in Lake Geneva, which is almost regularly trough-like in shape, and which has a mean depth of 500 feet, a temperature of 39.2° F. is observed at a depth of 330 feet. Lake du Bourget, which has a mean depth of only 265 feet, has a temperature of 38.7° F. at the same depth. Glacier torrents which empty into lakes contribute to the warming up of the deep waters. This fact, though it looks like a paradox, is, however, easily understood by anyone who has seen the waters of the Rhone flowing into Lake Geneva. The yellow stream of the Alpine river is carried on for some distance by its momentum over the blue surface waters of the lake, but soon the weight of the muddy stream suddenly causes it to sink amid swirls known locally as the *bataillère*. The heavy water forces away the bottom waters, which have a constant temperature of 39.2° F., and the mingling consequent on this displacement tends to spread the warmth of the surface water in summer and to raise the temperature of the cold surface layers in winter.

These considerations lead us to adopt Forel's classification of lakes into three kinds :—(*a*) Those with a tropical *régime*, in which the surface always has a temperature of more than 39.2° F. and never freezes. They occur either in the hot belt or in the temperate belt, when the water is of sufficient depth. (*b*) Those with a temperate *régime*, in which the surface water may reach a temperature of 39.2° F. and may even freeze. They are found in the mountains of the temperate belt, especially in continental regions. (*c*) Lastly, those with a polar *régime*, in which the surface nearly always has a temperature of 39.2° F. and is frozen during the greater part of the year, and in which inversion of temperature is the rule. They occur in cold climates and at high altitudes in every part of the world.

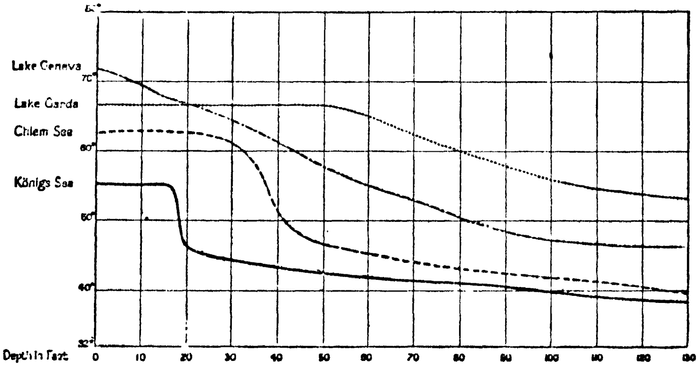

Fig. 35.—Temperature curves for various lakes. (After Forel.)

Seasonal Variations in Surface Level. After their abnormal thermal system, the most interesting peculiarity of lakes is their variation in surface level. The changes are sometimes great enough to alter the appearance of the lakes completely. In extreme cases the lakes may disappear for a time. The variations depend on the balance of supply and loss of water. The supply is derived partly from the rain that falls on the surface of the lake, but chiefly from the tributary streams, whose volume depends on rainfall. Loss of water is due partly to evaporation, but more especially to the outflow of the river which has its source in the lake. Since all these phenomena depend on climate, the surface level of lakes is bound to be subject to periodical variations according to season ; and these are more or less perceptible according to the topography of the lake basin itself and of the surrounding area which feeds the lake.

The surface level of lakes is most stable in countries with an equatorial climate, for in such regions the temperature—and consequently the amount of evaporation—varies but little, and the rainfall system contains no dry season. Lake Victoria is the only lake which is more or less in this position, but its drainage area extends S.E. over abnormally dry regions ; hence, a difference of 13 feet is observed between the maximum height (which occurs in May) and the minimum in October.

In tropical climates the occurrence of a dry season causes variations which increase with the shallowness of the lake and the flatness of its shores. In Africa, Bangweulu is utterly changed in appearance from one season to another, and the differences in Lake Chad are even greater. In desert regions permanent lakes are almost unknown. The *shotts* or *sebkas* of the Sahara are basins with flat and generally muddy bottoms which are only submerged after rainstorms and which are surrounded with saline crusts. In Central Asia, Lop Nor, which is fed by the Tarim with water derived from the melting of the snow on the Himalayas and Kunlun, changes its position when its basin is silted up.

In temperate climates the variations in surface level are ordinarily less marked than in the hot belt, because the rainfall system does not contain a true dry season. They are chiefly caused, therefore, by changes in temperature. In cold countries and in mountain regions the supply of water both from rainfall and from tributary streams ceases in winter, for then the snow lies on the ground. Hence, the level is highest in spring. This is the case in the great lakes of Canada and the United States—which form the greatest extent of fresh water on the Earth's surface—and also in the Russian lakes.

Whatever the climate, topographical conditions may increase or diminish the changes of level. Thus, even in the wettest and most stable climate a shallow lake is liable to dry up. Big tributaries with an extensive drainage area tend to stabilise the level; but a restricted area of drainage, such as is found in crater lakes and in certain tectonic lakes, makes the level of the lake depend directly on evaporation. The existence of an outflowing stream favours stability, for the volume of outflow always increases when the level of the lake rises. Crater lakes are subject to sudden variations. Lakes in calcareous depressions usually have a subterranean outlet and the volume of this outflow is naturally limited by the section of the passage through which it runs. Hence, such lakes often inundate their shores.

The sheets of water which spread over the bottoms of *poljes* in the Illyrian Alps swell suddenly after heavy rain and do great damage to the villages situated around their margins on the alluvial tracts which are the only cultivable areas in this stony region. On the other hand, they dry up almost entirely in years of deficient rainfall, leaving a muddy bottom which breeds marsh fevers. In Italy, Lake Fucin has been drained off by an artificial channel 3¾ miles long. The capital of Mexico is built on the shores of Lake Tezcoco, which lies in one of those inland basins that abound in the American highlands. In order to protect the city against floods and to avoid the dangers arising from marshes, steps have had to be taken to ensure a regular outflow from the lake by constructing a canal over 29 miles in length, and by boring a tunnel 6 miles long through a mountain range.

Variations over Long Periods. The seasonal variations of lakes do not bring the surface back every year to the same levels. The mean level rises or falls according to the abundance of rainfall and the greater or less insolation received during the summer. It is recognised that the lakes which show the greatest variation over long periods merely follow changes in climate, and such variations are especially marked in hot, dry countries. Thus, the great African lakes recently underwent a steady fall of level over a period of 25 years, and it is only since about 1876 that Tanganyika has began to discharge water into the Congo once more. Lake Eiasi, which had almost dried up, is again spreading over the saline steppe. Lake Chad has completely changed in shape since it was seen by the early explorers. In the United States exactly the same variations have been noticed in the Great Salt Lake, which has been rising since 1850, turning peninsulas into islands and flooding a strip of its low shores between 6 and 18 miles wide.

It is evident, then, that a lake may finally disappear if its secular variations do not periodically restore it to the former level. This fate threatens especially lakes in dry regions which have no outflow on the surface. But it also awaits every lake, for the silt deposited by tributary streams tends to fill up their basins, whilst the outflowing stream, by deepening its bed, increases the volume of water that runs out. Hence, lakes are to be considered merely as temporary features in the evolution of the Earth's surface.

CHAPTER IX

RIVERS

Springs. All streams, with the exception of mountain torrents, have their source in a spring. The study of springs is, therefore, an indispensable preliminary to that of rivers ; but it is also a matter of wider geographical importance, for the position of springs in desert lands has a direct bearing on the site of human habitations and even in regions with a sufficiently abundant rainfall they are of capital importance. For instance, in the neighbourhood of Paris a practised observer can everywhere recognise the level of the springs by the alignment of villages on the slopes of the hills.

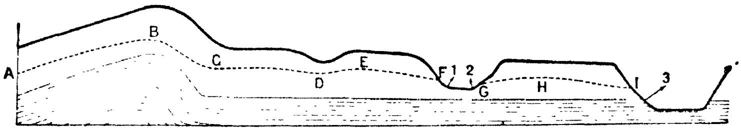

FIG. 36.—Surface springs and water-table.

Permeable rock in white. Water-table or upper level of saturation = ABCDEF, GHI (dotted line). 1 and 2 = surface springs ; 3 = outcrop spring.

Spring water comes directly or indirectly from rain. Absorbed and soaked up by the soil, the rainwater forms a superficial layer which gives rise to *surface springs.* These are the only springs in districts where the rock is impermeable. They are numerous, but liable to contamination. The best springs are those which are derived from water tables, i.e., layers of water which has percolated through permeable rock (e.g., sand, gravel, sandstone, chalk, or limestone) that covers a fairly wide area and rests on an impermeable layer. When the layers are horizontal, the surface of the water slants down towards the spring (see Fig. 36 E F), and rises close to the surface in depressions. The regular output of springs depends on their topographical position. Two kinds of spring may be distinguished: *outcrop* and *valley springs*. The former occur on hillsides in regions where the impermeable layer appears at the surface (see Fig. 36, 3); they are naturally the most constant since they can only dry up if the underground water is completely exhausted. The latter occur when the impermeable rock is near the surface, but does not reach it (Fig. 36, 1 and 2); they dry up if the level of underground water falls below a certain point. An examination of the Parisian Basin shows how much more favourable outcrop springs are than valley springs to human habitation. The former have determined the positions of the villages in the immediate neighbourhood of Paris, for they are all built on the hillsides. The latter predominate in the district of Soissons, where the valleys are sometimes marshy, at other times dry.

In limestone districts the underground circulation of water has somewhat abnormal features. The rock is dissolved along its cracks, and a network of caves is formed which are large enough to hold even lakes and torrents. These are fed by rainwater or even by rivers which suddenly disappear beneath the surface. At the mouth of these subterranean passages the water reappears in springs of such great volume that it forms quite a large stream. The Fontaine de Vaucluse is so well known that the name *vauclusian spring* is given to this type. In the Paris Basin they are called *douix* (e.g., the sources of the Seine). Their output is sometimes rather irregular—which is explained by the narrowing of the underground passages and by their windings, which form a kind of syphon.

The Volume of Water Discharged by Rivers in its Relation to Rainfall. The study of rivers has, like that of springs, become a scientific subject. We know that all the water in rivers is derived from atmospheric precipitation. The chief problem of river systems is, therefore, the determination of the relation that exists between the amount of water which falls on the ground and the amount which runs off through the rivers. A rainfall chart enables us to calculate the volume of water which falls in the basin of a river. Dividing this by the area of the basin we get the mean depth of the rainfall or, as it is called, the *pluviometrical index* (P). By dividing the volume of water discharged by the river in a year in the same way by the area of its basin, we get the *index of discharge* (D). The difference P—D represents the amount of water which is lost, i.e., the *deficit in the discharge.* The ratio D : P is known as the *coefficient of discharge.*

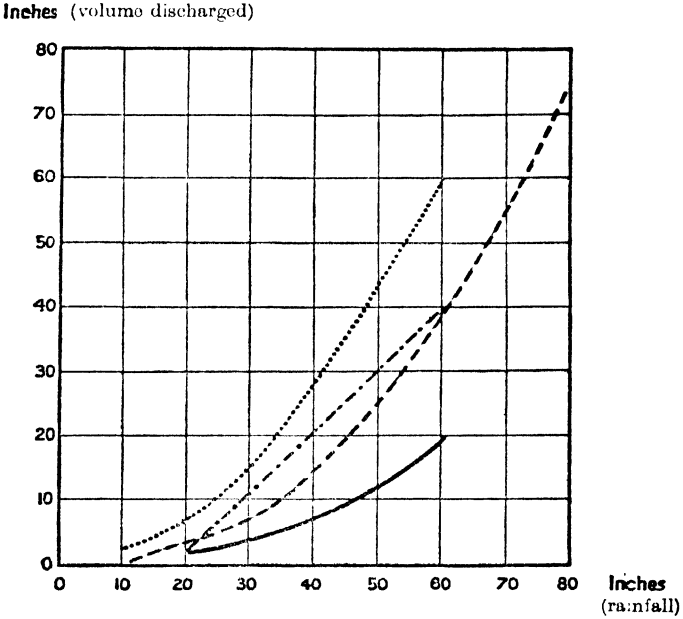

FIG. 37.—Showing relation between amount of rainfall and volume of water discharged by rivers. Both values are treated as depths of water evenly distributed over river basins.

……………… Rivers of Central Europe.
– – – – – – Rivers of the United States north of Lat. 40° N.
———— Rivers of the United States on the plains south of Lat. 40° N.
–·–·–·– Rivers of the United States on the mountains south of Lat. 40° N.

To discover the cause of the deficit, the whole history of the water that falls on the surface of the ground must be surveyed. One part of this water flows off on the surface and reaches the river directly; another part is evaporated; while a third percolates into the ground to reappear in springs or to be restored to the air through the respiration of plants. A very small portion is retained by decomposed rock or by vegetation. If curves showing the relation of the index of discharge to the pluviometrical index are drawn based on the research carried on in Europe and the United States, the variations in the coefficient of discharge are brought out clearly (see Fig. 37).

The coefficient increases more rapidly in the temperate zone (A and B) than in the hot belt (C), and in uplands (C^1) than in plains (C). It is always greatest in damp climates, as is shown by the shapes of all the curves. This means that the deficit in the discharge is greater on the average wherever the temperature is higher and consequently where evaporation is more intense. The steep slopes of mountainous regions reduce the amount of water which percolates through the soil and make the flow-off more rapid. The increase in rainfall leads to the saturation of the soil as well as of the air and sometimes lowers the amount of percolation and evaporation almost to nothing. Proof of this was given in the last floods of the Seine in 1910, when the coefficient of discharge rose as high as 89 per cent, though its average is 28 per cent.

To sum up, the amount of water discharged by a river depends on the amount of rainfall, on the gradient, and on the temperature. Fig. 37 shows that it begins with a rainfall of 1 inch in the temperate zone, and with one of 16 inches in the subtropical zone. Still higher figures may be expected for the hot belt. As shown by the researches carried on in Europe, the coefficient is greater in winter, when the deficit diminishes owing to the fall in temperature and the arrest of vegetable growth. On the main the coefficient is calculated to be 60 per cent between January and March and 20 per cent between May and October.

River Systems. We do not yet accurately know all the facts concerning the flow of every big river, but we have records of their variations in depth, which indicate their variations in volume. From these data, different types of river systems may be distinguished. Climate evidently determines the general differences. But surface relief, geology, and vegetation must be taken into account if the peculiarities of each stream are to be explained. Steep slopes allow of rapid flow-off, lessen the amount of percolation—even on ground composed of the most permeable rock—and increase the coefficient of discharge and the difference between the maximum and minimum depth of the stream. Impermeable subsoils are favourable to a flow-off on the surface, even if the slope is gentle. Percolation is restricted to the light surface layer, and numerous springs dry up or increase their outflow suddenly. On the other hand, in ground where the rock is permeable, percolation takes place freely and feeds the stores of underground water which escape evaporation and supply constant springs. When there is no rain, the volume of the streams is maintained by these springs. In broken limestone districts the streams sometimes disappear completely, only to reappear further on in vauclusian springs. In the lower course of big rivers there is a great deal of percolation, which moistens the alluvial plains. In semi-desert regions the whole surface flow-off may be absorbed in this way. The presence or absence of forests causes differences like those due to the permeability or impermeability of the rock, for trees prevent the rain from falling directly on to the ground and consequently check the run-off on the surface. The thin surface layer of soil, when protected by trees against erosion, even on moderately steep slopes, may retain the water, which, moreover, is sheltered from evaporation by the foliage.

Snow-fed Streams. Apart from torrents, if one considers all the great rivers about which the necessary facts are known, one is led to ask the reason for the very marked differences in the system of feeding. The process depends on both climate and relief. If the stream is fed exclusively by melting snow, the supply of water ceases altogether in the winter. These very special conditions are only realised in desert regions which are encircled by lofty mountains and in plains in the cold belt. The best example of the first case is afforded by the rivers of Turkestan and Afghanistan. Floods in spring, which are maintained in summer by the melting of glaciers and of the snow on the lofty peaks, are characteristic of these curious rivers, which owe their existence solely to the mountains of Central Asia. Their periods of flood never fail to occur, and they enable extensive oases to be developed by means of irrigation. Their volume, instead of increasing as the stream flows down, gradually diminishes until it sometimes disappears altogether. The only rivers in Russian Turkestan which reach the Aral Sea (the Sīr Daryā and the Oxus-) discharge into it only half the water which they contain on leaving the mountains.

In the Siberian plains the fact that the snow which falls in winter remains on the surface of the ground cuts off the water supply of the rivers. The rivers themselves are completely frozen over. When the thaw sets in with spring, immense floods occur, together with the breaking up of the ice. The Yenisei rises 30 or 35 feet and floods an area 30 miles wide at its mouth. The Ob at its confluence with the Irtish inundates a strip of country between 12 and 40 miles wide.

Streams Fed by both Snow and Rain. In plains situated in the subdivision of the temperate belt which has cold winters, and generally in all high mountain districts, the melting of the snow plays an important part, but the rains which occur in the mild season are by no means negligible—especially as the maximum precipitation usually takes place in summer. The Russian rivers and the Upper Mississippi are the best-known examples of this type. In spite of the wetness of summer, the rivers attain their minimum volume in autumn, because evaporation and the development to maturity of the vegetation tends to exhaust the underground water and the surface springs. In winter these influences disappear, but the water supply is also very nearly cut off, since the snow remains on the ground. In spring the thaw causes sudden, violent floods, which are due both to the melting of the snow and to the run-off of the first rains of the season, for the rainwater cannot percolate into the ground, which is still frozen at this period.

In high mountain districts the melting of the snow in spring causes floods, which are all the more sudden because they begin in the upper course of the rivers, where the gradients are very steep. But the floods are maintained by the melting of the snow on the higher peaks, which continues into the summer, and by the glacier torrents, which swell more and more. The summer rains cause a further rise in the water, which attains its maximum depth in July. The minimum depth occurs in winter, when all the sources of supply are cut off or greatly reduced. This system, which may be termed *Alpine,* includes all the great rivers that rise in the Alps. The Rhine at Waldshut affords an excellent illustration (see Fig. 38).

Streams Fed by Rain. Over the greater part of the temperate zone and throughout the subtropical and hot belts, snow is rare, and lies for too short a time on the ground to play an important part in the feeding of rivers. Rain supplies all the water which flows off.

The curve illustrating the volume of streams depends on both temperature and on the rainfall system. In temperate countries which have no dry season, the influence of temperature is the more important. The Seine, the Saône, the Main, and the Neckar illustrate this (see Fig. 38). Their period of minimum volume is the summer, although this is the rainiest season, because the coefficient of discharge is then greatly lowered by evaporation and by the growth of vegetation ; and their period of maximum volume occurs at the end of winter, for during that season evaporation is less, owing to the cold, and the soil has had time to become saturated. The average discharge of these streams amounts to nearly one-quarter of the rain that falls, though in Alpine rivers the proportion rises to and even exceeds one-half.

The proportion is still smaller in streams in the sub-tropical belt and in countries which have a dry season. The curve showing the volume follows the same general path, but has a greater range. The volume of streams may diminish to the extent of complete disappearance. This quasi-torrential system is common in regions with a Mediterranean climate. Extensive beds of pebble through which a trickle of water threads its way give the streams of these regions the appearance of the *wadis* of the African and Arabian deserts. In Southern Italy and Sicily they are known as *fiumari.*

Since there is so little variation in temperature in the hot belt, the rainfall system determines the river systems. Wherever there is a pronounced dry season, the curve of volume is the reverse of that shown for rivers in the temperate belt, for the dry season generally occurs during the northern winter; and this is true of monsoon regions as well as normal tropical climates. The Nile at Khartoum is an excellent example of this type (see Fig. 39).

In equatorial regions the system shows less variation ; but the equatorial belt is too narrow for a great river to lie entirely within it. The Amazon itself, although it flows along the Equator, is influenced by tributaries which have a tropical system.

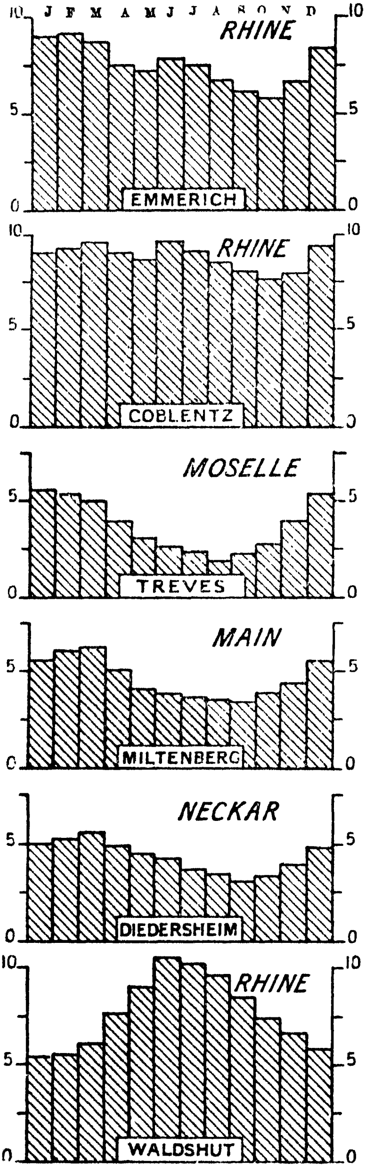

FIG. 38.—Seasonal variations in the volume of the Rhine and its chief tributaries. Heights in feet.

The Rhine. In reality, there is hardly a single great river which can be unhesitatingly placed in any one of the categories just laid down. The influence of tributaries modifies the system of the main river, which may itself flow through regions with different climates, since great rivers rarely fail to rise in mountains. The shape of the basin, the direction of flow, the arrangement of the network of tributaries, all have as great an influence on the river system as the gradient itself has.

Let us take the Rhine as an illustration. Mountains are found only in the upper course, which is separated by a gorge from the middle course. This section of the basin is spread widely over a region of hills and low mountains, among which flow a large number of tributaries. Hence, as may easily be understood, the system is liable to variations. The river is certainly Alpine as far as Basle (see Fig. 38, Waldshut). The presence of lakes in parts of the course does not suffice to check the torrential flow of the floods in spring. The river continues to rise until the middle of summer, and the Alpine influence is so strong that it is felt right down to the plains. The tributaries which join the main stream have a completely different system, for they have their periods of minimum volume in summer and are flooded in spring and winter, e.g., the Moselle, the Main, and the Neckar. Their winter floods swell the Rhine just when the main stream from the Alps has reached its minimum period. Thus, two systems are combined with two maxima, one in spring, the other in winter, and with a minimum period in autumn. The summer maximum, which is due to Alpine conditions, has an increasingly less marked effect in the lower course, while the spring maximum becomes correspondingly more important. Similarly, the autumn minimum is more and more pronounced as one goes downstream. But on the whole the volume is kept fairly constant. This fact constitutes the great advantage which the

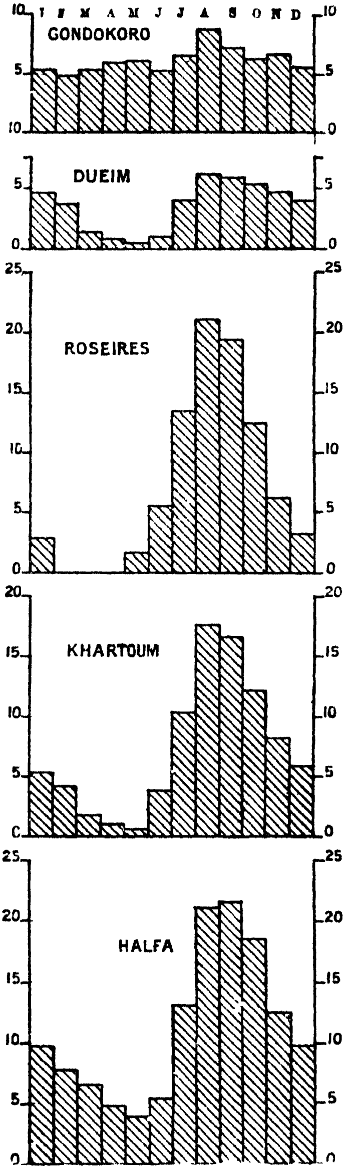

Fig. 39.—Seasonal variations in the volume of the Nile (according to Lyons). Heights in feet.

Rhine has over the Danube, and which has made the river into a navigable waterway of exceptional importance.

The Nile. Another example, taken this time from the hot belt, will complete the explanation of great river systems. The Nile flows northwards from the equator to Lat. 30°, a distance 3,473 miles. In its basin is represented every type of hot climate, even the desert type, which prevails throughout the lower course. Moreover, some of the tributaries in the upper course originally come from the southern hemisphere and consequently are influenced by the rainy seasons of that hemisphere. The shape of the basin also deserves attention. Of relatively small area in the equatorial belt, where the rainfall is most abundant, it widens out immensely in the Sudan region and on the borders of the Sahara, only to become gradually narrower and narrower in the lower course, where the river bed is merely a drainage channel for the water of the Sudan and the regions round the Equator. That the Nile can fertilise the plains of Lower Egypt and reach the sea in spite of the enormous loss of water due to evaporation and percolation during so long a course, is owing to the fortunate co-operation of floods which have their rise in different parts of the basin.

The sources of the Nile lie on a lofty plateau, where water accumulates in vast lakes which fill areas of recent subsidence. The surface of the lakes amounts to one-fifth of the total area of this part of the basin. The lakes are joined together and fed by torrential streams that flow down the terraces of the plateau in a series of falls. The system of the White Nile, which is an outlet of this lake district, reflects the changes of level in Lakes Victoria and Albert. The rise of water in this stream corresponds to the period of greatest rainfall in the equatorial regions and reaches Gondokoro in July and August. At this point the altitude of the valley bottom has fallen to 1,540 feet. From that point to Fashoda the fall is only 230 feet. In this region there stretches a vast plain from which all the streams fed by tropical rains converge on the river, and a multitude of lateral arms and marshes receive the overflow of the floods and give rise to a luxuriant aquatic vegetation, which causes the remarkable green colour of the river as it passes through Egypt. But evaporation is enormous, and the volume of the river would be greatly reduced but for the reinforcements brought by the Sobat. This tributary gives the system of the Nile a definitely tropical character at Dueim, a character which is still further emphasised by the confluence of the Blue Nile, which brings such mighty floods from Abyssinia that the waters of the main river are dammed back for a time. Most of the water which flows across the desert to the sea is definitely derived from Abyssinia. Evaporation accounts for nearly all the equatorial waters, which are almost stagnant in the Kir district. But for the Sobat, only a tiny stream would reach Khartoum; and but for the Blue Nile, the Nile would not reach Egypt, and Kir would be another Chad. The inferiority of the Bahr-el-Jebel is certainly due to its gentle gradient. Its index of discharge is less than 3.94 inches as compared with its pluviometrical index of 47.24 inches, and its coefficient of discharge is less than 8 per cent. The Blue Nile, on the other hand, has a coefficient of discharge amounting to 20 per cent, a figure which is almost as great as those for rivers in the temperate belt.

APPENDIX TO PART II

I. SUGGESTIONS FOR FURTHER READING :—

(*a*) OCEANOGRAPHY.

THOULET : *L'Océan, ses lois, ses problèmes* (Paris, 1904, pp. 397), and

RICHARD : *L'Océanographie* (Paris, 1906, pp. 398).

These two works are easy and richly illustrated. The first deals with oceanography in its physical aspect, while the second adds chapters on the biological aspect.

MURRAY, SIR J.: *The Ocean*, in Home University Library Series (London, 1913). A readable introduction to the subject.

CHALLENGER REPORT, Vol. I, 1907. A work of reference.

Regional oceanographical studies :—

THOMSON, SIR C. WYVILLE : *The Atlantic* (Macmillan, 1877).

SCHOTT, G. : *Geographie des Atlantischen Ozeans* (Hamburg, 1926).

FLINT, J. M. : *Oceanography of the Pacific* (Washington).

ZIMMERMANN, M. : *L'Océanographie du bassin polaire boréal d'après Fr. Nansen*, in Vol. XIII, p. 97 of *Annales de Géographie*.

(*b*) LAKES :

DELEBECQUE : *Les lacs français* (Paris, 1908, pp. 436).

COLLET : *Les Lacs.*

(*c*) RIVERS :

BELGRAND : *La Seine, étude hydrologique* (Paris, 1872, pp. 622). This is a classic.

AUERBACH, B. : Articles in *Annales de Géographie* : The Rhine, 1892, p. 212 ; The Oder, 1897, p. 313 ; The Elbe, 1902, pp. 54 and 134 ; the Vistula, 1903, p. 214 ; the Weser and the Ems, 1904, pp. 138 and 257.

For a general treatment of hydrographical questions, see De Martonne : *Traité de Géographie Physique*, Part III, pp. 334-482 (4th edit.).

II. PRACTICAL EXERCISES.

The following observations are suggested for those who wish to test their understanding of this part of the work :—

If you are staying at the seaside, observe the tides. Note the difference between the high and low water levels on a pile or on the vertical wall of a quay ; observe the daily rise or fall of these levels according to the time of the month and check the relation between these changes and the phases of the moon. In schools near the sea, the master can naturally carry out these observations with his classes. In schools not so situated, he should urge those of his pupils who are about to stay at the seaside to make the observations for themselves.

The position of springs on hillsides and their relation with the sites of villages may easily be observed during an excursion into the country on the slopes of any big valley. It will be as well to construct beforehand with the help of a map a geological section of the valley or slope to be studied and to mark on it the level at which springs may be expected to flow. Then, the existence of the springs in villages should be noted and their altitudes compared with the level marked on the section.

PART III

SURFACE RELIEF

CHAPTER X

GENERAL LAWS OF TOPOGRAPHICAL RELIEF

It has already been found necessary to mention in the preceding chapters the influence which relief exerts on climate, on the distribution of seas, on lakes, and on river systems. In the study of economic geography, this influence is met with at every step, for the distribution of population and routes, and the position and growth of towns all depend on details of relief. Hence, it is not surprising that the branch of physical geography which deals especially with the topographical features of the Earth's surface has been studied with greater care than any other. Enquiry has been carried far enough to demonstrate the infinite variety of these features and the complex nature of the causes which give rise to them.

To understand the principles of surface relief, one must study the ground, and the reader will certainly find some difficulty in understanding the following chapters if he does not keep his eyes open and search—as far as his travels will permit him—for confirmation of the principles which will be laid down here. Failing an opportunity of direct study of topographical features on the ground, he may substitute an examination of a topographical map which shows these features.

Topographical Maps. Let us look at the maps given in Fig. 40. All details which do not directly concern relief have been eliminated. To show height a device similar to that used for representing the depth of seas and lakes has been employed, namely, points which are of the same altitude have been joined by curves known as *contours.* They are drawn on these maps at intervals of 10 metres, but any *vertical interval* may be used, whether greater or smaller than this. The principle on which the curves are drawn ensures that the steeper the slope the closer together will be the contours, as may be seen by examining Fig. 40 and comparing the features there shown with Figs. 41, 42, 43. As the slope becomes less steep, so the interval between the contours grows greater; as the slope becomes steeper, so the contours become closer together. A change of gradient is, therefore, marked by a sudden change in the distance apart of the contours; e.g., the contour for 160 in Fig. 40a.

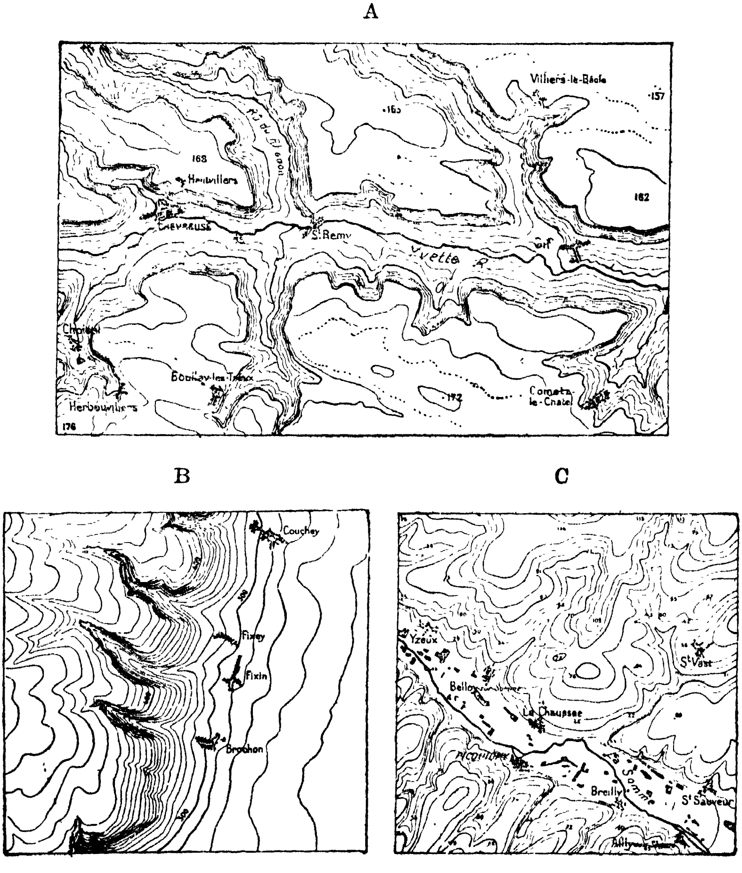

Fig. 40.—Three types of topography
A, the plateaux of Hurepoix, south of Paris; B, the Côte d'Or; C, the valley of the Somme in Picardy.

When the slope is too steep for all the curves to be shown distinctly, the contours are replaced by a conventional sign consisting of *hachures,* which represents rocky scarps (see Fig. 40 B).

The old French Staff map, on a scale of 1 : 80,000, and several other topographical maps, confine themselves to a system of hachuring to show relief. The object in drawing features on this system is to produce a picture something like that of a relief drawing, in which the gentlest slopes are the most lightly shaded. The hachures are lines drawn perpendicular to the contours and are thicker and closer together as the distance between contours grows less, that is as the slope becomes steeper.[1] But to make the picture realistic, the relief must be lit up from one side ; and the moment this is done the shading which results from the hachuring is no longer a direct indication of the degree of slope. However skilfully executed and artistic maps drawn on this system may be, maps which show height by contours are to be preferred, as being more accurate. They are as easily read after a little careful practice.

Valleys can always be recognised by the re-entrant angle outlined by the contours at their head. The narrower and more steep-sided the valleys are, the more acute are the re-entrant angles ; compare the wide valleys in Fig. 40 A with the ravines in B. In flat-bottomed valleys the contours are wide apart and cross the valley in sweeping curves (see Fig. 40 C). Rounded heights can be recognised by the path of the contours, as in Fig. 40 C ; similarly in Fig. 40 A and B the sharp-edged tablelands are clearly marked.

Valleys Formed by Erosion. Close examination of a map will show that the valley is the predominant topographical feature. In fact, the whole topography of a district depends on the development of valleys and their branches, on their width, and their depth. The maps in Fig. 40 are not special cases, but the examples shown in them have been taken from regions which differ as widely as possible. Map A represents a portion of Hurepoix, near Paris, a region of tertiary beds of sand and calcareous strata. Map B gives a section of the Côte

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[1] For more detail see Appendix to Part III, Practical Exs.

d'Or in Burgundy, a region of very broken strata which are chiefly calcareous. Lastly, Map C is of a part of Picardy and shows the valley of the Somme, which is dug out of nothing but chalk. Examples could be multiplied, and in all of them the same preponderance of valley forms would be seen.

This fact brings us to an important conclusion, viz., that fluvial erosion is the chief agent in the formation of topographical relief. And, indeed, there is no doubt that valleys are due to the erosion of the rivers which flow in them. To realise this, one has only to notice the close relation that exists between the volume of the streams and the breadth and depth of the valleys in a river basin. The correspondence is too great to be regarded as a mere coincidence. Besides, we can observe the actual working of the erosive forces of a stream. The narrowest valleys, the gorges with vertical sides suggestive of gaping cracks in the Earth's crust, are just the places where the work of erosion is most easily recognised. Such expressions as "the sculpture of the land" emphasise the importance of the work of streams in modifying the surface of the land by carving it up delicately. The work progresses slowly but steadily; hence, all topographical features must be regarded as being in process of evolution.

Features Due to the Structure of the Subsoil. If the three maps in Fig. 40 are compared, some remarkable differences are observed. In the first is seen a plateau cut up by steep-sided valleys; in the second the chief feature is the escarpment of the Côte d'Or, which has been penetrated at several points by narrow ravines; in the third, rounded hillocks surround the broad valley of the Somme. These differences are chiefly due to the structure of the rock. In Hurepoix the character of the topography is explained, as is shown in Fig. 41, by the occurrence one upon the other of layers of clay, sand, and limestone. (Erosion has carved out valleys in these layers, but not at equal rates in different layers.) Thus, changes in gradient occur where the sand joins the top layer of limestone and has been rapidly worn into a steep slope; and also at the junction of the sand with the clay which forms a gentle slope down to the valley bottom. Hence, in cases like this it is necessary to study the geology of the region in order to understand the details of its relief.

By using a good geological map one can draw a block diagram like that in Fig. 41, which shows at one glance a diagrammatic perspective of the relief and two cross-sections of the underlying rock. We shall frequently use this device in order to illustrate the relation between the surface features and the nature of the underlying rock, for geological structure is one of the most important factors in relief.

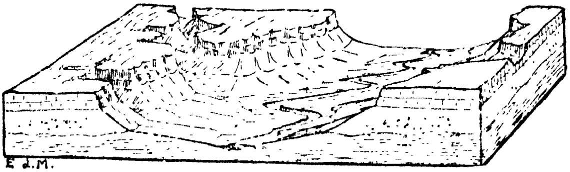

FIG. 41.—Section model of the plateaux of Hurepoix. (To be compared with Fig. 40A.)

Features Due to Tectonic Movement. The map of the Côte d'Or shows us a very different case of geological influence. The principal feature here, as shown by Fig. 42, is a dislocation of strata. The eastern portion of the layers has sunk along a crack, and so given rise to what is termed a *fault*. Erosion has begun its attack on the block which remained as an escarpment after the faulting, and has carved in it narrow ravines known locally as "world's ends"; but it has not yet succeeded in erasing the scarp which runs along the line of fault. The position of human dwellings has been determined by this feature, and villages line the foot of these vine-covered slopes. Displacement of the surface layers of the Earth's crust often causes similar topographical features; hence, the study of such move-

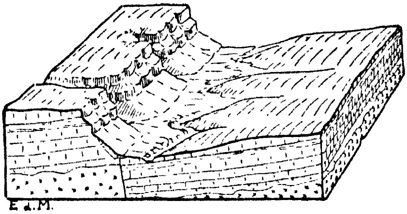

FIG. 42.—Section model of the Côte d'Or. (To be compared with Fig. 40B.)

ments is the mainspring of geology and is known as *tectonics.* The geographer is bound to take notice of them, especially in dealing with mountainous regions.

Features Due to the Form of Erosion. In the map of a corner of Picardy, the only marked topographical feature is the Somme valley. Rounded hills separated by broad re-entrants enclose the valley and stand out in marked contrast with its flat, damp, lake-studded bottom through which the stream winds between the indented slopes. Nothing in the rock structure explains this difference, and here erosion is the only factor; but, as is shown in Fig. 43, its action is not the same on the dry, undulating hillocks, on the indented slopes, and on the floor of the Somme valley. The broad re-entrants in the chalk scarp contain no streams, and the absence of water-courses on heights composed of permeable rock explains the comparative absence of villages. Where the slopes are steep, the rainwater streams down, hollowing out ravines. Silt which the stream cannot carry off accumulates in the valley bottom, and the situation of the villages on the edge of the damp plain at the foot of the slope where springs come to the surface emphasises the change of gradient which marks the junction of the zones of erosion and deposition.

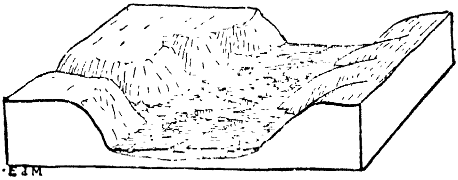

FIG. 43—Section model of the valley of the Somme in Picardy. (Compare with Fig. 40c.)

Many other similar examples might be given, and, generally speaking, every change of gradient which is not due to the structure of the underlying rock is caused by the junction of two regions in which erosion proceeds in different ways. The two forms of erosion which are most frequently observed in plains and hills in the temperate belt are erosion, properly so termed, which wears down high ground, and deposition which fills up depressions with the waste brought down from higher levels. But the moment one goes into a mountainous region or leaves the temperate belt, one finds topographical features which are due to other processes of erosion. Thus, glaciers erode their beds as they move down the sides of lofty mountain ranges, and, of course, topography which results from glacial erosion is different from that caused by fluvial action. In deserts the wind accomplishes a peculiar kind of erosion and heaps up the waste material so as to form huge seas of shifting sand. On the other hand, quite a different type of erosion can be seen by a visit to the seaside. Coastal topography is due to the action of waves and to the deposition of sediment by the tides and currents of the coast.

So, erosion which is ceaselessly modifying the features of the Earth's surface is to be studied in its four aspects of *fluvial*, *glacial*, *aeolian*, and *coastal* erosion, and in each of these forms two processes must be considered, viz., the process of denudation and the process of accumulation.

Climate as a Factor of Relief. Topographical forms which are caused by certain processes of erosion are easily recognised and have, as it were, a family resemblance to each other. And indeed there are many groups of features in various topographical forms which the geographer must learn to recognise. If the distribution of these groups of features is examined, it will be found to be determined by climate. The one exception is coastal erosion, which owes its scene of action on the coasts to the great upheavals and subsidences of the Earth's crust. But erosion by wind and the peculiar topographical features it fashions are restricted to the deserts, while glacial erosion occurs only in regions with a polar or a mountain climate. Hence, climate is a very important factor in relief.

It should be noted, however, that the distribution of the various groups of topographical features does not depend entirely on existing climatic conditions. During the quaternary period a general fall in temperature caused a great part of Europe and North America to be covered with glaciers, for their morainic deposits can be seen all round the Alps and in the plains of Germany and Russia, while the erosion executed by them has left on the mountain valleys through which they passed an imprint that fluvial erosion has not yet removed. During the same period the existing deserts were less dry—a fact which explains the traces of fluvial topography that are found in them. Hence, in explaining the features of relief of a district, it is necessary to take into account not only the present climate, but frequently also the conditions which prevailed in the most recent geological ages.

Predominance of Fluvial Erosion in Topography. To sum up, a study of topographical maps leads to the following conclusions :—

(*a*) Topographical features are due chiefly to erosion.

(*b*) The nature of the rock nearest the surface often causes the most characteristic features, either by the differences in the nature of layers in which valleys are carved or by the displacement of the layers.

(*c*) Features which cannot be explained by these geological facts are due to the connexion of certain processes of erosion with particular places.

(*d*) Erosion assumes various forms, giving rise thus to certain family likenesses in groups of features whose distribution on the Earth's surface is determined by the climatic conditions either at the present time or in recent geological ages. The forms are : fluvial, glacial, and aeolian erosion. Coastal erosion stands alone, and is independent of climate.

To these must be added a fifth conclusion, which will be demonstrated in the following chapters. Topographical features due to fluvial erosion are the most important ones for the geographer. Their evolution is best known and their relation with geological structure is best understood. They predominate in the temperate zone and are consequently most easily observed on the ground by people dwelling in Europe or North America, while their influence on human activity has been greatest and can everywhere be observed. They occur more frequently than any of the other groups of topographical features. At present they prevail in hot, sub-tropical, and temperate climates outside high mountain regions and deserts. But in past geological ages fluvial topography extended over areas now desert, though well watered at that time, and also over areas now glaciated, though formerly less cold or less elevated. We shall see in Chapters XV and XVI that the topography of deserts and glaciated regions can only be understood by taking into account past fluvial action. Finally, even coastal features result from changes wrought by the sea on land topography—which is most frequently determined by the erosion of running water.

Thus, fluvial topography is found everywhere, and most of the reader's attention should be devoted to its study. First of all he should try to understand how valleys are normally developed according to real laws which are as precise as those of meteorology.

CHAPTER XI

EROSION BY RIVERS AND THE EVOLUTION OF VALLEYS

Torrents. In 1841 Surrell, the engineer, formulated the chief laws of erosion after studying the torrents in the Alps. Let us follow his example. The catastrophic changes wrought by torrents strike the imagination and demonstrate how rapidly a mountain can be destroyed. Every big valley shows evident signs of torrential violence, and one has merely to climb halfway up a valley side in order to get a complete view of the denudation proceeding in the basin of one of the torrents on the opposite slope. Fig. 44 represents the kind of picture which meets one's eye.

Three parts are easily distinguished in the course of a torrent. First, there is a sort of funnel-shaped basin down which the water streams in converging channels that it digs for itself. Down the slopes of this basin masses of rock are often seen falling in ruin, landslides slipping, and in spring avalanches rushing. Secondly, there is a deep, narrow ravine which is sometimes obstructed by avalanches or landslides until at last the accumulation of water behind the obstacle forces the dam and produces a terrible flood, sweeping away everything in its path, bringing along trees and huge blocks of rock, and rushing out into the main valley with a roar of thunder. Finally, there is a kind of flattened cone with its apex at the mouth of the ravine. Through this cone the torrent flows sometimes to the right, sometimes to the left, often changing its bed after a flood. During a single flood the stream often brings down masses of mud and pebbles enough to bury the houses of a village.

Surrell gave to these three parts the names of *catchment* *basin*, *channel*, and *cone of deposition*. Each is produced by a different process of erosion. The catchment basin is being constantly enlarged through the combined action of superficial disintegration of rock, land-falls, earth-slides, and the running off of surface water and loose material. The channel is deepened by the corrasion of the bed or *thalweg*, which is abrased by the passage of *débris* and eaten away by the swift current. The cone of deposition, or, as it is often called, the alluvial fan, is built up by the torrent dropping the waste it carries at the entrance to the main valley where the gradient of the bed lessens. Its conical shape is due to the displacement of the bed round a pivotal point, viz., the mouth of the channel. These three parts are met with in every valley, and the whole development of the valley depends on the relative speed with which erosion proceeds in each division.

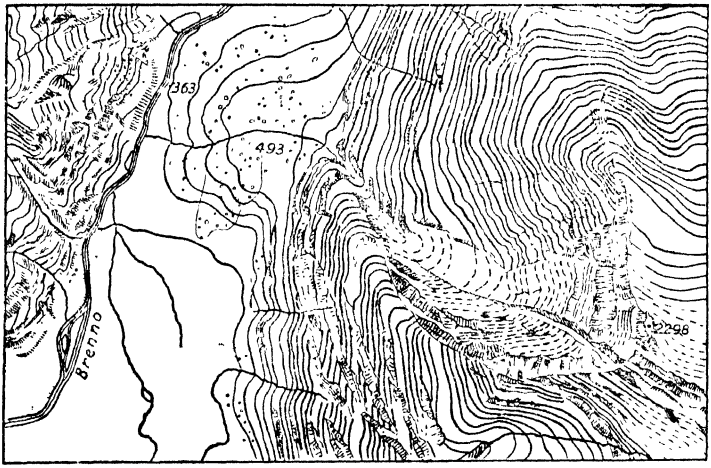

FIG. 44.—The Biasca torrent (scale 1 : 75,000, from the Swiss map on 1 : 50,000), showing the catchment basin, the channel. and the alluvial fan. A typical instance.

The Graded Line and Base Level of Erosion. The rapidity of torrential erosion is so great that it may be observed and its progress measured. It has been noticed that the deepening of the channel works its way upstream. This occurs in all streams, and the reason for it is easily grasped. The corrasion of the bed is caused by the friction of the water and of the matter it bears along. It therefore depends on the volume of the water and the velocity of the current. And the volume of rivers under normal conditions constantly increases towards the mouth, since the river is always receiving tributaries.

Several other important conclusions have been arrived at through the observation of the beds of torrents. The gradient from source to mouth is often very irregular, but on the whole it increases with distance from the mouth. This is not surprising if corrasion always works its way upstream. However, the corrasion of the bed cannot go below the level of the bottom of the stream where it enters the cone of deposition. The same features are seen in every stream, and a comparison of the gradients of a certain number of rivers shows that they more or less resemble a hyperbolic curve at a tangent to the lowest point. This ideal theoretical curve is known as the graded line.

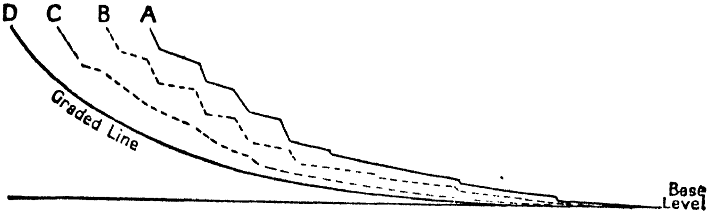

FIG. 45.—Illustrating the progress of a river in cutting down its bed to the graded line. A, B, C are successive profiles of the bed.

Note (1) that the lines become more and more regular; (2) the ideal curve (D) is first reached near the mouth of the river; and (3) the distance of the source from the mouth grows with every step of progress towards the graded line.

Under normal conditions, corrasion cannot lower the bed below the lowest point of the curve. This point, to use the expression which is now accepted, is the *base level* of erosion. Rivers which flow into the sea have the sea-level as their base; their tributaries have the bed of the main stream at their confluence; and streams emptying into lakes have the lake-level as their base.

In every river basin there is a close connexion between the main stream and its tributaries and sub-tributaries. No stream can corrade its bed below the level of the valley into which it flows, and the gradient of the bed of a tributary diminishes regularly until the confluence is reached. Every exception to this law is caused by anomalous circumstances which can be explained by local geological conditions or by the action of agents of erosion other than running water. Rivers which flow into the sea have for the moment a fixed base level; but not all such rivers have become graded. Only great rivers show any real approximation to the graded line, and subsequent streams usually present the greatest irregularities in gradient. Erosion constantly tends to remove these irregularities, as Fig. 45 shows.

Rapids, Cataracts, Pot-holes. Corrasion of a river bed takes place most rapidly at points where there is a break in the gradient, and the processes of erosion are best observed at such points.

If the gradient is sufficiently steep, the liquid surface of the water loses its balance and, falling forward, forms waves known as *rapids*. In times of drought when the water is low, the unevennesses of the river bottom are sometimes uncovered and rocks appear above the surface. Rapids are a considerable obstacle to navigation on the great African rivers, such as the Nile and the Congo. When the change of gradient is still greater, the whole mass of water tumbles down with a roar, forming a *cataract* or *waterfall*. Every waterfall tends to develop into rapids, and the change of gradient gradually works its way upstream, diminishing at the same time. But meanwhile the sides of the valley grow steeper along the whole section where corrasion takes place. This is clearly seen in the Niagara Falls and in the Victoria Falls, below which the river rushes headlong through a gorge several miles long.

In mountain regions the wildest gorges are always cut through the edge of a rock shelf over which the river is forced to pass. Examination of such gorges often shows the actual working of the processes by which rivers corrade their beds. Round holes bearing some resemblance to the interior of a pot and partly filled in with rounded pebbles are frequently seen at the side of a river bed. During floods the water eddies round in these holes, whirling the pebbles round and so gradually enlarging the holes.

The whole river bed is honeycombed in this way. The widening of the *potholes*, as they are called, until they join each other quickly carves out a gorge through the hardest rock. Nothing illustrates this better than a visit to Pont des Oules, near Bellegarde (Ain), where the Valserine suddenly plunges into a gorge before joining the Rhone.

River Capture. The tendency of rivers to become graded not only results in the rapid deepening of the valley at points where the gradient is steepest, but also in the gradual cutting back of the source of the river, as is shown in Fig. 45; and the process can easily be observed in torrents which are enlarging their catchment basins. Hence, all rivers tend to increase the areas they drain. But they cannot do this without a struggle, and the most powerful streams extend their basins at the expense of others, by *capturing* their subsequent tributaries. This phenomenon is sometimes seen in actual progress, because for some time after deflection the stream describes at the point of capture the characteristic bend known as the *elbow of capture*. Sometimes the captured stream runs, in the opposite direction to the general slope of the ground, in a steep-sided valley which has evidently been recently cut. Marshes often cover the ground abandoned by deflected streams.

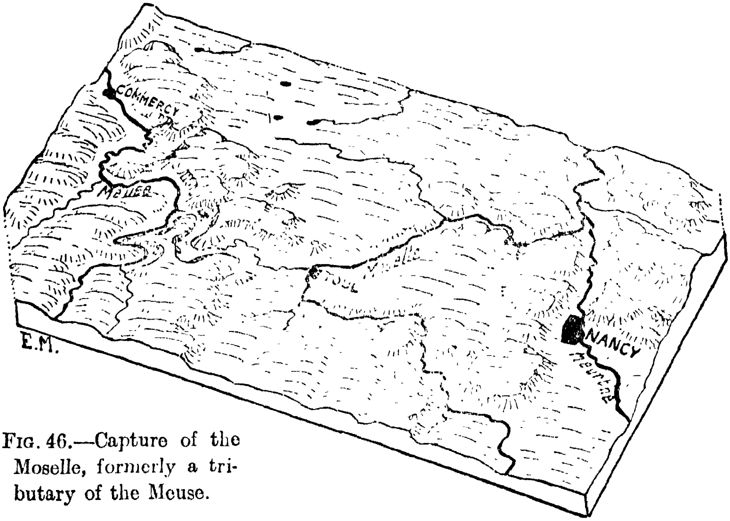

Fig. 46.—Capture of the Moselle, formerly a tributary of the Meuse.

Nearly all these features are found together in the case of the capture of the Moselle (see Fig. 46). In its present course, the Moselle turns sharply north-eastwards on reaching Toul, and soon enters a valley which becomes increasingly narrow and steep-sided until it reaches its confluence with the Meurthe. At Toul, however, a wide valley lies open before the Moselle, leading in the same direction as the river takes up to this point. This valley leads directly to the Meuse and is followed by a high road and a railway. The canal which joins the Marne to the Rhine also goes through it. But obviously the sluggish brook which trails through it cannot have hollowed out such a big valley. The clearly outlined meanders show that the valley can only have been carved out by the upper Moselle and that this stream was once a tributary of the Meuse, while the Meurthe was the main stream of the river that flows through Pont-a-Mousson and Metz. The difference in level between the Meurthe at Nancy (650 feet) and the Meuse at Commercy (790 feet) explains how a tributary of the former has been able to capture a tributary of the latter. The elbow of capture is at Toul. The marshes of Saint Remy prove that the condition of the drainage in the *dead valley* is still unsettled. Deprived of the supply formerly received from an important tributary, the Meuse has a starved appearance as it flows through a valley which is too large for it. Proofs are not wantin to show that this capture did take place, for bits of rock from the Vosges have been found in the alluvial soil deposited by the Meuse, and these can only have been brought thither at a time when the Meuse received a tributary from those mountains.

There are many similar examples. An examination of the map of France on a scale of 1 : 500,000, or preferably on one of 1 : 200,000, shows that the Bar, a tributary of the Meuse, has been captured by the Aire, a tributary of the Aisne; that the Petit-Morin has been captured by the Somme-Soude, as is clearly indicated by the marshes at St. Gond to the south of Épernay, etc. Similarly, in Yorkshire a subsequent tributary of the Aire has successively captured the consequent streams of the Wharfe, Nidd, Ure, and Swale, which formerly followed parallel courses to the sea. In the United States the Columbia River shows remarkable instances of capture. Examples of capture which has either just taken place or is about to occur have also been observed. For instance, the capture of the Rio Fenix in the Andes is of such recent date that Moreno, the explorer, actually re-diverted it to its former course by means of a trench dug by six men, thus displacing the water parting which separates the drainage of the Pacific from that of the Atlantic.

The Erosion of Slopes. If erosion was restricted to the deepening of river channels until the graded line was reached, all valleys would be gorges. Actually, the corrasion of the channel is accompanied by a corresponding wearing away of the sides of the valley. The latter process is due to the same agents as are responsible for the enlargement of the catchment basin. The effect of water running off on the surface is most easily understood. Such water digs little channels and tends to deepen them to the graded line, so that the whole surface of the valley sides gradually assumes the hyperbolic curve tangential to the streams.

The erosion of the sides of a valley is also effected by the mere sliding down of waste produced by disintegration. This process is more active when the soil is not held together by vegetation, but it takes place even where a continuous carpet of vegetation covers the earth, as experiments in the Wienerwald have proved. Wherever the naked rock comes to the surface on steep scarps, falls of rock occur from time to time. Thus, while the stream gouges out its bed, the run-off of surface water, the slipping down of disintegrated matter, and actual rock falls cause the valley sides to be worn away and tend to widen the section of the valley. The stream, however, has not only to corrade its bed, but also to sweep away the waste which is constantly entering it from off the slopes. Often it expends all its force in doing this, sometimes it is unable to effect it. In this case an accumulation of sediment takes place.

Upland Plains and River Terraces. The factors which govern the transport of sediment are the velocity and volume of the stream and the weight of the transported matter. The velocity of the stream is the most important and depends chiefly on the gradient. Hence, the accumulation of sediment occurs most frequently in sections of the river in which there are great changes of gradient, i.e., chiefly in upland regions, and, generally speaking, in the upper course of streams where the graded line has not yet been reached.

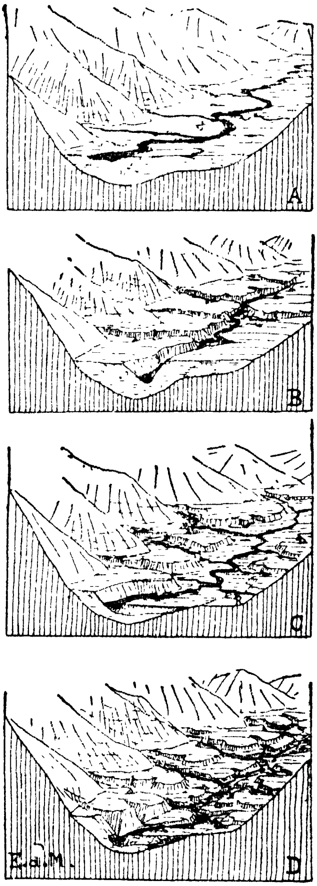

Fig. 47.—Formation of alluvial terraces.

As sediment is deposited whenever the gradient suddenly becomes less steep, alluvial plains alternating with steep-sided valleys are a prominent feature in mountainous districts. These plains are usually given an undulating surface by the alluvial fans of the torrents which enter them. The district of Valais in Switzerland is a typical example. It contains 295 alluvial fans, whose mean angle of slope is 11°, on each of which stands a village whose inhabitants have chosen the site so as to avoid the marshy ground between the fans. When the main stream is strong enough, it cuts through the fans and gives them a terrace-like appearance. A good instance of this may be seen in upper Maurienne in the French Alps. Lake basins are sometimes silted up to form more even plains, and these may be recognised by their almost horizontal surface.

All plains in upland valleys are destined to disappear sooner or later, since the corrasion of the river bed down to the graded line will in time remove the irregularity in the slope above which the plain is formed. The river begins by cutting a kind of gorge in the alluvial soil, and its tributaries do likewise. In this way alluvial terraces are formed (see Fig. 47). If deposition starts again, another plain may be made at a lower level. Should corrasion then resume its work, other terraces will be cut below the first group. In upland regions and in the plains which border them such interlocking terraces are frequently to be seen, and their occurrence is especially characteristic of the Alps and the surrounding regions, where their influence on the distribution of population and the path followed by routes is marked. In Asia and America the mountain ranges are often fringed by such terraces. To understand the reason for this, one should remember that the deposition of sediment depends not on the gradient alone, but also on the volume of the streams and on the waste itself. A change in climate may diminish the volume of the rivers and cause them to deposit alluvium, which they will erode afterwards, should rain become more abundant.

Flood Plains and Shifting Meanders. The lower course of every important river is generally marked by vast alluvial plains which extend right down to the base level. As they are sometimes inundated by floods, they are usually known as *flood plains.* The path followed by the channel of such streams is as liable to change as those of torrents in an alluvial fan. The river often splits into several branches, some large, others small. At times the sediment deposited raises the bed of the river and forms natural embankments between which the main stream flows above the level of the surrounding plain. In the valley of the Lower Mississippi all human dwellings are placed on these embankments, which bear the local name of *levées.* On the Lower Danube they are known as *grindu,* and their outline marks the position of former branches of the river which have now been abandoned.

The course of a river through a plain is always winding and describes curves known as *shifting meanders.* Their instability, which is included in the connotation of the name, is explained by the physical laws of running water. The moment the path of the channel diverges from the straight line, the line in which the velocity of the water is greatest (normally in the middle of the stream) moves away from the convex bank and approaches the concave bank. The latter bank is, therefore, worn away, and becomes more and more concave, while the former near which the velocity is less is silted up and becomes more and more convex, as is shown in Fig. 48. Hence, there is a constant tendency to increase the departure from the straight line, until finally there is a mere strip of ground left between the curves, and a flood may cause a new shortened channel to be cut through it. The abandoned meander forms an arc-shaped lake, known in England as a *mortlake* and in the United States as an *ox-bow*. Large scale maps of great alluvial plains, like those of the Danube, the Rhone, and the Mississippi show innumerable instances. The detailed surveys of the course of the Mississippi which were executed in 1881 and 1894 bring to light even more curious developments. Each meander shifts its position downstream as a whole. Fig. 48 explains the reason; the concave bank is clearly subject to less erosion on the upstream side of a meander than on the downstream, since on this side the influence of the gradient is added to the centrifugal force.

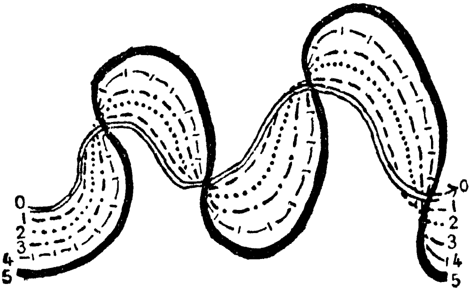

FIG. 48.—Development of meanders.
The arrow shows the direction of the stream.

Flood plains are as a whole a permanent feature, since they are connected with the base level. But they are sometimes cut into terraces, owing to tectonic movements which either increase its gradient or lower the base level. One or other of these movements must frequently occur, because nearly all great rivers have rows of terraces right down to their mouths. In the Seine, the Rhone, and the Garonne this feature is particularly well developed.

Various Types of Valleys. The corrasion of river beds, the erosion of valley slopes, and the deposition of sediment everywhere combine in modelling the topographical features of a district. But the shape of a particular valley depends on the more or less marked predominance of one of these processes. When the corrasion of the bed proceeds too quickly for the slope of the valley sides to be correspondingly lowered, the valley remains a *gorge*. When corrasion of the bed and erosion of the valley sides are equal, a *normal* valley results. If the slope of one of the sides is lowered more quickly than the other, the valley is said to be *asymmetrical*. The last type is very common. The swifter progress of erosion on one side of the valley may be due to its geological character, as, for instance, when it is formed of rock which is more easily acted upon than that of the other side by the run-off of rainwater, or which is more liable to land falls or slides. It is very often found in subsequent valleys in folded regions, and such valleys are termed *monocline*.

When the same kind of rock forms both valley sides, the asymmetry is due to erosion alone. This is the case in the hills of Armagnac, which have been dissected by a number of valleys, whose eastern slopes are always steeper than the western (see Fig. 49). Here the asymmetry is no doubt due to the greater action of the run-off of rainwater on the slope on which the driven rain falls more vertically. In other places the direction of the steeper slope changes, though it always remains on the right bank, e.g., the Danube in Hungary and the Volga in Russia. In such a case it is supposed that the current of the stream is deflected against the right bank by the influence of the rotation of the Earth in the same way as winds and ocean currents.

Interlocking Spurs. One more type of the asymmetrical valley deserves attention, the valley with interlocking spurs. This is to be distinguished from the shifting meanders which are found in alluvial plains and develop with the deepening of the valley. Well known examples are the Meuse in the Ardennes, the Moselle in the Vosges, and the Seine near Rouen (see Fig. 50); but few valleys in hilly regions do not belong to this type. The meanders may be supposed to have been formed on the surface of the plateau in which the valley has been cut, at a time when it was less elevated or when the stream was depositing sediment; but the channel has not necessarily been cut down in its present position. A close examination of the meanders of the Seine will suffice to show that they are not tied to a fixed path.

The asymmetry is the first thing that strikes one: the flattened lobes of the convex banks lie opposite to the abrupt amphitheatre-like concave banks. These lobes are covered with woods, because the Seine has deposited on them a kind of pebbly silt. Elsewhere, for instance in the Ardennes, the alluvial soil of the convex bank has been cleared and cultivated, and is the only part which is inhabited; while the steep amphitheatres of the concave bank remain as wooded as the plateau itself. The steepness of the concave bank shows that it is being undercut by the stream and that it is retreating. Cases occur in which the widening of the meanders has caused

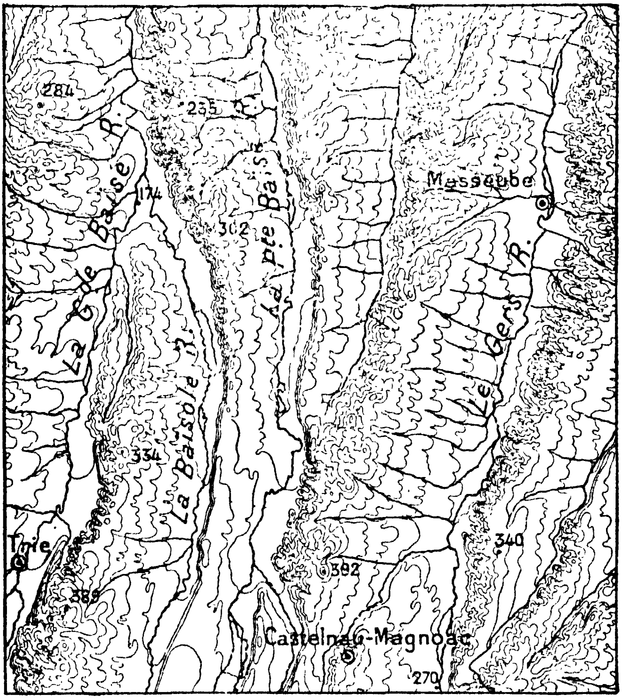

FIG. 49.—Asymmetrical valleys in the plateau of Lannemezan.
(Scale 1 : 250,000 with a V. I. of 20 m. From the official map of France on a scale of 1 : 200,000.)

two branches of a meander to meet and the elbow to be abandoned. Such a development is on the point of occurring in the first meander shown in Fig. 50, near hill 85. Several former cuttings can be seen in the valleys of the Moselle and the Neckar. Abandoned meanders form arc-shaped depressions,

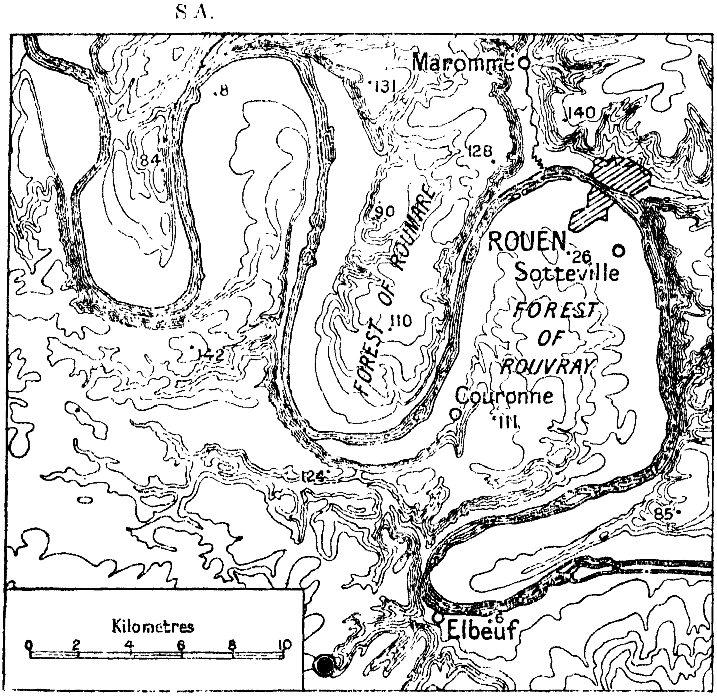

FIG. 50.—Meanders of the Seine near Rouen. (From the official map of France on a scale of 1 : 200,000.)

Note (1) the development of alluvial plains; (2) the undercutting of the banks at the base of each meander, which clearly indicates the downstream movement of the meander as a whole (the first and fourth meanders are almost entirely removed); (3) the capture of the Sainte Austreberte (S.A.), which has been forced to abandon its lower course which formerly led into the western branch of the fifth meander and to flow into the main river at the fourth meander just opposite the 8 m. spot height.

which are still marshy if the cutting through of the base has been recent, and which are always covered with a layer of silt and under cultivation. At Lauffen on the Neckar the cutting of the base cannot be of great age, for a waterfall still marks the occurrence.

In the meanders of the Seine there is another curious fact;

the river hugs not only the concave bank, but also the upstream portion of each lobe on the convex bank. Pronounced undercutting and asymmetry of these lobes results from this, as is shown in Fig. 50, particularly in the 1st, 4th, and 5th meanders. This proves that the meanders tend to move downstream and in doing this they may completely cut off the lobes on the convex bank, as has almost happened in the 1st and 4th meanders in Fig. 50. When this stage is reached, a valley widened by meanders will seem disproportionately broad as compared with the volume of water which winds through it. This explains the form of certain alluvial valleys enclosed by steep-faced plateaux, like those of the Somme (see Fig. 40 C), the Lot, or the Dordogne.

The Cycle of Erosion. The evolution of valleys through the development of meanders in a stream is a particularly illustrative example of the changes which erosion may cause topographical features to undergo. Such changes tend towards a definite goal and always occur in the same order. The corrasion of the river bed tends to reduce the gradient to the graded line, the erosion of the sides of the valley widens the section of the valley more and more, while the sediment, which is retained in upland plains so long as the profile of the river bed continues irregular and contains falls, is gradually carried further downstream as the profile becomes more regular, and does not stop until it reaches the flood plain which touches the base level. Fixed laws govern the succession of topographical aspects which the valley assumes as a result of this process. In normal conditions a gorge is constantly being widened, a cataract constantly creeping upstream and lowering its gradient. As long as the base level remains fixed and the land mass stable, as long as there is no appreciable change in climate, and as long as the forces of erosion act on the same kind of rock, no throw back in the order of events is possible. After the main stream has reached the graded line, then comes the turn of the tributaries, and one after another the valleys all widen out more and more. In this way a general lowering of the relief is brought about, the mean altitude of the basin is lessened, and all prominent features are rubbed off (see Fig. 51). Finally, only two or three very wide valleys will be left, separated by rounded ridges. To express this final aspect toward which the evolution of topographical features tends and which is almost that of a plain, the American geographer Davis has invented the term *peneplain*, which is now generally accepted. The definite series of stages which leads to it he has proposed to call the *cycle of erosion*.

To the same geographer are due the figurative expressions which have been adopted by most geographers and which indicate the three chief stages of the cycle. In the first stage great activity is observed in the agents of erosion : rapid corrasion of the river bed, rock falls and the development of gullies where the valley sides are steep, and captures which modify the river systems. This stage is *youth*. Gorges, cascades, upland plains are youthful features. When the main rivers have reached the graded line and the valley sides have gentle slopes, the changes in the surface continue, but more slowly and regularly. The topographical features are suited to the nature of the rock and seem to have been arranged so as to ensure the steady flow of streams. This is *middle age*. If the evolution continues, the gradient of the slopes will be observed to be lowered still further and the general surface will approach nearer and nearer to what has been called a peneplain. Disintegrated matter accumulates and levels the irregularities in the rock surface, filtering the water and reducing the amount of surface run-off. The rivers become slow and peaceful and bear along only fine clayey particles. Deposition is no more active than erosion, and the agents of change seem all asleep. This is *old age*. The peneplain is the typical form of this stage.

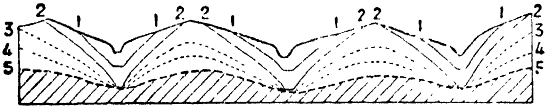

FIG. 51.—A peneplain. Showing the successive stages of erosion.

Forms of Relief which are Due to More than One Cycle. The geographical importance of these ideas is seen when regions whose features are the outcome of several successive cycles of erosion are observed, as is notably the case in the Central Highlands of France. To understand how a region may undergo more than one cycle, one must remember that the regular development of a cycle of erosion assumes the complete stability of the rock and the base level. The slightest change checks the regular succession of stages of erosion and begins another cycle.

The difference between features due to an old and a new cycle is easily seen when the first cycle reaches old age and the second is still in its youth. Such a state of things is to be seen in Limousin, where narrow valleys and steep gradients, giving rise to rapids are carved out of a granite platform whose slightly undulating surface is crossed by wide valleys with such feeble gradients that the water runs off only with difficulty.[1] A definite line with a sudden change of gradient separates the domains of the two cycles, thus confirming the law which was formulated above (Chap. I); for on the one hand the running off of water on the surface, disintegration, slides, and falls of rock are seen at work, whilst on the other erosion is checked and the waste produced by slow disintegration accumulates on the ground. Human activity finds different surroundings in the areas of youthful features produced by a recent cycle and in those of senile features caused by the former cycle. Villages are often placed at the point of contact, i.e., at the side of the valley which they command; agriculture proceeds on the plateau; and the steep valley slopes are wooded or bare of vegetation.

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[1] See the Staff Map of 1:80,000, sheet for Aigurande.

CHAPTER XII

INFLUENCE OF GEOLOGY ON TOPOGRAPHY

Upper Limousin. In order to understand the principles by which the difficult question of the influence exerted by the geological nature of the rock of a district on the local topography should be studied, let us begin by analysing two typical instances. Upper Limousin may be taken to illustrate the character of the topography of a granite district. Here one is immediately struck by the monotony of the scene and the absence of prominent features. There is a good deal of relief, but the valleys are all like one another, and all the hills have the same appearance. Unless one is quite familiar with the district, one finds it difficult to recognise places as one looks about from high ground. On all sides there are the same rounded hills, and the same wide valleys, which often have a marshy bottom. Both the hills and the valleys rise one after the other in a series of steps, and there is no definite line of separation between hill and valley. No map could represent such a landscape, and we have, therefore, preferred to illustrate it by a diagram (see Fig. 52). The only striking, picturesque detail is the presence of boulders on the heights and at the heads of valleys. In certain granite districts these boulders are a characteristic feature of the landscape. In Sidobre, for instance, they are

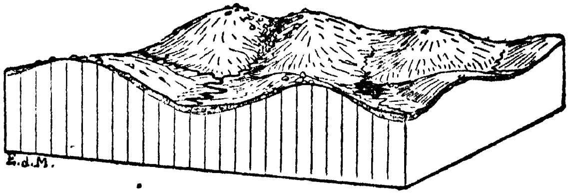

FIG. 52.—Granite topography.

strewn in confusion along the valley floors, forming veritable rivers of rocks under which torrents roar. They are known locally as *compayrés*. Similar features may be seen in Cornwall or on the western slopes of the Welsh Mountains.

The topography of a granite district is not without its influence on human life. The abundance of water and of springs explains the dispersion of the inhabitants, who live on farms or in little hamlets. The clearing away of ancient forests causes the spread of bare ground on the heights, whilst the damp valley bottoms, when drained, form fat meadow land or in other places marshy basins occupied by artificial ponds.

Causes of Granite Topography. It is not enough to describe the characteristics of granite topography; an explanation of the causes of such characteristics must be added. We should ask ourselves whether the facts which have been observed are really peculiar to granite districts and if they occur wherever this species of rock is found.

The abundance of water is due to the impermeable nature of the rock. Superficial springs are numerous, as is always the case in regions of impervious rock. The rounded topographical features are caused by disintegration, and by the slipping of rock waste down the slopes. Fig. 52 shows that the layer of granitic *sand* is deeper in the valley bottoms than elsewhere, and that it is watersoaked there. This sand is rapidly formed, in spite of the hardness of the granite rock itself, by the infiltration of water which dissolves the felspar. This process disintegrates the rock into a kind of clayey sand.[1] As granite is a massive rock, decomposition attacks it equally all over, working parallel with the surface of the rock; hence, disintegration can only cause it to become more and more rounded in shape. However, granite, like all other kinds of rock, is liable to be cracked through, though the cracks—which are known as *diaclases*—are invisible so long as they have not been widened by decomposition. By penetrating through these joints, water

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[1] Granite is formed of three elements, which are all visible to the naked eye, mica, which appears as scales usually black in colour; quartz, which is pure silica and of a glassy white; and felspar, which has a dull white appearance varied with glittering facets and which is a silicate of aluminium and potassium, a mixture which readily becomes oxydised under the action of water charged with carbonic acid.

disintegrates the rock. That is why one sees rounded boulders which are being gradually eaten away by decomposition and are embedded in heaps of sand formed by their own disintegration. The run-off of surface water carries away the sand and leaves the boulders isolated on the ridges or in the valleys, where they gradually creep down to form *compayrés.* The formation of boulders is not peculiar to granite; any massive rock can form them. It sometimes occurs in diabasic rocks, basalt, or even in compact forms of sandstone.

It should be added that granite does not always present the same characteristic topography as has been described above. In high mountain regions it forms not rounded ridges, but ragged peaks; e.g., the Aiguilles of Mont Blanc. This difference is due to climate. In regions of perennial snow the rock is bare, and is subjected to great variations in temperature and to vigorous decomposition, caused chiefly by frosts at night, which, by expanding the water that has penetrated into the diaclases, splits the hardest rock by this mechanical action.

In tropical lands also, granitic reliefs are different from those in temperate climates. They still have rounded features, but far steeper slopes. Hence, they form steep-sided peaks and deserve the name "Sugar Loaf," which has actually been given to a picturesque height dominating the magnificent harbour of Rio de Janeiro. The climate also accounts for the fact that in the tropics these granite peaks are disintegrated into scales parallel with the ground. The rock waste thus produced slips down in falls of rough stones. Intense insolation and variations in humidity are certainly the cause of this.

Even in temperate regions outside mountain regions granite topography which differs from those first described is sometimes found. The topographical aspect of Upper Limousin, which is also found in Sidobre, Morvan, and certain parts of Brittany, is middle-aged. Rejuvenation may cause the carving out of narrow, steep-sided gorges with rocky scarps. An example of such a throw back has already been described as existing in Lower Limousin (see p. 163).

Causses or Karsts. Let us now turn to limestone topography, taking the Causses region in the south of the Central

FIG 53.—Typical karst topography. (From the official French map on a scale of 1 : 200,000 ; V.I. 20 m.)

The hollows are shaded by stippling.

Highlands of France as our example (see Fig. 53). The first thing that strikes one is the rare occurrence of valleys and the depth and narrowness of the few that occur. Within the limits of the map in Fig. 53 the only valleys through which rivers run are those of the Tarn and the Jonte. They are both steep-sided gorges with rocky and at times vertical scarps; while overhanging pinnacles are not rare. Outside these valleys there is not a trace of running water. The dryness of the plateau has almost completely repelled human habitation; but for one little hamlet, the villages are all in the valleys, where big springs feed the rivers.

In spite of the absence of streams, the surface of the Causses is far from being without relief, but the features are rather puzzling. In vain does one look for the usual network of branching valleys and glens. It is all a confusion of humps and enclosed depressions. These depressions which have been emphasised by shading in the map, may be very large or quite small. If the latter, they are known locally as *sotchs*. Sometimes they are marshy at the bottom; hence, these are the only places where one ever finds water, cultivated ground, and an occasional hamlet. Everywhere else the rock is bare or covered over with a thin, reddish soil through which the rock appears at every turn. Sometimes the rock is streaked with cracks or crossed by fluted ridges. In the French Jura such rock is called *lapies*, in German-speaking countries *karren*. At the bottom of a *sotch* or on the edges of rounded hollows, a kind of symmetrical basin often occurs, whose clayey bottom is cultivated, if it is not occupied by a pond. In Slavonic countries such a basin is termed a *doline*. Sometimes, instead of a basin, there is a gaping hole like a well, usually surrounded by trees and bushes. In some districts of France the feature is known as an *aven*, but other local names are *bétoire*, *pot*, *goule*, *embut*. The variety of names proves the wide distribution of the form. A descent into one of these well-shaped hollows often brings one to grottoes, which honeycomb the rock and open on to steep slopes on valley bottoms.

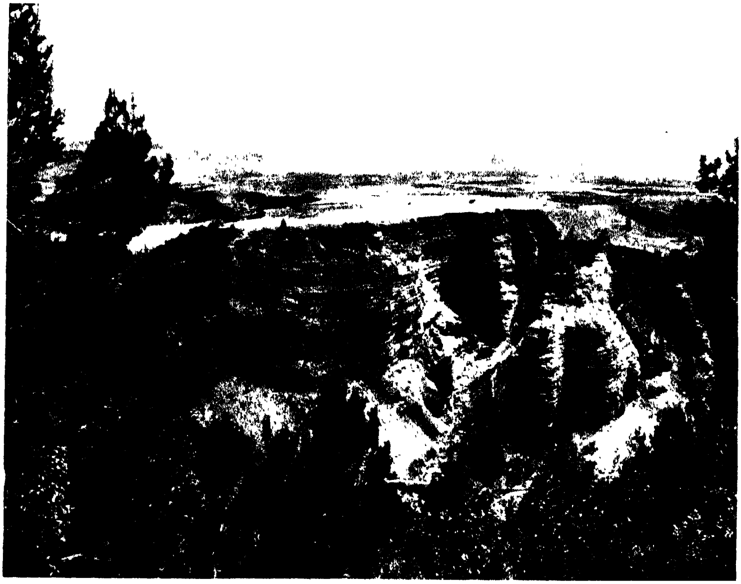
The characteristics which are found in nearly all limestone districts, then, are a scarcity of water, deep, narrow valleys, enclosed depressions or *sotchs*, *lapiés*, basins or *dolines*, well-

PLATE I

INFLUENCE OF ROCKS ON RELIEF

A.—VALLEY IN THE PLATEAU OF SIDOBRE, SHOWING TYPICAL WEATHERING OF GRANITE

Note the boulders partly standing out of the sandy soil



B.—LITTLE CAUSSE AT THE EDGE OF THE PLATEAU OF AIGONAL

Note the *avens* on the left marking the subterranean course of the Bramabian, which issues from the wide cavern at the bottom of the ravine in the foreground

shaped holes or *avens*, and networks of grottoes. They have been particularly well studied in the region known as the Karst or Carso in the neighbourhood of Trieste; hence, geographers speak of a Karst topography and of the characteristics of Karst regions. What is the cause of this type of region? Is the type peculiar to limestone districts? Is it always found wherever this rock occurs?

Origin of Karst Topography. We have already pointed out (in Part II, Chap. IX) the peculiar nature of the circulation of water in limestone districts. The comparative absence of streams, and consequently of valleys, is due to the permeable character of the rock. Rainwater percolates through all permeable rocks, especially sand, loosely-formed sandstone, gypsum and salt. Whilst percolation is due to the natural spaces that exist between the particles of sand and sandstone, it is caused in limestone by a fine network of diaclases which become enlarged by chemical solution. The permeable character of limestone is chiefly the result of the solubility of carbonate of lime, which is the chief constituent of limestone, in water charged with carbonic acid. Gypsum and salt are still more soluble than limestone, but they are seldom found in such extensive masses. They lack the cohesion of limestone, and the caves which are sometimes formed in them by solution fall in immediately.

In sandstone districts one often notices the scarcity of running water, the same precipitous or overhanging cliffs as occur in limestone, since the run-off of surface water is so small that it cannot form regular slopes. But, usually, circular hollows and branching caves do not occur, as these features are caused by the solution of the rock at the surface and beneath it. Grooves and ridges like those of the *lapiés* have been observed in sandstone and even in other kinds of rock, but the grooves are never so deep, nor the ridges so prominent as in limestone. In limestone, moreover, the *lapiés* have been noticed to be all the more true to type when the limestone is pure. Hence, the cause of their development must be solution working with the gradient and the cracks.

Enclosed depressions are also due to solution, but especially to solution which occurs beneath the surface and which in a way undermines the surface. When solution takes place in layers near the surface, it produces the subsidence which results in a *doline*, at the bottom of which there accumulates a clayey residue forming the red earth known in Italy as *terra rossa.* When solution takes place along more or less vertical cracks, it forms *avens.* When it attacks the rock far below the surface, it causes a network of caves. The water which disappears from the surface runs through the caves, forming in them lakes and torrents, which corrade their beds in the ordinary manner of running water and assist in the further enlargement of the subterranean passages.

Varieties of Limestone Topography. All limestone districts do not resemble the Causses or show all the features of karst topography developed to the same extent. This is sometimes due to geological influences. Limestone *massifs* have more vertical and higher cliffs than do *massifs* formed of a mixture of silica and limestone, in which latter each layer of rock forms a terrace. Chalk, which constitutes the structural rock in all Picardy and a part of Champagne, eastern Normandy, and the south of England, is a soft limestone which is often mixed with clay and is always full of cracks. The features of karst topography are but little developed in districts formed of this rock, *lapiés* are unknown, and *dolines* rare; but water is never seen in them. The big valleys alone contain rivers. The bottoms of these valleys are flat and often marshy and peaty, while their sides, though rather steep, do not form scarps, but have a characteristic convex outline. Fig. 40 C has already given us an illustration of this kind of topography.

Dolomite, or magnesian limestone, is a rock composed of carbonate of lime and carbonate of magnesia. The latter element is comparatively insoluble; hence, the decomposition of dolomite yields sand, and scarps of this rock are like those of sandstone. Dolomite limestone gives the most picturesque illustrations of calcareous relief. Here are seen rock masses like ruined towers, pillars, and arches; e.g., the famous cliffs of Montpellier-le-Vieux in the Causses region or those of Larzac. In South Tyrol a whole region of jagged peaks has assumed the name of the rock, viz., the Dolomites.

But geological structure does not always supply the reason for the various forms of limestone topography. Relief develops gradually, and limestone topography, like any other, must be expected to offer a progressive series of aspects. The absence of surface erosion by running water seems to deny the working of the law of the base level. But, actually, the erosion is effected by underground streams, and these have a base level fixed by the impermeable layer on which the limestone rests, or if this layer happens to be below sea level, by the level of the sea itself. The circulation of underground torrents and the development of caves and *avens* depends on the vertical distance which separates the surface of the ground from the base level of the limestone. This explains the difference that exists between the plateaux of the inland district of Carniola, which is riddled with a host of small, shallow *dolines*, and the mountains of the seaboard of Carniola with their *avens* and their huge *dolines* hundreds of feet deep; or the difference between the little Causses of Quercy with their network of streamless valleys and the main Causses with their few, steep-sided, narrow valleys and their lofty plateaux pitted with *avens* and *sotchs*.

But just as normal surface erosion lowers the surface of the ground by merely carving out valley after valley, so the erosion that occurs in karst regions lowers the surface by eating out *lapiés*, producing *dolines* by undermining processes, and digging *avens* and caves, so that it gradually approaches the base level of the limestone. At the same time the clayey residue left from the decomposition of the limestone accumulates on the surface in the *dolines*, at the mouths of the *avens* and all other cracks, so that the erosion of karst regions imposes a check on itself at the end of a certain time, just as normal fluviatile erosion does. Hence, one may speak of young and old regions of karst topography. The last stage seems to have been reached in countries where the rivers flow once more on the surface, as for instance in parts of the plateau of Burgundy.

Geographical Attributes of Rocks. The foregoing study of granite and limestone topography has shown us the spirit in which we must approach the interpretation of geological influence on topography. It is clear that there is no connexion between geological classification and geography. The geologist distinguishes the strata which form the Earth's crust according to their age; but it is of little importance to the geographer to know that a district is formed of primary or tertiary rock. What is important is that he should know what kind of rock it is formed of. But even the classification of rocks as accepted by geologists is of little use in geography, since it is drawn up on the basis of origin and composition, not of influence on erosion. The geographer must certainly know the classification if he wishes to understand his subject thoroughly, but he must not expect to find it a guide to the explanation of surface relief. Thus, we have seen that the formation of boulders is not peculiar to granite, or *lapiés* to limestone, and that neither granite nor limestone always yields the same topographical features.

The characteristics of relief are determined first of all by certain physical and chemical properties of the various kinds of rock. Permeability is, perhaps, the most important. The greatest geographical contrasts are seen between countries formed of permeable rock and those formed of impermeable rock. In the one there is a scarcity or total absence of streams and even of valleys, and an ill-defined or even abnormal topography; in the other there is an abundance of water and the topographical features are regular and deeply cut. Solubility progressively increases the effect of permeability, since the water which percolates through the rock keeps on widening the passages through the ground. This gives limestone districts their peculiar topography. Rocks which occur in masses differ profoundly from those which are naturally divided into layers or crossed by cracks or diaclases. The former are naturally impermeable, the latter allow percolation to take place along their seams. The development of boulders and rounded features are peculiar to massive rocks. A very important character is the coarseness of the grains and their greater or less cohesion. A rock which is composed of fine grains cannot be attacked by disintegration in the same way as one composed of coarse grains. If the grains are very cohesive, the slopes strongly resist erosion ; if the cohesion is slight, the slopes are quickly carved up and crumble away.

These are the points for consideration in interpreting the influence of geological structure. But certain circumstances have also to be taken into account, since they modify that influence. Of these the chief is climate, which increases or decreases the action of the run-off of surface water, slides, and chemical or mechanical disintegration, according as it is rainy or dry, extreme or temperate. Lastly, it must never be forgotten that topography is evolved gradually and that its nature may be different at various stages in the cycle of erosion.

Structural Platforms. One last point deserves closer consideration, the effect of the contact of different types of rock. We pointed it out at the beginning of this part (see Chap. X, p. 142), but we are only now beginning to catch a gleam of the explanation. Whenever in the same river basin or in a valley erosion acts upon rocks which have not the same properties, the line of contact of these rocks is marked on the surface of the ground by some topographical irregularity, and the irregularity is emphasised in proportion as the development of the topography proceeds towards middle age, and is gradually removed as old age is reached. The resultant forms vary according to the conditions under which the contact between the rocks takes place.

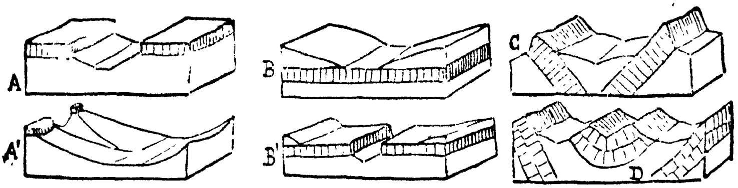


FIG. 54.—Evolution of valleys in a region composed of rocks of different resistant character.

In a region of horizontal layers the profile of the valleys depends on the relative depth of these layers and on the circumstances attending their superposition. The whole district round Paris affords instances of steep slopes in less cohesive layers, like sand, when they are covered by a layer which offers greater resistance, as, for example, limestone or sand (see Fig. 54 A). If the layer which offers resistance is beneath the less resistant, it has no influence on topography until the stream cuts its bed down to it (see Fig. 54 B). Conditions may change according to the stage which has been reached by the cycle of erosion and the depth to which the river bed has been cut. If the valley is carried down to a great depth in a comparatively incohesive layer, the resisting bed of rock will in the end be completely removed, and the topographical aspect will be that shown in Fig. 54 A,[1] which is similar to case B. On the other hand, if the process of corrasion continues after the stage shown in B has been reached, it will result in a gorge cut through the resisting rock, whilst the less resistant rock above the hard layer will be almost entirely removed. Thus, a platform will be left (as in B), which may cover a fairly large area, and in which only the main valleys will have penetrated to any depth in the hard rock. The name *structural platform* may be given to level surfaces of this origin, to distinguish them from *erosional platforms*, which are raised peneplains. The latter can only have been formed in close relation with the base level; the former may be developed at varying altitudes, since its height above sea-level and its gradient depend on the geological structure of the rock.

The district round Paris is the classic region of structural platforms. Each layer of limestone has a corresponding platform, of which the best developed in the neighbourhood of Paris is one of coarse limestone that constitutes the platform of the Ile-de-France and continues into the Soissons district. East and south-east of it, Brie and Beauce are in a more recent stage of development. The difference in outward appearance between these plateaux and the intervening district round Paris is well known : the one with its dry, monotonous, and usually treeless plateaux, which are studded with farms and widely scattered villages, and with its extensive estates and its cereal or beetroot cultivation; the other with its varied topography, carved out of sand or clay, with its cool and often wooded valleys, its springs, its varied forms of agriculture, in which early fruits and vegetables predominate, and its numerous villages, which are often surrounded by vineyards.

Escarpments : Consequent and Subsequent Valleys. As we go eastwards from Paris we find right up to the Vosges a series of structural platforms which are generally of limestone and cut by valleys of type A (Fig. 54). These platforms alternate with depressions of clayey sand and valleys corresponding more or less to types A[1] and B. But some new features appear.[1]

The plateaux usually have a clear-cut edge which is often wooded and always faces east, and which is broken by relatively narrow valleys. Near by stand *buttes*, which have obviously been detached from the plateaux by erosion (e.g., the *buttes-témoins* of Toul, Grand-Mont de Nancy, *butte* de Vaudémont). The surface of the plateaux is not horizontal, but inclined towards the west. They are asymmetrical. Their steep face is known as an escarpment, and the villages which lie in a row at its foot often have the suffix *dans la côte*, *sous les côtes*, or simply *la côte* attached to their names. A river often flows at the foot of these slopes. Thus, the Moselle follows the Côtes de Moselle for some distance. The valleys of such rivers are always asymmetrical. On one side stands the steep limestone escarpment, crowned with woods and having springs and big villages at the foot; on the other a slope which rises so slowly that it appears to be a plain, well watered and containing many little valleys. Sometimes studded with tiny lakes, it has a fertile soil and is full of meadow-land and highly cultivated areas. It invariably bears a local name, e.g., Voëvre, Saulnois, Xaintois, Bassigny.

The general asymmetry of the relief indicates that the layers of rock are not horizontal, but inclined towards the west. These essential features are found wherever the same conditions exist. The depressions and the escarpments which dominate them mark the point of contact between layers of rock which offers resistance to erosion and beds of clayey sand which are easily eroded. In England a series of escarpments are met with on a journey from London to Wales. In South Germany, between Bohemia and the Black Forest, there is a region of escarpments formed by the erosion of beds of sandstone or limestone. The highest is the Rauhe Alp, the edge of which rises to 2,600 or 3,000 feet and stands fully 1,600 feet above the valley of the Neckar. Its outlying buttes look like great peaks, and are crowned with castles, one of which was the original home of the Hohenzollerns.

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[1] This description should be followed, if possible, on a good physical map of France (scale 1 : 500,000, or better, 1 : 200,000). See also Fig. 46, which represents the slopes of the Meuse and the Moselle in the Nancy-Verdun-Toul district.

To understand the formation of such escarpments, the cycle of erosion must be supposed to have begun by carving out valleys parallel with the general slope of the rock, as is shown in Fig. 55. The run-off of surface water down the slopes of these valleys was bound to form secondary valleys, and the erosion of these at the junction of layers of rock which offered a different amount of resistance gave rise to asymmetrical valleys. The valleys which were formed first are called *consequent*, the later ones *subsequent*.

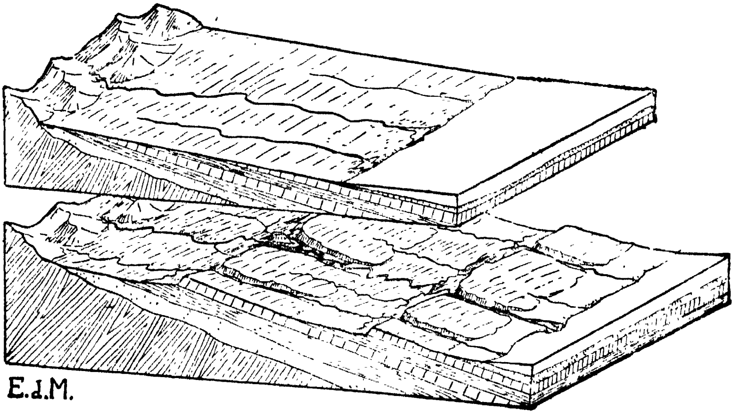

FIG. 55.—Development of subsequent valleys and the evolution of the coastline.

In the case of the eastern part of the Paris basin there is certainly no doubt that the drainage must at first have led down to the seas or lakes which occupied the district round Paris during the tertiary age (see Fig. 55). But a general view of the escarpments of Lorraine and Burgundy brings out an important fact, viz. their general outline, apart from festoons caused by erosion, is not rectilinear as in Fig. 55, but curved. They describe arcs of concentric circles so clearly that the geologist Elie de Beaumont called attention to their shape nearly a century ago. The explanation is quite simple. The layers of rock are basin-shaped and lean towards the centre of the Paris basin, instead of being uniformly inclined towards the west, and the convergence of the rivers towards Paris depends on this arrangement.

On examination, the district of Morvan is found to have the reverse arrangement. The ancient block mountain, which is a last offshoot of the Central Highlands, is surrounded on the east, north, and west by a series of arc-shaped escarpments, but their steep face is turned inwards. The layers form a convex protuberance like the ruins of a dome which once covered Morvan. One of the subsequent valleys has special importance, for it marks the line of contact with the old block mountain. The name *terre plaine* which has been given to it is significant. It forms the heart of Auxois, a region of rich pasture and plough land, full of villages and dominated by wooded limestone escarpments with some famous outlying buttes like the one on which Vézelay and its magnificent cathedral stand. Fig. 55 shows that this development is natural. It is also found at the edges of the Vosges, the Ardennes, and the Black Forest. The name *Baar* used in Wurtemburg to describe it is the equivalent of the Burgundian *terre plaine*.

These details show that the conditions become more complicated as soon as the slope of the layers of rock ceases to be uniform. When it is broken by tectonic dislocations, the evolution of topographical features becomes very complicated and a special chapter will be devoted to its study.

CHAPTER XIII

VOLCANIC TOPOGRAPHY

Before approaching the study of tectonic influence, let us examine one more particular case of the influence of rocks on relief. The tables of geological classification contain a class of rocks which deserve, even from the geographical point of view, to be set apart by themselves. They are volcanic rocks, produced by volcanic eruptions. Whilst other kinds of rock affect topography only when they have been subjected to erosion, volcanic rocks form topographical features by themselves. Eruptions build up cones on the Earth's surface with such speed that erosion has no effect on their surface, so long as the volcanic activity lasts.

Vesuvius. Vesuvius is a classic volcano. Its regular cone, which dominates the Bay of Naples, ends in a *crater* or kind of funnel, which pierces the top of the mountain, and from which rises an almost continuous column of smoke. The regularity of the cone is broken on the south by the Somma, a crescent-shaped rampart overlooking the Atrio del Cavallo, and itself dominated by the still deeper slopes of the main cone. This cone seems to have been a later addition, the result of renewed activity on the part of the volcano owing to some special occurrence or after a period of temporary quiescence. It is climbed with difficulty, since one's foot sinks into the crumbling dust, which resembles ashes in colour and consistency. Lower down the ground is firmer, and consists of hard, black rock bristling with lines of irregular hummocks that trail down the slopes. The history of the volcano is well known. The ash ejected from it is known to have caused the destruction of Herculaneum and Pompeii, while the incandescent streams of lava flowing over the crater lip or from temporary vents in the mountain side as far down sometimes as the villages, gave rise as they cooled to trails of blackish scoriaceous rock. A long tale of disasters has failed to prevent man from dwelling round the mountain. A ring of villages encircles it, and cultivation prospers on the fertile soil, which is watered by the many springs that rise at the base of the mountain.

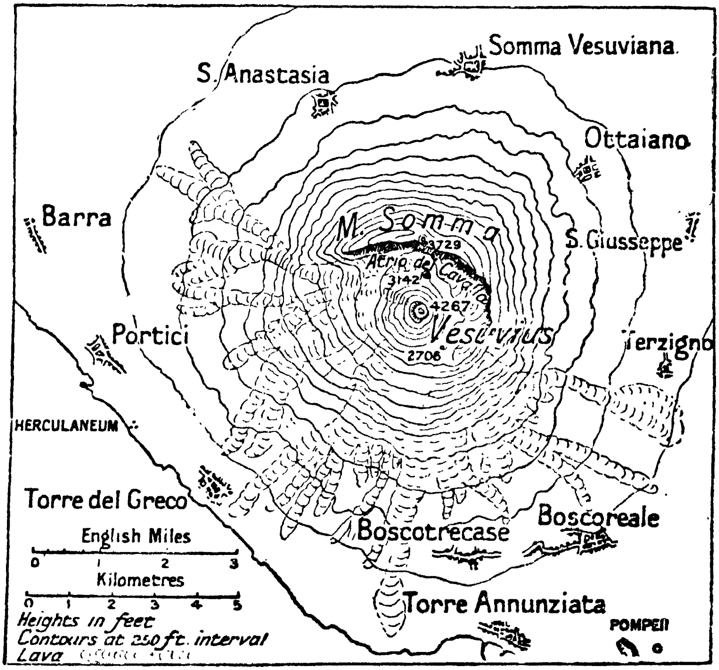

FIG. 56.—Vesuvius and its neighbourhood. From the official map of Italy (1 : 100,000).

The last phase of activity in Vesuvius was closely observed. After the eruption of 1872, wreaths of smoke issuing from the crater were the only signs of constant activity. But now and again molten lava was seen overflowing in little streams and explosions were observed to hurl jets of steam and clouds of ash into the air. The ash fell round the crater and raised the central cone, so that its altitude finally increased above 4,590 feet. Gradually the lava streams became greater, the mountain seemed to swell, and cracks opened in its sides, giving passage to streams of lava. On April 7, 1906, at 10.45 a.m., a vent situated at a height of about 1,970 feet ejected a vast quantity of fluid lava, which flowed rapidly down the slopes and, after destroying part of the village of Bosco Trecase, reached the gates of Torre Annunziata. The same day spurts of molten lava were seen to be shot from the top of the central cone and to rise in the air like incandescent jets. This phenomenon, which is comparatively rare in Vesuvius, causes *volcanic bombs*, formed of spirally twisted lava and scoria, in which ash and lava are mingled. The incandescent jets were followed by a huge column of thick dark wreaths like storm clouds streaked by lightning. This cloud of vapour, laden with ash formed of pulverised rock and with stones of various sizes, rose in almost continuous vertical jets. The ash and stones fell down again all round the crater. At 12.30 p.m. and at 2.40 a.m. next morning the last two great explosions occurred, accompanied by a frightful detonation and an earthquake. Vast quantities of fine ash were ejected and, falling on the district round Ottaiano, completely destroyed it, causing 250 casualties among the inhabitants. This was the end. From April 8 onwards the explosions gradually lessened in force and at the beginning of May ceased altogether. Then it was seen that the top of the central cone had been blown away, and the altitude of the mountain decreased by some 320 feet, while the Atrio del Cavallo was partially filled with *débris*. Probably Monte Somma was due to a similar, though far more powerful, explosion. The existing crescent was probably part of the lip of a larger crater which was destroyed by an eruption, while the central cone was subsequently built up.

Vesuvius is the type of volcano formed by the accumulation of ejected matter, whether ash or scoria, and of lava streams.

Mount Pelée. Mount Pelée, on the other hand, may be taken as the type of volcano which emits viscous lava. It has achieved fame by the disaster at Saint-Pierre in Martinique and the excellent study devoted to it by Lacroix. Here, again, we find man persisting in his attachment to the deadly mountain on account of the wonderful fertility of its soil. Since its destruction in 1902, the town has been rebuilt in exactly the same place. The viscosity of the lava and the nature of the ejected matter distinguish Mount Pelée from Vesuvius. The lava of the former is of a different chemical composition, being richer in silica, and has a lower temperature. On account of this latter attribute, its streams do not flow so easily. The summits of volcanoes of this kind are often formed by a sort of pustule caused by the piling up of very short flows of lava. This fact was specially noted by Fouqué at Santorin in the Ægean Sea. Lacroix observed the crater mouth of Mount Pelée to be blocked by a sort of lava-crust, which the force of imprisoned gases constantly pushed upwards, causing the rise of a kind of sharp spine which collapsed on attaining a certain height (see Fig. 57).

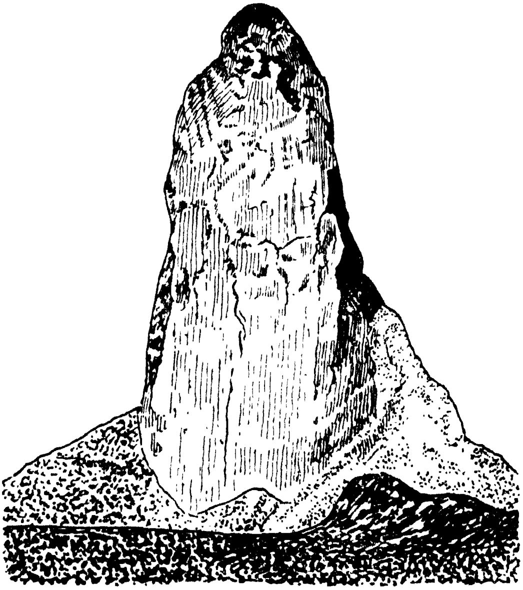

FIG. 57.—The spine of Mount Pelée. (After Lacroix)

The Saint-Pierre disaster was due to the blocking of the vent pipe. At a moment when the force of the imprisoned gases became too strong, a breech was opened in the mountain side, through which escaped a terrible cloud. This burning cloud, as it has been called, differed from the clouds emitted by Vesuvius, in being very much denser. Laden with ash and enormous blocks of stone, the gases could not rise, and they rolled down the side of the mountain, like a sort of balloon, becoming progressively inflated. As Saint-Pierre happened to be in the path of the burning cloud, it was burnt and then buried under the *débris* which the gases held in suspension.

Volcanoes which emit acid, viscous lava are, in fine, less regular in their working than those which eject basic fluid lava. They differ in appearance, the former having at their summit a rounded or pointed pustule, the latter usually having a cone of ash or scoria with a crater at the top.

Lava Basins : Mauna Loa. It is comparatively rare for lava to be so fluid as to be able to flow out continuously and without eruption. The phenomenon is seen, however, in Kilauea, the auxiliary crater of Mauna Loa in Hawaii. At the bottom of this immense cauldron a lake of incandescent lava boils unceasingly. Its edges solidify, but are liable to sink and form a series of terraces. The sight of cascades of lava overflowing from this basin and of jets of lava shooting into the air like jets of water can never be forgotten. The gradient of the lava streams is naturally very gentle, and the surface is comparatively regular ; hence, the usual form of the volcanoes is that of a flattened cupola whose sides rarely have a greater angle of slope than 7°. Thus, Mauna Loa rises like a gigantic pancake, more than 300 miles in diameter, from a submarine depth of

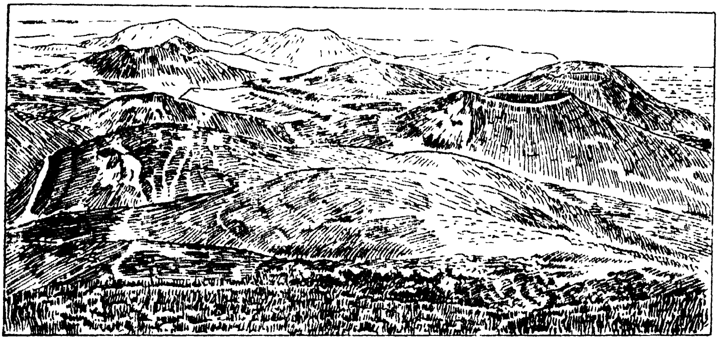

FIG. 58.—Panorama of the line of Puys in the Central Highlands of France (Sketch from a photograph taken from the northern slopes of the Puy-de-Dôme.)

The Nid de la Poule and Clierzon are in the foreground ; in the background Puy de Louchadière is on the left, Puy de Jumes on the right ; in the middle ground Pariou, Puy des Goules, and Sarcoui stand in a row on the right, and Petit Suchet, Puy des Gouttes, and Puy Chopine on the left.

PLATE II

Volcanic Relief

A.—ACTIVE VOLCANOES IN JAVA

The cones are of cinder and scoriae and show craters. In the background is Mount Smeroë

B.—VIEW OF PUY-EN-VELAY

Note the volcanic necks round which the town centre

13,000 feet to a height of 13,675 feet, with an angle of slope varying from 4¼° to 6½°.

Iceland is almost wholly formed of lava-flows of the same kind, and possibly the plateaux of Aubrac in the Central Highlands of France have the same origin, since there is no trace of craters in them.

The Chain of Puys in Auvergne. Volcanoes seldom occur singly. The Chain of Puys which dominate Limagne and the town of Clermont Ferrand illustrates their mode of grouping. The extraordinary panorama which lies at the feet of a spectator on the Puy de Dôme cannot fail to strike even those who are accustomed to such sights (see Fig. 58).

North and south runs a line of cones, some wooded, others still showing the red or brown tints of scoria, some topped by a crater, others rounded like a bell. It seems evident that the difference in level between the plateau which they stand on and the plain below has influenced the alignment of the cones. Geologists have discovered faults along it. On closer examination differences are noticed which are due to the nature of the activity formerly displayed by each of these little extinct volcanic centres.[1]

Sarcoui, which is bell-shaped, is a pustule of acid lava. Puy de Dôme is probably a peak similar to Mount Pelée, and is surrounded by screes that have fallen from its sides. Puy de Louchadière and Mount Suchet are simple scoriaceous cones. Puy de Come and Puy du Pariou are double cones, one within the other, and formed by successive eruptive phases. Puy du Pariou has a Somma and an Atrio just like those of Vesuvius. Most of the cones formed of ejected matter have emitted lava streams which are visible to the eye. Their surface, which is dryer and more stony than that of a Causse, and bristles with hummocks of rock and irregular hollows, has acquired for them the name of *Cheyres* (from *Petra* =stone). It is often covered with thin scrub. Lava-streams sometimes obstruct the valleys and form lakes like that of Aydat. Springs gush out from their sides. In their descent the brooks follow the little valleys

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[1] The details of this paragraph should be followed on the Staff Map (1 : 80,000) on the sheet for N.E. Clermont-Ferrand, which is partly reprinted in the author's *Traité de Geographié Physique*, Fig. 167, p. 427.

on the plateau, cutting gorges through the steep face looking towards Limagne. However, if the region is examined carefully and lava-streams recognised by the blackish escarpments of basalt which is sometimes fractured into prismatic columns, some will be found on the valley sides or even at the top of a hillock. This is notably the case with Mount Serre, which advances like a causeway to the edge of Limagne. This sort of inverted relief is evidently due to erosion, the action of which on volcanic structures remains to be studied.

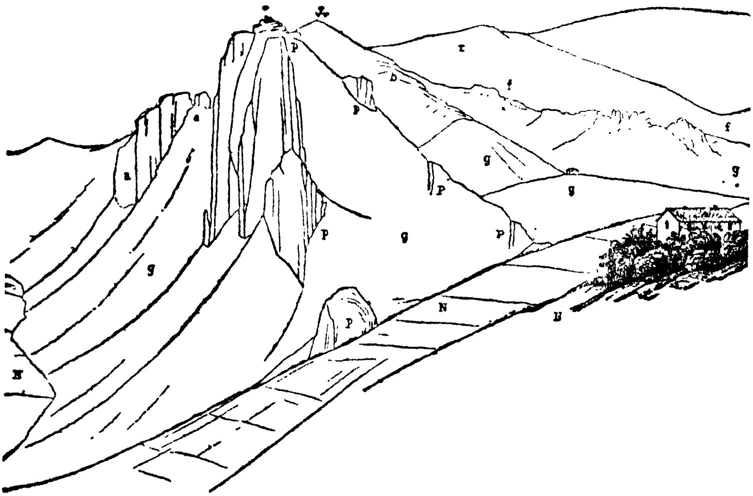


Fig. 59.—The Euganean Hills. (From Suess: *The Face of the Earth.*)

Evolution of Volcanic Relief. The destruction of volcanoes is sometimes due to eruptions. This is illustrated by the eruption in Krakatoa in 1883, which blew away two-thirds of an island of 12¼ square miles. Usually, new lava-streams and freshly ejected material soon hide the effects of such eruptions and rebuild the features which have been destroyed. We have already shown that this was done by Vesuvius. However, a vast cavity may sometimes be left, like the *calderas* in the Azores. They are at times occupied by a lake, with an island in the middle, formed by a new cone; e.g., Crater Lake in Oregon, U.S.A., and Lago de Vico in Italy.

The final destruction of volcanic structures, however, is reserved for erosion. It begins as soon as the volcanic activity becomes dormant. Its first effect on the cones of ash is to carve out gutters down the slopes. These are termed *barrancos* in the Azores. The ease with which the ash and cinders are removed allows the work to proceed apace, and the rock peaks from which the gutters radiate crumble down while the channels are being deepened by each heavy shower. The complete removal of the ejected matter which forms the cones leaves the more resistant lava exposed to form a sort of plug in the vent of the extinct volcano. A protuberance thus appears in place of the hollow crater and causes a real inversion of relief. Such a protuberance is termed a *neck*. Many examples occur in ancient volcanic districts. The extraordinary site of the town of Puy-en-Velay is one of the best known. The peaks of the Euganean Hills, whose bold outline stands up in the middle of the Plain of Lombardy, and North Berwick Law in Haddingtonshire, are formed of necks remaining from tertiary volcanoes (see Fig. 59).

Erosion also attacks the lava-streams. When they spread over large areas, their comparatively gentle slope and their permeable nature give the relief some features of resemblance to that of regions composed of horizontal layers of limestone or sandstone. A few steep-sided valleys separate dry plateaux, which are not unlike the Causses, except that they lack the *dolines* and *avens*. Examples are the *Planèzes* of Cantal and the heights of Aubrac in the Central Highlands of France. The basaltic plateaux in Oregon, an extremely dry region in the Western United States, are real desert land. Where erosion has been at work for long enough, the valleys are fairly wide, and the plateaux are reduced to narrow ridges or isolated blocks. In Mexico the latter are called *mesas*. Examples of the type occur in Velay (Butte de Polignac) and on the edge of the plateaux of Aubrac and Limagne. These mesas often determine the position of a village, for a spring usually rises at their foot, and a castle, defended on all sides by steep scarps, is frequently perched on their flat tops.

Lava-streams which flow down valleys oust the rivers. These then flow along the edge of the lava-stream and are swelled by springs rising from under it. If the valley thus filled has been carved out of a less compact rock, which is more liable to disintegration and crumbling than solidified lava, another channel will at once be carved out on one side of the lava-stream at the surface junction with the structural rock, and, as may be imagined, after a time the lava-stream will become a positive feature in the topography, thus causing a real inversion of the former relief. This has happened in the case of some of the lava-streams issuing from the chain of Puys on the edge of the plateau of Limagne which have followed valleys hollowed out of tertiary clay, e.g., Mount Serre, whose curious outline has been referred to already.

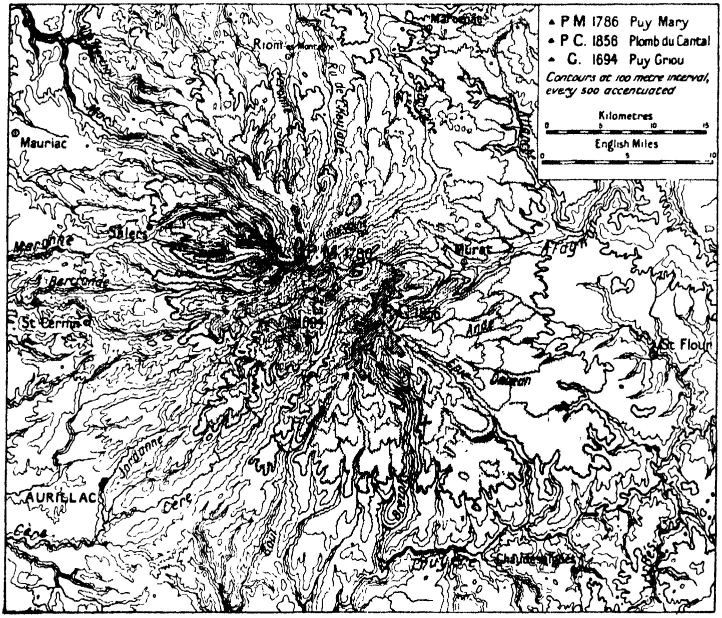


FIG. 60.—Cantal. (From the official map of France on a scale of 1 : 200,000.)

Note the radiation of streams from the central point and the characteristic triangular shape of the intervening plateaux. Compare the topography developed by the river in the S.E. corner with that of the volcanic area.

Cantal. The evolution of a big volcano which has been built up by lava-streams and the ejection of cinder and scoria, causes complex topographical features, of which an example may be found in Cantal (see Fig. 60).

Traces of a crater will be sought in vain, for it has long disappeared. Its edge probably rose something like 3,000 feet above the highest existing peaks. These are mostly *necks*, of which Mount Griou is typical. The most prominent geographical feature is the radial arrangement of the valleys, which began as *barrancos* running down the divergent slopes of the cone. These steep-sided, damp-bottomed valleys separate triangular plateaux of basalt, known as *planèzes*. Their surface is waterless, but has already suffered decomposition enough to form a fertile soil, and is therefore covered with rich crops in the lower portions (e.g., the *planèze* of Saint Flour), and with rich pasture lands dotted with cowsheds on the higher but narrower ground. A ring of towns encircle the old volcano, viz., Saint Flour, Murat, Salins, Saint Cernin, and Aurillac.

Although it is so worn by erosion, Cantal is still a clearly recognisable volcano. But denudation may continue until the lava streams have almost wholly disappeared and the last traces of ejected material have been removed. Nevertheless, one mark of volcanic topography, viz., the radial arrangement of valleys, can never be wholly effaced. An example of this occurs in the Rhön Block in Germany.

Geographical Distribution of Volcanoes. The great dislocations of the Earth's crust which have determined the distribution of land and sea, plains and mountains, seem also to have regulated the distribution of volcanoes. The proved connection between the chain of Puys and a sudden change of level due to a dislocation of the rock is observed almost everywhere, and volcanic regions are usually belts following the main lines of dislocation.

Thus, the whole western coast of the New World is bounded by the Rocky Mountains and the Andes, while close off shore there are great ocean deeps. Hence, from Alaska to Patagonia, passing through British Columbia, California, Mexico, Peru, Bolivia and Chile, there runs a continuous line of volcanoes, which are often of imposing height and capped with perennial snow even at the Equator. Many are still active. Round them are huge lava-covered districts, which in the Western United States extend over areas greater than France and Spain together. Similarly, the festoons of mountainous islands off the coast of Asia, which are on the edge of extremely deep submarine trenches, bristle with volcanoes, from Kamchatka through Japan to the Philippines and even to New Zealand. The most imposing cones formed of ejected material occur in Japan (Fujiyama) and in the Sunda Islands. The most terrible eruptions have also been observed in this zone, e.g., those of Krakatoa and Bandaisan. Another volcanic belt crosses East Africa and Western Asia from the sources of the Nile through Abyssinia and Arabia to Armenia. It corresponds to a line of fractures which will be mentioned again in the following chapter. The Mediterranean volcanoes are connected with the recent subsidences which, as will be seen later, have dislocated southern Europe.

In short, the importance of volcanic relief is due to the fact that the last phase of geological history was one of violent tectonic dislocations provoking eruptive activity. The volcanoes of previous ages have been removed by erosion.

CHAPTER XIV

TECTONIC INFLUENCE

The Côte d'Or and Jura Mountains. Let us compare two contour maps showing the relief of a part of the Côte d'Or and a portion of the eastern Jura. The obvious topographical differences observed are due to the nature of the dislocation that govern the main irregularities of the surface of the grounds. The main feature of the Côte d'Or (see Fig. 61) is the escarpment overlooking the plain of the Saône. We have already explained its origin (see p. 143). It is caused by a fracture with subsidence of the eastern side, i.e., by a fault. The straight path followed by the feature contrasts with the winding lines of relief in the Jura (see Fig. 62), but is characteristic of regions where faults have occurred. The top of the Côte d'Or itself forms a terrace, a plateau edge. To the west of it there is a second and higher plateau, rising to more than 1,600 feet, and even more denuded, but as distinctly flat-topped as the first. Most fault regions give rise to shelves of this kind, which are separated by lines of sharp change of level running more or less in a straight line.

The Jura district is quite different in appearance. Instead of plateau-terraces, there are relatively narrow ridges and long, winding valleys, which, however, all have the same general direction and are more or less parallel. These are the characteristic features of all folded regions. If we study the Jura as a whole in a good atlas, we are struck by the arrangement of the rivers. The course followed by the Doubs is particularly characteristic, with its sharp bends. This type of hydrographic network, to which the name *Jurassian* has been given, and which is formed by longitudinal valleys joined by short transverse branches, is also found in all folded regions. Even when the mountains have been completely levelled by erosion, the features of the type remain as a testimony to the ancient folds. The valleys of the Jura are obviously different in appearance, according as they are longitudinal or transverse. In the first case they are usually wide; in the second, narrow and steep-sided. This contrast, which is expressed locally by the names *val* and *cluse*, occurs as a general rule in folded regions and survives for long ages in spite of the action of erosion.

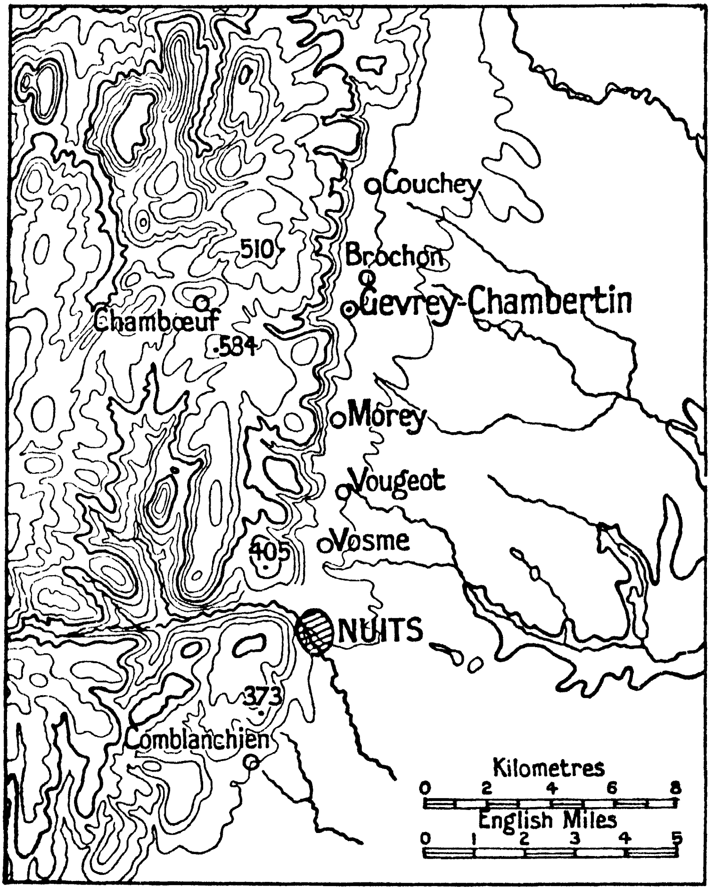


FIG. 61 —The Côte d'Or. (From the official map of France on a scale of 1 : 200,000.)

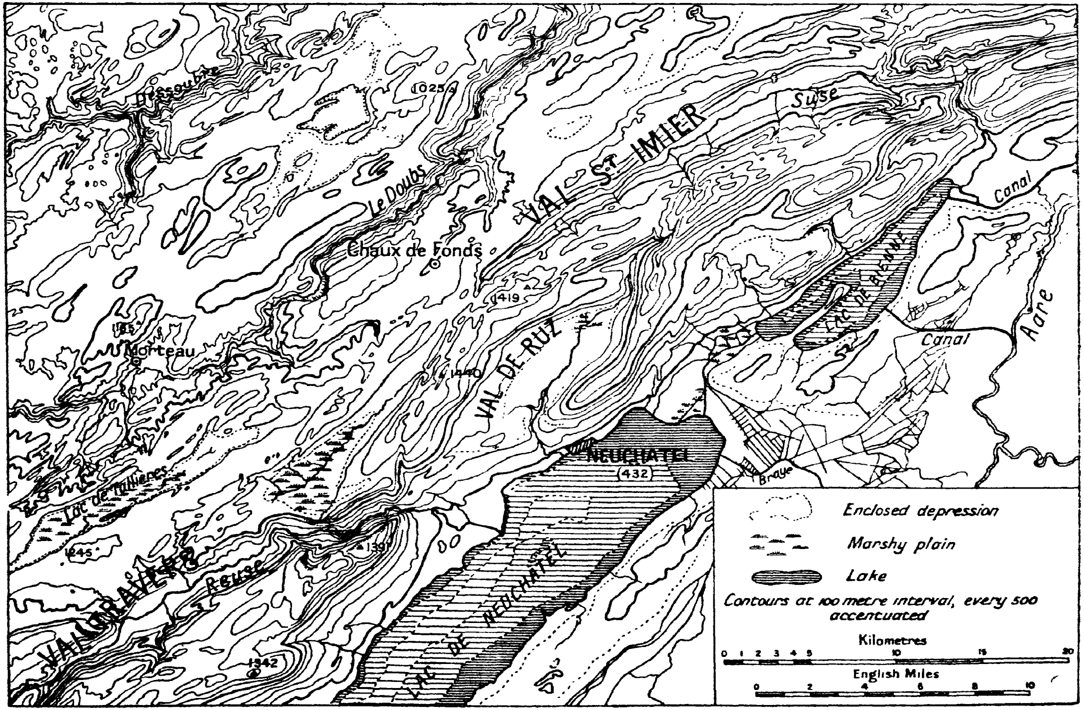


FIG. 62.—Part of the eastern Jura. (From the official map of France on a scale of 1 : 200,000.) Compare the folded topography here shown with that of the Côte d'Or given in Fig. 61.

To sum up, striking differences exist between districts in which the structure is due to faulting and those in which it is caused by folding. In the one there are flat-topped features and regularly outlined shelves; in the other, chains of mountains and long depressions, valleys forming a network of wide passages and deep trenches. In each case the details depend on the course taken by the dislocations and on the more or less advanced stage of the cycle of erosion.

Faulted Structure. Two main types of faults are to be distinguished: one in which subsidence occurred in the direction in which the ground sloped away before dislocation took place, and one in which subsidence occurred on the side which was originally the higher. In the latter case the type is called a *reversed fault.* It is evident that in these conditions the topographical changes are bound to be greater. The run-off of drainage water is checked by the escarpment of the fault and lakes are sometimes formed. This is seen in Oregon in the Western United States (see Fig. 63). The depth of the lake depends on the amount of subsidence, or *throw*, of the fault. Two adjacent faults sometimes turn their escarpments in the same direction, as Fig. 63 shows. But, on the contrary, it sometimes happens that the escarpments face away from each other. In such a case a portion of the surface may be isolated between

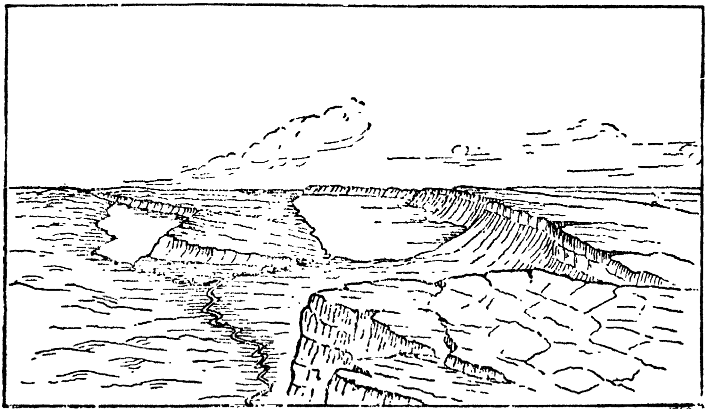


FIG. 63.—The Oregon lakes, produced by reversed faults. (After Russell)

two areas of subsidence. Continental Geographers call this a *horst*, borrowing the word from the German miners, but English geographers prefer the term *block mountain.* Several of the little mountain masses of Central Europe north of the Alps are block mountains bounded by faults, e.g., the Thüringerwald, which is a sort of rampart built between the plains of Thuringia and Franconia; the Harz Mountains, which form an isolated block in the middle of the North German plain; the Vosges, and the Black Forest.

Two adjacent faults whose escarpments face each other form,

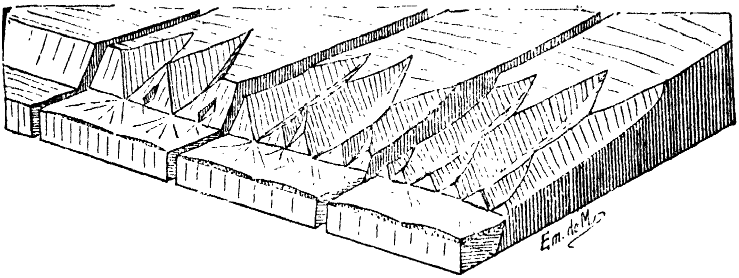


FIG. 64.—A series of topographical models showing the evolution of a fault escarpment.

on the other hand, a *rift valley.* Examples of this are the lowlands of Scotland between the Highlands and the Southern Uplands, the Rhine Valley between the Black Forest and the Vosges, and Limagne between Forez and the plateau on which stands the chain of Puys. Often these rift valleys are filled with alluvium and form fertile plains which are comparatively dry and have a continental climate. Sometimes the subsidence is so great that water accumulates in the rift and gives rise to one or more lakes. This is what has happened in the highlands of East Africa, and the great lakes which feed the Nile (Lake Albert, Lake Albert Edward, and Lake Victoria) and the Congo (Tanganyika and Bangweulu) lie in a rift valley. This is also the case with Lake Baikal. In regions with a hot, dry climate, it is not unusual for rift valleys to form areas of inland drainage. The lakes may then become salt, owing to the evaporation of the water. Examples of this can be seen in the row of lakes reaching from Abyssinia to Kilimanjaro along the most imposing and most continuous rift valley known on the Earth's surface. At times the depression falls below sea level, as in the case of the Dead Sea, the surface of which is 1,290 feet and the bottom 2,600 feet below sea level.

Evolution of Faulted Reliefs. Erosion attacks relief which is due to faulting and tends to destroy it. It first of all eats away the edges of the upthrow and cuts narrow ravines in them, as we have seen happen in the Côte d'Or. The ravines become valleys, which penetrate further and further into the projecting

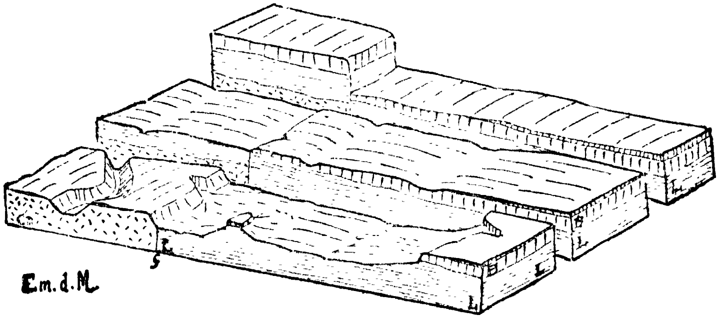


FIG. 65.—Section models showing the evolution of the escarpment of Morvan at Précy-sous-Thil, France. Note how the fault seen in the first model (in background) has been removed by erosion in the second stage, but brought out again by continued erosion in the third stage (front).

Cr=crystalline rock (very resistant); B, limestone (moderately resistant); L, the clayey marls of the lias formation (small resistance).

mass, and, by widening their sectional outline, wear away the fault escarpment gradually, as is shown in the series of diagrams in Fig. 64. It can now be understood that all trace of faulting may at length be removed. There are few sheets of the detailed geological map of France which do not reveal one or more examples of faults which have been levelled off in this manner.

Even when a difference of level is proved to coincide with a line of faulting, careful observation frequently shows that the depression of the surface towards the subsidence is really due to the erosion of less resistant layers of rock. This is notably the case in the faults in Auxois on the eastern edge of the plateau of Morvan (see Fig. 65). Levelled during the first cycle of erosion, the terraces due to faulting have in a way been revived in a second cycle owing to the difference in hardness between the granite and the marls of the lias beds. No other explanation can be given of the isolated limestone hills whose tops are on a level with the old block.

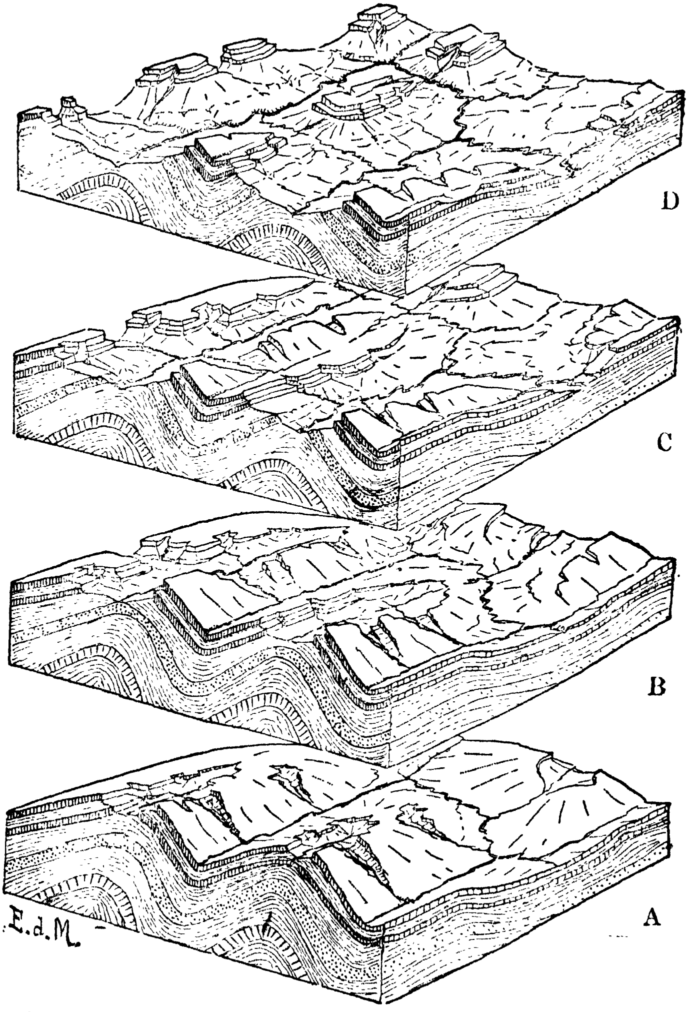


FIG. 66.—Section models showing the evolution of the relief of a folded region.

Folded Structure. Forms due to folding are more complicated than those caused by faults. They are developed like them from structural forms modified progressively by erosion.

The Jura district is typical of mountain regions in which the structural forms are still in a good state of preservation. The *vals* correspond to tectonic depressions in the shape of long gutters known to geologists as *synclines* (see Fig. 66 A), while the ridges correspond to the tectonic lines of positive relief which form a kind of upfold known as *anticlines*. The *cluses* are transverse valleys which pierce the anticlinal ridges. They are often observed to pierce the ridges at the least elevated points, and geologists agree that the anticlines are lower just at these points than elsewhere. Most transverse valleys are due, therefore, to an original saddle in the folds.

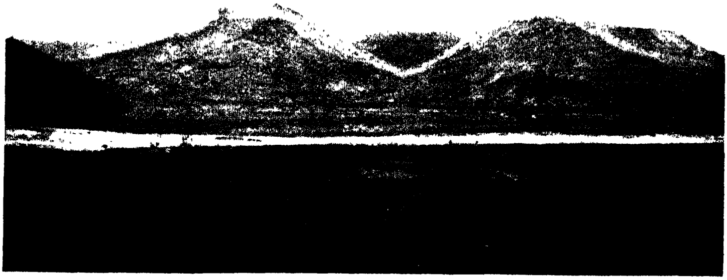
But the topographical features are far from being modelled exactly on tectonic forms. Even in the Jura depressions are found on the site of anticlinal ridges. They may be recognised, as shown in Fig. 66 B, by the asymmetrical features which enclose them and by the scarped slopes which stand face to face. Such escarpments have very steep faces and are known in the Jura as *crêts*. Fig. 66 B shows that the *crêts* sometimes form a loop enclosing an anticlinal valley and illustrates the connexion between this development and the wearing away of the original anticline. Even in the Jura examples of this are known, while in the Alps and the Pyrenees they abound. Sometimes the *crêts* turn their gentler slopes towards each other, instead of the escarpments, as the same figure shows. Such an occurrence marks the presence of a syncline. In ranges in which erosion has cut deeply into the tectonic relief, it is not a rare occurrence for the bottom of a syncline to form a ridge between two depressions which have been swept out on the site of former anticlines. This is illustrated in Fig. 66 C.

The stages leading to inversion of the tectonic relief will now be grasped. In the first the valleys are synclinal with consequent streams flowing down the anticlinal slopes. Then subsequent streams develop *crêts* and widen the depressions in the clayey layers of the anticlines. As the anticlinal valleys are cut in softer rock, they soon become the principal ones and capture the streams of the original valleys. In the end the synclines remain as the hills. The Alpette range in the Grande Chartreuse highlands and Mont Charbon in the Bauges are the classic examples of synclinal hills.

FOLD TOPOGRAPHY

A.—TRANSVERSE VALLEY OF THE BORNE IN THE PRE-ALPS NEAR GENEVA

The stream flows in a longitudinal valley (*val*) before entering the *cluse*, or transverse valley, through the anticline



B.—INVERSION OF RELIEF DUE TO EROSION: A SYNCLINAL MOUNTAIN

The valley of the Buech, near Laragne

The action of erosion is, therefore, capable of reversing the relation between the prominences and depressions of the relief, but it does not remove the traces of folding, for these are preserved by the direction of the ridges and valleys and the arrangement of the river system. A folded region can always be recognised by the resemblance of its river system to that of the Jura district and by the parallel lines of its topographical features.

Rejuvenation of Relief in Brittany. If the action of erosion is carried to the end of its cycle, it is capable of levelling the highest mountain ranges completely and of reducing them to the condition of a peneplain. But the geological structure always retains the germs of folded relief, and these may develop again the moment erosion begins its work afresh. Such has been the case in Brittany. The geological map shows in this province belts of different rock following the axis of ancient folds. At first sight the monotony of the topographical features is striking. In all directions there are the same flat horizons, the same undulations, the same rounded hills. Of the mountains formed here in the primary age nothing remains. Yet close examination shows at certain points a remarkable adjustment of the topography to the geological structure.

In its course south of Rennes the Vilaine passes alternately between steep-sided valleys cut through bare hills, which are covered with pine woods or barren spaces, and at other times through wide verdant troughs in which scattered farms stand amid meadows and fields of damp, clayey soil (see Fig. 67). The quarries here show that every hill is made of a layer of hard sandstone and each depression of a layer of schist. The largest depression, forming what is known as the Rennes basin, has been carved out in a great mass of precambrian clayey schists (see Fig. 67 X). There is no connexion between the present relief and the structural forms, but the direction in which the ridges and the valleys that separate them run is exactly the same as that of the ancient folds. Moreover, one has only to climb a hill to be convinced that the folds were formerly effaced completely and owe their rejuvenation only to a new cycle of erosion, for one notices that all the hills are of exactly the same height and that the depressions in the schist disappear a short distance from the valley of the Vilaine, rising to join the sandstone hills and to form a hopelessly monotonous horizon such as appears throughout Brittany.

Wholesale Tectonic Movements. How has the rejuvenation come about? Its occurrence postulates a change in the relative height of the base level and the peneplain. Such a change might occur as the result of faulting.

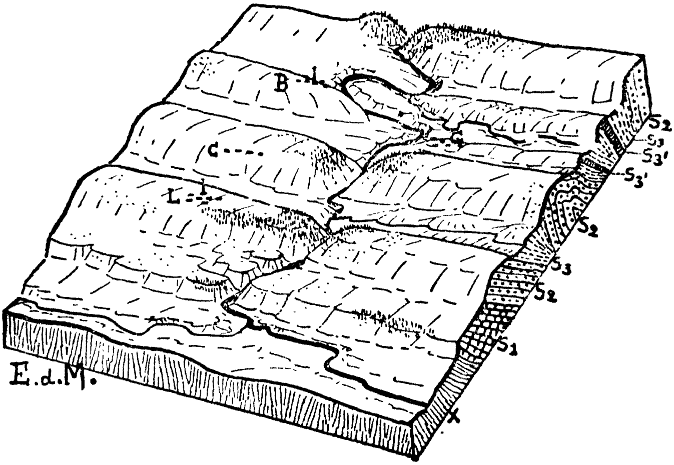


FIG. 67.—Section model of the Silurian plateaux south of Rennes, showing rock sculpture of the Appalachian type in Brittany.

X = precambrian argillaceous schists ; S_1 = red Cambrian schists ; S_2 = Armorican sandstone ; S_3 = the schists of Angers with bands of sandstone. Pine woods indicated by vertical shading. Note (1) the uniform height of the wooded crests of the sandstone hills ; (2) the wasteland (shaded with dots) ; and (3) the projection of even small bands of sandstone above the schistous rock in the valleys.

We have seen that several of the minor upland regions of Central Europe are block mountains and have been broken by rift valleys. A rejuvenation of the ancient folds, like that described in Brittany, is often seen in them. But erosion may also be given a fresh start by an uplift unaccompanied by dislocation. The uplift of the slope a few feet per mile in a constant direction and over the whole extent of a great river basin is enough to raise the sources of the streams a few hundred feet and to give the water the force to begin the corrasion of its bed once more, through the increase in the gradient. Such wholesale tectonic movements have certainly occurred.[1] The Central Highlands of France owe the character of their river systems and the throw of their highest peaks in the direction of the Alps and the Mediterranean to the gradual rising of the surface to the south-east. Even the peneplain of Brittany has not remained at the same level throughout. It is relatively depressed on the east along the axis of the lower course of the Vilaine and Rance, whilst in the district of Finistère it reaches a height of 650 feet. This district is dominated by still higher hills, the Monts d'Arrée, which had probably escaped the general levelling process of the previous cycle. Wholesale tectonic movements may also be held responsible for the rejuvenation of fault topography, and instances are so frequent that recent fault topography may be regarded as exceptional.

Geographical Distribution and the Age of Folds. The topographical differences between regions of folded and of fault structure survive all the changes wrought by cycles of erosion. But the general outlines of relief are in the end determined by the latest earth movements. It is, therefore, as important to know the age of the folds as to be familiar with their geographical distribution in order to understand the relief of the land. In Europe the highest mountains have been formed by the most recent foldings, those of the tertiary age, and they embrace within their winding paths the outlines of the axes of the folds. The lofty range known as the Alps would be an even more imposing mass if quite recent dislocations and subsidences had not broken its continuity in the south and formed the basins of the Mediterranean.

North of the Alpine belt no mountain in Europe exceeds 7,600 feet, and there are none of the continuous ranges which are so characteristic of tertiary folds. Alluvial plains or depressions like the Paris basin, which are cut out between escarpments alternate with limited areas of isolated highland, which often form block mountains (e.g., Thüringerwald and Harz) or show

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[1] The American geologist, Gilbert, who was the first to point out these movements, has given them a name of Greek derivation, which has been accepted into current use in scientific geographical works. On the ground that they affect vast areas, and even whole continents, he has named them *epeirogenic* movements. (Gk. ἤπειρος = continent, as opposed to *orogenic* movements.) English geologists seem to prefer the terms *continent-building* and *mountain-building*.

signs of wholesale tectonic movement. In them are seen the monotonous horizons which are characteristic of ancient peneplains, but quite as often signs of adjustment to a folded structure are noticeable. Like Brittany, all these highland regions were folded at the end of the primary age, were levelled by erosion, and have had their relief rejuvenated by recent dislocations or wholesale earth movements contemporary with the Alpine folds. They bear witness to the former existence of lofty mountain ranges which were as continuous as the Alps, and which are designated by geologists by the name of the old Hercynian Forest which extended over these regions in Germany. Even in the midst of the Alpine zone remains of the Hercynian Highlands are also found, around which the tertiary folds seem to have been moulded (see Fig. 68). But recent subsidence has left only a few remnants in Corsica and Sardinia, on the coast

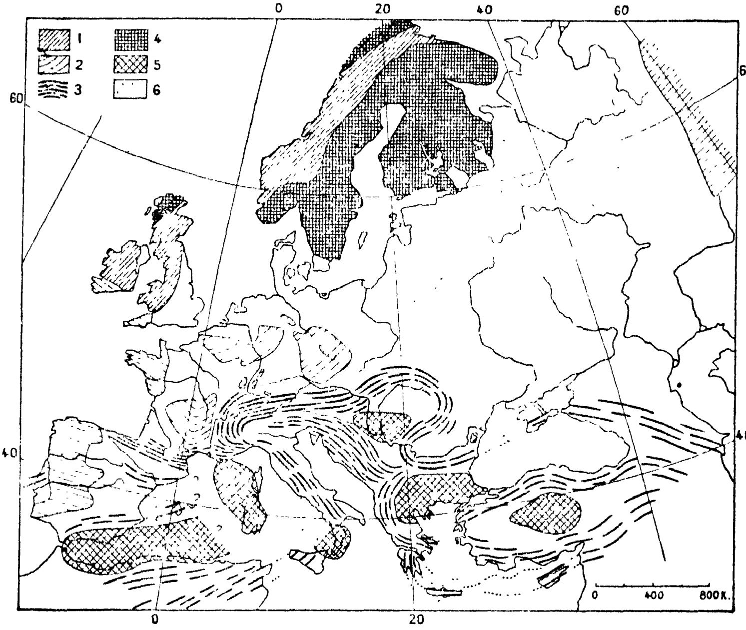

FIG. 68.—Lines of folding in Europe.

1, the Caledonian belt; 2, the Hercynian belt; 3, Alpine folds; 4, Huronian block formations; 5, remnants of Hercynian blocks among Alpine folds; 6, primary rock of the Russian platform.

of Africa and on the edge of the Plain of Hungary. North of the Hercynian zone, the mountains of the Scandinavian Peninsula and the British Isles bear witness to the existence of still older folds which owe their present relief to recent earth movement and to the consequent erosive activity.

The relations which have been discovered in Europe between the periods of folding and the continuity and height of the mountains they formed are observed also in Asia. The highest mountain ranges in the world, the Himalayas, the Hindu Kush, and the Kunlun, are a continuation of the Alpine folds through the intermediary chains of Asia Minor and Iran. Ramifications of the fold may be followed up as far as Indo-China. South of this great zone of closely packed folds and mountains stretching like festoons from one end of the Old World to the other, there are in Africa, Syria, Arabia, and India plateaux or flat-topped mountains which may be said to belong to a region in which there has been no folding since the primary age. The only important irregularities in their relief, apart from volcanoes, are block mountains and rift valleys. North of the zone of Alpine folds the mountains of Asia seem to have had the same origin as the Hercynian Highlands of Europe. If they surpass them in height, they are not so high as the Himalayas, and above all not so continuous. They are broken up into block mountains by faults, and contain rift valleys, which are sometimes occupied by lakes like Lake Baikal.

The contrast between ancient and recent folds is also seen in the New World. The Appalachians which fringe the east coast of North America are mountains of the Hercynian type. Folded during the primary age and levelled by erosion, they have been partially covered by ocean deposits, but recent earth movements have rejuvenated erosion in them so that parallel ridges have been once again formed along the outcrop of layers of the hardest rocks. On the Pacific side, on the other hand, the more mighty, more elevated, and more complex system of the Rockies is a collection of ranges due to folding and recent uplifting, as were the Alpine ranges in Europe. In South America the same contrast is seen between the Andes, which were uplifted in the tertiary age, and the plateaux of eastern Brazil.

CHAPTER XV

GLACIAL TOPOGRAPHY

General Nature of Glaciers. Let us glance at a big Alpine glacier. In the dazzling mass which clings to the mountain side two parts are easily distinguishable. On the one hand, there is a level sheet of what looks exactly like snow spread out in a large basin-shaped hollow in an amphitheatre of ridges and peaks. This is *névé*. On the other hand, there is a ribbon of ice stretching down a valley and winding down between its steep sides. It is often streaked with bluish *crevasses* and always more or less laden with trails of mud and pebbles. This is the *glacier tongue*.

The *névé* is not really a field of snow. A more or less continuous crevasse runs round it along the foot of the scarps which hang over it. This is the *rimaye*. A glance at this crevasse shows that under the surface layer of snow there already exists a compact mass of ice. A cross section of the *névé* reveals a slightly concave surface and a slight general slope downhill. A cross section of the glacier tongue, on the contrary, reveals a slightly convex surface, and the whole tongue has an appreciable general slope downhill. The *névé* lies wholly above the snow line. The snow which slips down the inner face of the amphitheatre collects here and turns into a form of ice that differs considerably from that of frozen water.[1] Glacier ice is a sort of crystalline mass formed of closely packed crystals, the joints of which are only visible when the ice is melting. Though hard enough to resist the ice-axe, the ice nevertheless becomes plastic under the immense pressure exerted by the

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[1] Snow is formed, as the reader knows, of fine spicules of ice collected in groups with wide spaces between them. Its transformation into compact ice results partly from melting followed by regelation, but chiefly from the compression caused by the weight of the fresh upper layers which are constantly being added.

upper layers of the *névé*, which are reinforced every year by repeated avalanches. It therefore flows like melted wax down to well below the snow line, forming the glacier tongue. In the *névé* the supply of snow is greater than the loss by melting, while the glacier tongue, on the other hand, melts more and more towards its lower end and gives rise to a torrent which often flows out through an arch, known as the *snout*. It is only maintained by the fresh supplies of ice received from the *névé*.

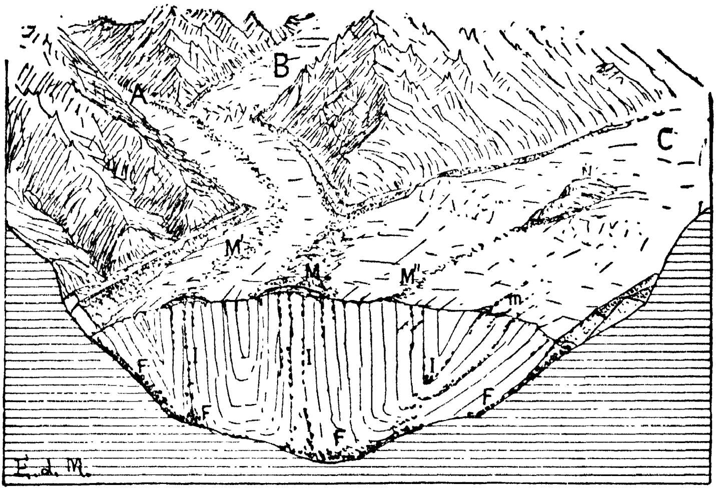

FIG. 69.—Diagrammatic view and section of an Alpine glacier, showing the different types of moraines.

M, M, M′=medial moraines derived from the lateral moraines of confluent glaciers (A, B, C); I=internal moraines; F—ground moraines.

In its descent the ice bears along rock waste, just as rivers sweep off alluvium. The waste transported by glaciers forms *moraines* (see Fig. 69). They are seen forming dark trails on the surface of the glacier, the "black vein" as it is called in the Mer de Glace. At the sides they appear like dykes or sharp ridges, called *lateral moraines*, and these sometimes join at the lower end of the tongue to form a *terminal moraine*. Such superficial moraines which are due to falls of rock on to the surface of the glacier usually consist only of angular blocks of stone. But below the surface there are other moraines due to the fall of superficial moraines into crevasses or to the corrasion of the rocky bed. Gripped by the ice and subjected to enormous pressure and vigorous friction, the rocks in *ground moraines* are usually polished and often striated in a characteristic fashion.

Variations in Glaciers and Glacial Erosion. The movement of glaciers and their moraines is very slow; e.g., 164 feet a year in the Hintereisferner in the Tyrol, and 318 feet per annum in the Rhone glacier. Yet the shape and position of the lower end changes quickly enough to cause topographical maps of lofty mountain regions to be inaccurate after a few years. For instance, the snout of the Glacier des Bois on Mont Blanc, which is shown on the Staff Map (1 : 80,000) as near the hamlet of Tines, has retreated to the slopes of Mottets, where it exists only as a narrow tongue sheltered in a gorge. Sketches drawn in the middle of the 19th century show the Rhone Glacier covering the present site of the Gletsch Hotel.[1] The retreat of glaciers is due to a disturbance in the balance of supply from the *névé* and of melting in the tongue. The supply depends on precipitation, on the amount lost by melting, and on the temperature. Changes in the lower end of a glacier are, therefore, signs of a change in the climate. In the Alps periods of maximum advance occurred in 1814, 1835, and 1870-80.

The retreat of glaciers has permitted very interesting observations to be made. The bed rock which had, up to a short time before, been covered with ice, is seen at the side or at the lower end of the glacier to be polished and lined with striæ like those on the pebbles in a ground moraine. They often assume the form of rounded masses and are striated, specially on the side from which the ice movement came. Such *roches moutonnées* are regarded as one of the surest signs of the passage of a glacier over a particular region. Rock basins containing little lakes fill the space between the *roches moutonnées*. The whole of an abandoned glacier bed sometimes forms a basin which is closed at its lower end by a kind of bar through which the torrent cuts a narrow gorge. At its upper end it is dominated

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[1] An international commission has been appointed to centralise observations of the movement of glaciers, of the position of their lower ends, and of their retreat or advance.

PLATE IV

VALLEY AND GLACIER OF ARGENTIÈRE

The amphitheatre of terminal moraines marks the former prolongation of the now retreating glacier. Note the shelf of *roches moutonnées* exposed by the shrinking of the glacier-tongue ; the *séracs*, or ice-pinnacles, further up ; the precipitous nature of the edge of the glacier-bed, marking the occurrence of erosion at the sides ; the projecting ridge of a former *verrou* ; and the sharp features of the surrounding peaks

by a steep escarpment at the top of which the glacier snout is seen shining. It may be concluded from these observations that glaciers, like streams, certainly cause erosion. The traces of it are especially evident on the sides of the glacier bed and at the foot of terraces, for polished and striated *roches moutonnées* are found in such places more than anywhere else. The glacier cuts away the foot of the sides of the valley through which it moves and of the terraces it has to pass over. Hence, it must gradually widen its bed and corrade it irregularly. This fact should be remembered when we try to explain further the topography of ancient glacier valleys.

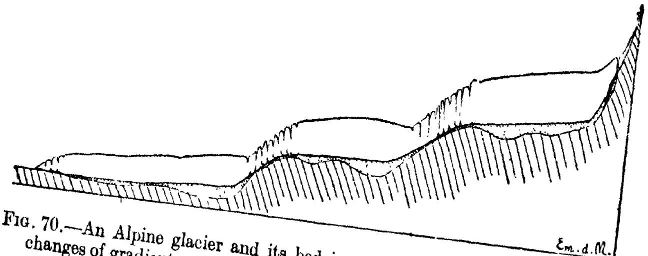

FIG. 70.—An Alpine glacier and its bed in section, showing crevasses at the changes of gradient and the unequal erosion of the bed. The stippling indicates the eroded portions of the bed according to the theory given in the text.

The explanation of glacial erosion assumes a knowledge of the laws of glacial movement. Though apparently rigid, the mass of ice is really what physicists call a *viscous fluid*. Every moving fluid wears away the sides of its channel and corrades its bed at a rate which varies with its velocity. But the fluidity of ice is not great enough to enable it to fit its bed exactly and to adopt itself to the changes in speed which are caused by the narrowing of the bed and differences in gradient. Hence, the ice breaks and forms crevasses, which are widened by melting, the intervening ice shrinking to mere pinnacles, known as *séracs*. Crevasses lessen the pressure on the bed. Now, the immense pressure of the glacier, whose depth sometimes reaches 1,000 feet in the Alps, is the chief factor in corrasion, and its effect far exceeds that of the extremely feeble velocity. The result is that corrasion diminishes just at those points where the velocity is greatest and attains its maximum where the product of Velocity × Pressure is greatest, that is, at the foot of steep gradients. Fig. 70 shows that the necessary result of this is the formation of basins in the glacier bed: hence the little lakes between the *roches moutonnées* which are seen below the snout of a retreating glacier and also most of the characteristic lakes that occur in regions formerly occupied by glaciers.

Different Types of Glaciers. As they exist at present, Alpine glaciers are local, i.e., formed in a region with a high snow line and due to the presence of lofty mountains. In cold regions, where the snow line is very low, the slightest elevation in the relief gives rise to real *ice caps*, which cover the whole surface. These two types of glaciation are essentially different both in respect of the appearance they give to the landscape and of the topographical developments they cause. Local glaciation is usually restricted to lofty mountains; regional glaciation sometimes covers the whole of a great land mass, like Greenland. Hence the proposal to distinguish *mountain glaciers* from *continental glaciers.*

Local Glaciation. The glacier chosen above as typical of the mountain class was a *valley glacier* and consisted of a *névé* and a well developed tongue. In the Alps there are smaller glaciers which consist of little more than the *névé.* Some occupy amphitheatres like those from which valley glaciers start in higher parts of the range. These are *cirque glaciers.* Others lie on high plateaux. These are *plateau glaciers.* The first type is too common for an instance to be given; the second, which is rarer, is well illustrated in the Alps in Dauphiné by the Glacier of Mont-de-Lans near La Grave in the Pelvoux highlands.

A more extensive local glaciation is seen in Norway. Vast fields of ice cover the plateaux which rise above the snowline, and glaciers issue from them down the neighbouring valleys, showing all the characteristics of Alpine glacier tongues. The almost complete absence of rocky peaks above the icefield causes the surface moraines to be insignificant, but ground moraines are very common.

The mountains of the south coast of Alaska form a centre of a very different kind. Instead of a continuous cap covering a plateau, there are true valley glaciers, but these are so well supplied with snow that they flow down from the mountains and spread over the coastal plain. Here they unite to form a flat lobe of ice, which is hidden under moraines thick enough to support forests; e.g., the Malaspina Glacier.

Regional Glaciation. Existing climatic conditions do not permit the study of true regional glaciation, except in polar regions. Greenland and the Antarctic Continent are almost entirely covered with ice, and a part of the Spitsbergen archipelago is in the same condition. It would seem that the Antarctic Continent is very irregular in its relief. Its glaciation is, so to speak, an extension on a gigantic scale of the Alaskan type. The barriers of ice which float on the sea and which have made such a great impression on explorers are the lower ends of vast lobes which have spread over the continental shelf. The most remarkable is the Great Ice Barrier, the front of which rises in a wall of ice 260 feet high and 560 miles in length.

The glaciation of Greenland has slightly different characteristics. No projections of rock have ever been seen in the interior; hence, it is an exaggerated type of Norwegian glaciation. Tongues of ice, as distinctly separate as the Norwegian ice-streams, move down the coastal valleys. Between them appear peaks of bare rock, surrounded with ice and known as *nunataks.* The glaciers deposit a great deal of rock waste which comes chiefly from ground moraines. Some of them move right down into the sea at the inner end of bays and give rise to icebergs.

Distribution of Quaternary Glaciers. Glaciers cover a sufficiently great area to call for a close study of their causes and various forms. But the importance of glacial topography is due less to the area covered by existing glaciers and to their morphological action than to the effect of quaternary glaciers which were in existence at the time of man's first development. Regional glaciation, which is now restricted to the polar regions, covered a vast area at that period (see Fig. 71). One-third of Europe and nearly half of North America were buried under immense ice-caps, which spread from the Scandinavian Mountains down over the lowlands of Germany and Russia, and from Labrador as far south as Saint Louis on the Mississippi. At the same time the Alps, which now contain local glaciers, were almost completely covered by huge glaciers of the Alaskan type, which reached down over the piedmont districts as far as Munich and Lyon and had their lobes covered with forests or tundra like those of the Malaspina Glacier. Mountain ranges like the Vosges and Carpathians, which do not now attain the snow line, contained local glaciers of the Alpine or Norwegian type.

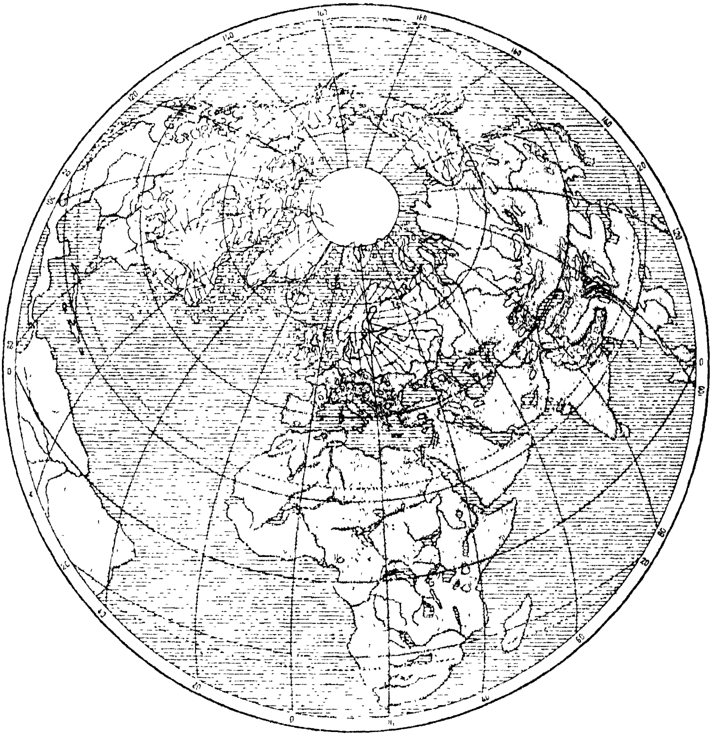

FIG. 71.—Extension of the ice-cap in the quaternary age.

The lines radiating from the centres of ice formation show the direction of the movement of the ice. Note (1) the centres of local glaciation, (2) the icebergs covering the northern seas, and (3) the lakes formed in the tropical and sub-tropical belts owing to the greater humidity and less heat of the period.

Like existing glaciers, the quaternary glaciers corraded their beds and deposited moraines, and the marks which they have imprinted on the surface of the lands have not yet been removed but form the chief features of the topography of mountain regions and even of the lowlands in northern countries. But it would be a mistake to think that these glaciers entirely remodelled the surface relief. Their erosive action was subsequent to the uplifting of the mountains, and acted on a system of relief which had already been carved out by fluviatile erosion. Moreover, it is known that, like the glaciers of to-day, the glaciers of the quaternary age were subject to phases of advance and retreat; that again and again they retreated some distance; and that there were interglacial periods during which normal erosive action resumed its work. It is, therefore, clear that the action of running water should be taken into account in explaining the relief due to this glaciation.

FIG. 72 —The cirques of Pétarel seen from Navette in Valgaudemar. (Sketch from a photograph by W. Kilian.)

Alpine Topography: Cirques. The action of quaternary glaciers evidently depends on the greater or less area they covered and has not left the same marks in regions of local glaciation as in those of regional glaciation. Wherever signs of local glaciation exist, the hill tops are more irregular, no matter what may be the nature of the rock, the tectonic conditions, and the altitude. The essential feature of their topography is the *cirque*. In the Alps, cirques often survive as the catchment basins of *névé*, while in the Pyrenees, the Carpathians, and the Vosges they must formerly have played the same part. Seen from afar, the typical glacier cirque looks like a niche hollowed out in a mountain side, and is usually placed high up above the large valleys (see Fig. 72). From a short distance, it is seen to be an amphitheatre surrounded by steep walls, down which fall fragments of rock, while its floor is cut up irregularly into *roches moutonnées*, with lakes or marshes, which show the former positions of the basins hollowed out in the rock.

The cirque may be described roughly as half of a circular basin. It usually begins as the catchment basin of a torrent, that is, a feature of fluviatile erosion which resembles a funnel cut in half. The development from catchment basin to glacier cirque is caused by the digging back of the lower parts of the walls and by the arrest of corrasion at the upper end of the channel of the stream. A local glacier is the only erosive agent which can produce this result. The undermining of the rock at the edge of the bed of ice and the crumbling of the surrounding walls under the action of frost may still be observed in little Alpine glaciers. The vigorous erosive action which attacks the bed of the cirque weakens at the mouth leading to the valley, either because the glacier goes no further, or because in moving down to the adjacent valley it is forced to break into crevasses in order to pass down the steep slope, and thus loses a part of its corrasive force.

The development of cirques gives an Alpine appearance even to comparatively low ranges. In the southern Carpathians, the Vosges, the Black Forest, the Pyrenees, the Sierra Nevada of California, etc., cirques break the monotony of the relief with their elevated platforms. If they are sufficiently close together and equally developed on each side of the opposite slopes, they eat away the mountain to a certain extent and leave between the crowd of niches only narrow, jagged ridges (see Fig. 73).

Glacial Valleys in the Alps. Cirques simply modify the appearance of ridges, but the changes effected by glacial action on valleys influence the whole relief system of mountain ranges. Nowhere is this better illustrated than in the Alps. On going up a large valley like that of the Isère or its tributary, the Arc in Dauphiné, one is struck by the sudden changes of gradient in both the valley bottom and the sides. Alluvial plains in which the river winds between alluvial fans, like those of Grésivaudan, the Bourg-Saint-Maurice basin in Tarentaise, the Chambre basin, or the Saint-Jean-de-Maurienne basin, alternate with narrow gorges like those of Aiguebelle, Pontamafrey, and Modane on the Arc, Moutiers, and Turra on the Isère. From the valley bottom these topographical features are hardly understood. The valley sides are often very steep, not only in the gorges, but even in the basins. Cascades rush headlong down them, seeming to issue from tributary valleys which appear to be *hanging* up above. Often it is difficult to see in what direction the main valley continues its course, for it is closed by a rocky barrier, and the gorge cut through this by the river can only be seen from close at hand. To get a view of the whole valley and to find one's bearings, the valley side must be climbed. But then other peculiar features are observed. The slopes become less steep and spread out in a sort of tilted terrace or *replat*, as it is called in Maurienne, on which the forests are replaced by hill pastures or even by cultivated fields, and on which a number of homesteads are often to be seen. Cascades fall from this terrace. The hanging valleys and the barriers of rock which separate the basins are about the same height. Often there are several terraces one above

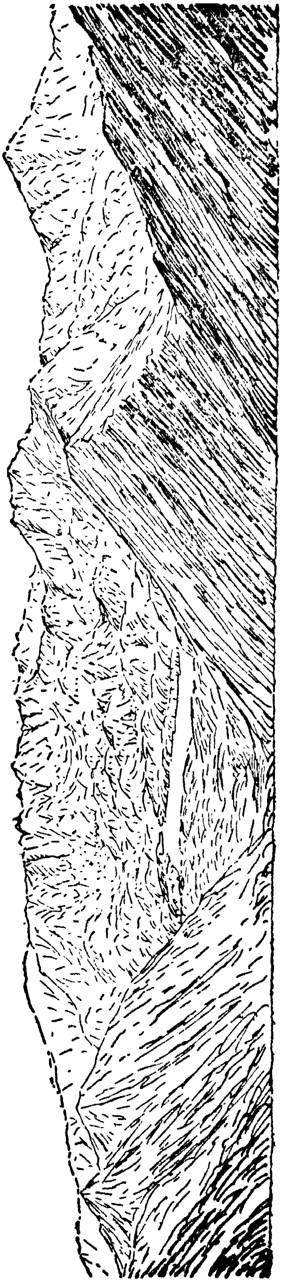

FIG. 73.—View of Retiezat in the southern Carpathians, showing the great cirque of Bucura with a lake and *roches moutonnées* in the bottom, together with the neighbouring cirques separated from the great cirque by steep ridges. (Sketch from a photograph)

the other, but right above again stand ridges sharpened by cirques, with glaciers or snowfields high up on the mountains. The shape of the valley below the terraces with its steep sides and level bottom in the basins is that of a trough.

These topographical features occur in every great Alpine valley, and their influence on human geography is always striking. Population is concentrated in the basin, and each alluvial fan has its village. The scarped walls of the trough are covered with forests or ravaged by torrents. The lower terraces have hamlets or isolated homesteads; higher up there are only spring pastures, known as *mayens* in Valais and as *montagnettes* in Dauphiné. The highest terraces are summer pasture grounds, known as *alps*. The cascades of the hanging valleys and the gorges through the barriers of the basins have led to the construction of factories at many places for the exploitation of the "white coal" thus afforded.

This peculiar form of relief is by no means the exclusive work of glacial erosion. Some of the details are youthful features, notably the irregular gradient of the main valley. The terraces at the top of valley sides might be the remains of steep-sided valleys showing signs of successive stages of erosion. But fluviatile erosion cannot explain the combination in the basins of steep sides, which are a sign of youth, and a broad alluvial floor, which is a sign of middle age. The barriers might be due to the action of running water if they always occurred in hard rock, but this condition is not necessarily fulfilled. The most astonishing anomaly, however, is the existence of enclosed basins. The water which collects in them forms long, narrow lakes, unless the accumulation of sediment completely fills up the hollow. This process of silting up has been observed in nearly all basins in which borings have been made.

Thus, at Grenoble in Grésivaudan, borings have been carried down to 150 feet without reaching bed rock. During the construction of the Loetschberg tunnel a terrible catastrophe resulted from the carelessness of the engineers. The gallery which they were driving under the Kandersteg plain entered an alluvial bed which was saturated with water.

Unlike fluviatile erosion, glacial erosion can act uphill.

Hence, the anomalies of Alpine valleys are to be put down to glacial action, working on valleys which had been deeply carved out before the invasion of the ice, and which had all the characteristics of youthful topography. A glance at Fig. 70 will show the whole theory of glacial erosion. It is easy to understand how the terraced gradient of a young valley changes, owing to the unequal corrasion of the glacier bed, into a series of humps and hollows. It has also been said that the glacier tends to widen its bed by undermining the sides. This action results in the trough-like shape of its cross section. The position of lateral moraines proves in fact that the glaciers of the quaternary age filled their valleys up to the highest terraces on the top of the valley sides (see Fig. 74). The barriers were originally narrows in the young pre-glacial valleys, and at these points glacial erosion has naturally been less active. The hanging valleys have been hollowed out to a less degree than the main valley either on account of the smaller volume of the tributary glaciers or because of their youth, which was naturally greater than that of the main valley.

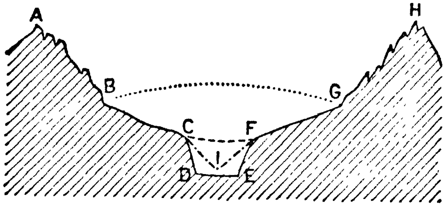

FIG. 74.—Cross-section of a glacial valley.

ABCIFGH is the preglacial valley ; BCDEFG the glacier bed ; CDEF the trough ; and BC, FG the hill pastures or *replats*.

Glacial Deposition at the Foot of the Alps. The traces of the glaciers of the quaternary age continue right down to the plains at the foot of the Alps. Vast masses of morainic rock waste have been laid down over the whole piedmont district of the Alps by glacier lobes which resembled those now existing in Alaska. These moraines form amphitheatres which face the mountains and centre round the mouths of the main valleys (see M in Fig. 75). On the mountain side of the amphitheatres there is usually a basin (Fig. 75 D C), which is sometimes occupied by a lake. This is the *terminal basin* and marks the position of the terminal lobe of the glacier. On the side away from the mountains the morainic wall descends gradually to a uniform slope formed by the sediment laid down by glacial torrents. Between the wall and the regular slope is an intermediate area, known as the *transition cone*, in which layers of alluvial deposits alternate with true morainic deposits. Both the transition cone and the alluvial plain which succeeds it have gradients due to torrential deposition. Hence, they have been under the action of fluviatile erosion from the time when the retreat of the glaciers relieved the streams of their burden of alluvium which forced them to deposit sediment, and when the rivers recovered a volume of water which enabled them to resume their work of erosion. The result of this has been the formation of terraces.

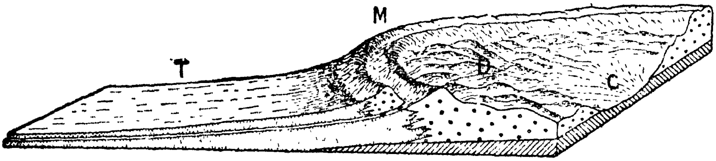

FIG. 75.—Section model of relief due to the action of streams on the moraines of a piedmont glacier.

All through the piedmont region of the Alps, many series of fluvio-glacial terraces like the one just described have been observed. The terraces belonging to distinct moraines in the same system are due to different periods of glaciation. The loftiest terraces are the oldest. They form clayey plateaux, wooded, damp, and sometimes marshy, like the plateau of Chambaran in Lower Dauphiné. The middle terrace, which is covered with *loess*, is, on the contrary, a fertile area and is much cultivated, especially in Bavaria. The big villages which grow up in it contrast greatly with the scattered homesteads on the morainic belt. The lower terraces, which are often covered over with pebbles, are dry and sparsely inhabited. Round Lyon they form desolate gaps in the midst of the old moraines, at the foot of which crowds of villages appear The Balmes Viennoises are an example of this.

Relief Due to Regional Glaciation. The immense ice-caps which covered the whole of Northern Europe and two-thirds of North America in the quaternary age originated in elevated regions, just as the continental glaciers of Greenland and the Antarctic Continent do in the present age. The whole surface of these upland centres of origin has undergone intense glacial

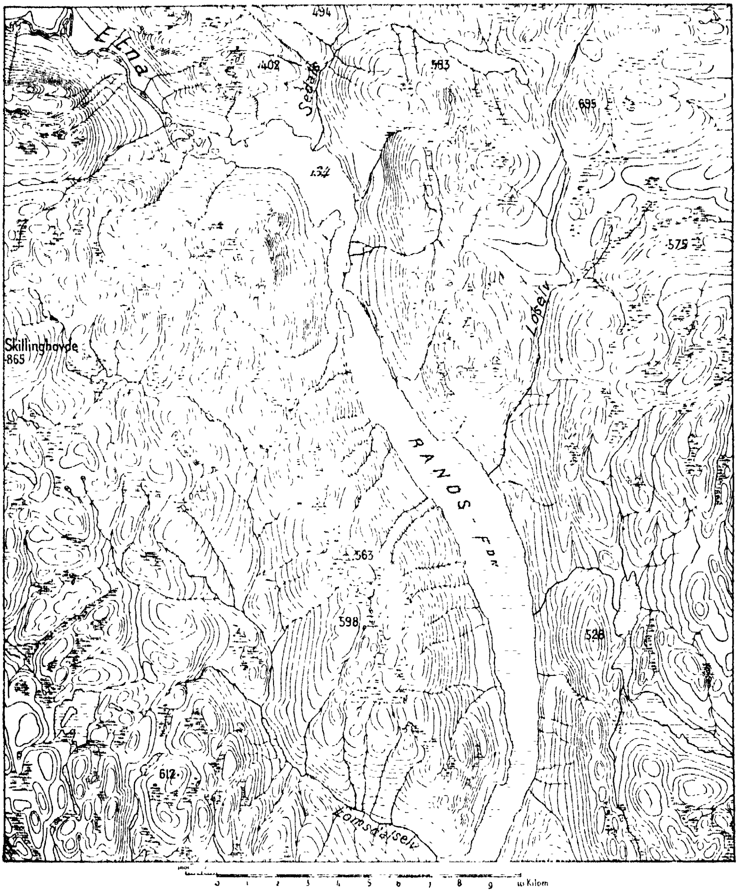

FIG. 76.—Glacial topography in Norway. Note the fjord and the plateaux strewn with lakes, marshes, and *roches moutonnées*. (From the official map of Norway on a scale of 1 : 100,000.) Scale 1 : 250,000, V. I. 30 m.

erosion. Hence the topographical features are less varied than those of the Alps, for in the latter the rocky cirque ridges have always risen above the ice and been exposed to the action of weathering; while in regional glaciation the features of glacier beds—*roches moutonnées* and enclosed basins—are found everywhere. In fact, the absence of sudden changes of gradient, the rounded nature of all positive forms of relief, the unsettled character of the river systems, and the great number of lakes and marshes, are topographical features of common occurrence in the Scandinavian Peninsula, Finland, Scotland, Labrador, Canada, and the North-Eastern United States.

Peneplains cut out of old crystalline rocks form plateaux, called *field* in Norway, which bristle with rounded hills and are dotted with marshes and tarns (see Fig. 76). The gorge-like valleys which pierced them before the period of glaciation have acquired some of the features of Alpine valleys, viz. basins containing lakes or filled with alluvium, barriers cut through by gorges, precipitous valley sides, and hanging valleys with cascades. The Norwegian fjords and the lake valleys of Sweden, as well as the lochs of Scotland, have been formed in this way. The plains on which the huge ice-caps of the quaternary age terminated have a confused topography due to the accumulation of vast masses of morainic deposits, which have been more or less reshuffled by very powerful glacial torrents issuing from the glacier ends. A swarm of branching lakes, enclosed marshy hollows, and rounded hillocks dotted about in a chaotic manner are characteristic of Finland, Prussia, Pomerania, and Central Canada.

The only trace of system in this relief is furnished by the rows of terminal moraines packed with blocks of stone several cubic yards in volume. The moraines are arranged in arcs which correspond to the former terminal lobes and are called *Salpauselka* in Finland. Within the arcs often occur long, narrow hillocks, formed of sand and striated pebbles, and known in Ireland as *drumlins,* and also dyke-like features formed of pebbles deposited more or less in layers and known as *æsars* in Scandinavia and *eskers* in Ireland. These wind in and out among the marshes and finally join up with the terminal moraine.[1] Still further back within the arc lies the ground moraine, consisting chiefly of clay, with pockets of sand and huge boulders. It forms monotonous plateaux which are

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[1] Drumlins and æsars are regarded as sub-glacial deposits. Æsars are probably formed by pebbles borne along by torrents which flow under the glaciers. Drumlins are probably accumulations of pebbles or alluvium in pockets or cavities in glaciers.

full of closed hollows and dotted with lakes. On the forward side of the terminal moraines stretch sandy plains, called *sandr* in Norway, which are caused by the wash from the moraines.

Very wide valleys with comparatively steep sides cross the terminal moraines, cutting through the plateaux formed by the ground moraine and the drumlins. Sometimes they are occupied by branching lakes, at other times by damp or marshy alluvial soil. These are the former channels of huge glacial torrents which flowed from the ends of the glaciers and which frequently changed their course according to the advance and retreat of the snout. Some of them have become great river valleys. In North Germany the Elbe, the Oder, and the Netze flow in borrowed channels of this kind.

Each of these topographical features has an economic value. In Germany especially, the sandy plains are the least fertile districts, and either lie waste or are covered with pine forests. On the contrary, the plateaux formed by the ground moraines are, especially in the country beforenamed, either cultivated with cereals or laid out as pasture lands. In Canada and in Finland, the drumlins and, to a greater degree, the æsars are occupied by farms and roads, which in this way avoid the marshy and sometimes flooded ground. The valleys which follow the old channels of glacial torrents are highways used, especially in Germany, for the convenient establishment of a network of canals.

CHAPTER XVI

DESERT RELIEF

Two Aspects of Deserts. The development of trans-continental railways has deprived deserts of their mysterious character. Several great lines pass through deserts in the Western United States; the Trans-Caspian Railway leads to Samarqand across the dunes of Turkestan; and though there is no Trans-Saharan line as yet, the railway has advanced through South Algeria as far as Figig and Warqla. It has, therefore, become easy to realise that deserts are not merely an expression of climate, distinguished by the absence of running water and of vegetation, but that they are characterised by peculiar forms of surface relief. Their most striking and best known feature is the vast area of sand dunes which stretch as far as the eye can see in undulations like the frosting on glass. But this aspect, which is known as *Erg* in

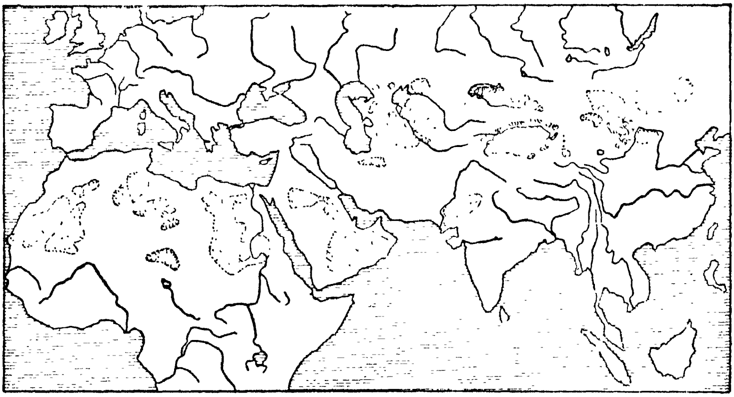

FIG. 77.—Distribution of sand deserts (*Erg* or *Koum*) in the Old World.

the Sahara, and as *Koum* in Turkestan, is by no means the only one, although Fig. 77 shows the large space it occupies in the broad belt of deserts which crosses the Old World from Morocco to Manchuria. Besides the sandy *Erg*, rock deserts, which are even wilder, though less monotonous, are also found throughout this region. In the Sahara plateaux deserts of this type are known as *Hamadas*. Elsewhere, as in Tibesti and Sinai, rock desert assumes the form of actual mountains.

Disintegration and Æolian Erosion. Rock desert is the most desolate type of these barren regions. Even among the sand dunes of the Sahara some traces of vegetation are found. But in a journey of many days the *Hamada* plateaux present to the eye nothing but an absolutely bare, pebbly surface. Completely exposed to the most extreme insolation, and to daily variations in temperature exceeding 158° F., the rock is attacked with extraordinary vigour by mechanical disintegration. During the heat of the day noises like the report of a pistol are not uncommonly heard: they are caused by the bursting of some overheated stone. Disintegration is especially rapid in heterogeneous rock, such as sandstone, pudding-stone, and granite. The grains thus broken off are swept away by the wind, and a cavity is left which is constantly being enlarged. Thus, the surface is eaten away, and the rock assumes a peculiar hollow appearance.

The rock waste which is too coarse to be carried away by the wind accumulates at the foot of escarpments, forming screes of coarse material packed at a steeper angle than is the case in wetter regions. The gradient of the slopes formed by bed-rock is also strikingly steep, while even slabs of marl or limestone form veritable escarpments. All the agents of erosion which reduce the gradient of slopes in wetter regions are absent here, and there is no run-off, no gradual landslides, no soil. The bare rock cracks under the great heat. Moreover, it is attacked by a new type of erosive agent, the wind itself, which is not content with merely sweeping off the finest particles of rock waste, but also dashes them against projecting surfaces in its path. The particles thus used as projectiles are mostly formed of grains of quartz, and are harder than almost any rock. The sand blast thus formed is particularly dense near the ground, as the traveller on foot finds at the expense of the skin of his hands and face. Hence, the force of æolian erosion acts chiefly at the base of projecting surfaces. This explains the vertical, or even overhanging, faces of the hillsides. Isolated blocks are worn away at the base and form bastions known in the Sahara as *gour* (singular *gara*). When a harder layer occurs at the top of the slope, *gour* often look like big mushrooms (see Fig. 78).

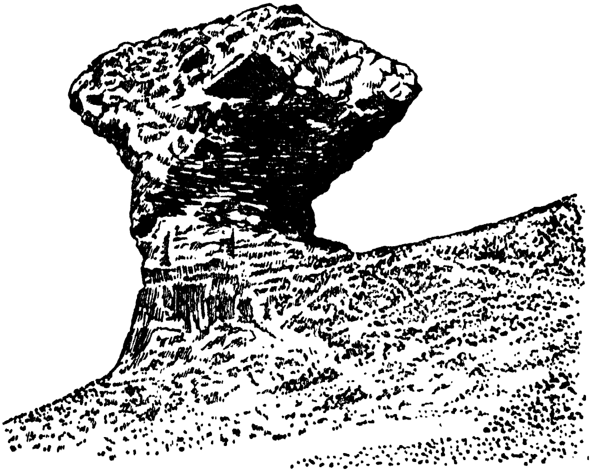

FIG. 78.—Mushroom rock or cheesewring, near Kargeh (Upper Egypt). A typical *gara*. (Sketched from a photograph.)

Run-off and Sand-burying. The wind is, however, not the cause of all erosion in the desert, nor is it, as one is tempted to believe, the absolute master of desert topography. Rain seldom falls, but it does occur at times in the Sahara. It falls in local showers, which have all the more erosive power because of their infrequency. The effects which they produce on the surface are indeed very like those caused elsewhere by the normal run-off of water on the surface or by torrents in spate. All explorers in the Sahara have witnessed the destructive floods which rush down the dry watercourses (*wadis*) after a rainstorm, sweeping away camps and herds before the necessary precautions can be taken against the danger. In Algeria people still remember

PLATE V

DESERT TOPOGRAPHY

A.—A ROCK DESERT: HAMADA OF TADEMAIT IN THE SAHARA

Note the flat surface of smooth pebbles and the traces of a caravan route

B.—A SAND DESERT: THE GREAT ERG TO THE SOUTH OF TAGHIT IN THE SAHARA

Note the row of crescent-shaped ridges, or *sifs*

the disaster in the Wadi Urirlu to the south of Ghardaïa, in which a battalion of *chasseurs d'Afrique* was surprised by a spate and lost twenty-eight men. The effect of these spates rarely goes beyond some five or six miles, for the mass of water becomes more and more laden with solid matter, forms a sort of paste, and finally can go no further.

In broken ground the result of this form of erosion is that the valleys are independent of each other, and there is no main valley with its tributary branches, as there are in regions where the erosion by running water is continuous. Hence, the plateaux are cut up into a maze of gorges, termed *chebka* in the Sahara. In plains lying at the foot of mountainous regions, the torrents show a greater tendency to shift their beds than do the most capricious mountain streams in Europe. There are no distinct alluvial fans, but a sort of glacis of loose material is often piled up to form a fairly steep slope, which spreads out some distance and is furrowed by a number of channels. Basins of inland drainage, being without any outlet to the sea, are in this way filled with a level bed of pebbles known in Mexico as a *bolsón*. The mountains look half buried, since they rise abruptly and very steeply out of a smooth layer of such material. This type of relief, which is found in every desert, whether in Central Asia, in the lofty plateaux of Algeria and the Sahara, in the Kalahari, or in Utah, may be termed sand-buried.

Traces of Normal Relief. A still greater part in the making of desert relief may be claimed for running water. The mountains always have a certain amount of rain, and the valleys that lie among them are sometimes so well developed that desert charactistics seem to be merely superficial. The edge of the Hamadas in the Sahara is often scalloped and carved out into isolated blocks, like a normal escarpment in France. Valleys with interlocking spurs are also observed. This normal fluviatile relief is certainly not the work of existing agents of erosion, but was developed during the quaternary age, when climatic conditions were different. Since the temperature was lower all over the surface of the Earth, as is proved by the great area covered by glaciers in high mountain regions, evaporation was also less intense, and perennial streams may have existed in places where now there are only *wadis* with sandy beds

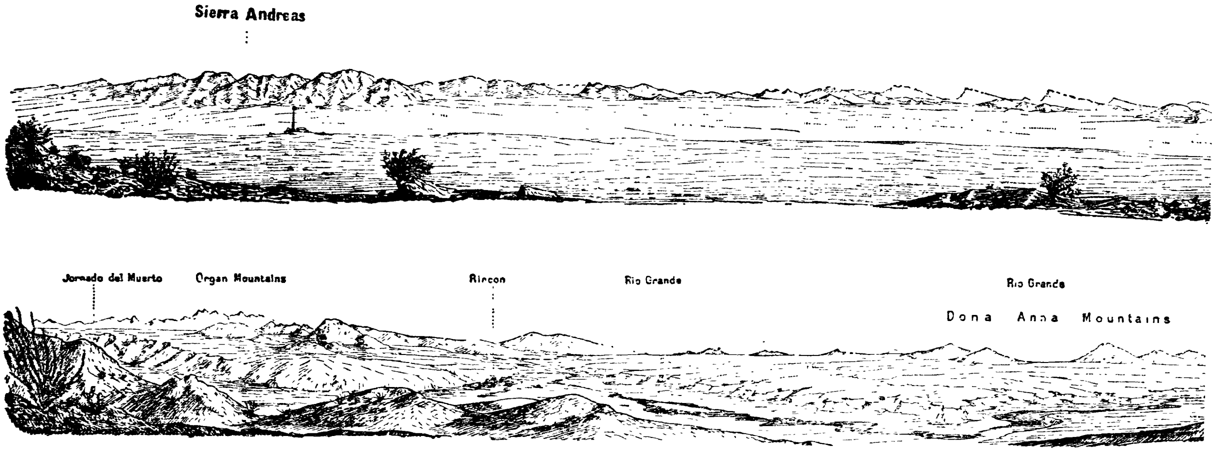

FIG. 79.—Two panoramas of *bolsones* in New Mexico. (Sketched from nature)

Above, the Jornado del Muerto. Below, the valley and terraces of the Rio Grande near Rincón. Note (1) the clearness of the tectonic forms in the Sierra Andreas. (2) the boldness of the volcanic relief in the Organ Mountains, and (3) the continuous alluvial slope round the Sierra Andreas. Nearly all the peaks rise abruptly like islands from the sea.

which are seldom touched by water and then only after a rainstorm.

Sand Deserts. If the surface of the rock desert seems dead, that of the sand desert seems very much alive. The least breath of wind blows up the sand on the ridges of the great dunes, and makes them look as if they were smoking. An increase in force or a change in direction of the wind may alter the shape of the dunes before one's very eyes. But there is very little change in their general appearance. The ridges are always asymmetrical, with the gentler slope facing the direction whence come the most violent or most frequent winds, and they have a very characteristic curved outline which forms a sort of crescent called *sif* by the Arabs.

To understand the formation of this strange type of topography, let us examine the simple forms of it which are to be seen on the borders of vast stretches of sandhills. In Turkestan small crescent-shaped sandhills are known as *barchanes*. The gentle slope is on the convex side, where the wind drives against the sand, causing it to pile up and fall over on the concave side. Their small size causes them to change their form according to the periodical changes of the wind. Thus, *barchanes*, with their concave surfaces turned north, regularly succeed those with their concave faces turned south as the season changes, and with it the direction of the winds. Groups of *barchanes* standing side by side and close together become long ranges of sandhills at right angles to the prevailing wind (see Fig. 80). Vast regions of such sandhills are formed by the multiplication of chains of *barchanes*. The complex features of individual hills are due to the greater or less mobility of the variously sized material of which they are composed. Whilst the prevailing winds regulate the general rhythm of the undulations, temporary changes in the wind sometimes cause the formation of secondary undulations which take shape rapidly. When the force of the wind is very great, it sometimes carries off more sand than it brings, and the sandhills are swept away. This is probably the origin of the *gassi* in the Sahara, which are long passages through the sandhills. Caravan routes across the Erg follow them, since the comparative shallowness of the sand allows wells to be dug and water to be reached more easily.

Loess. The constant shifting of the sand is bound to wear down the grains in the end, and the finest particles are swept beyond the limits of the desert. In the Mediterranean region showers of rain have from ancient times been noticed to contain particles of dust, and ancient writers have sometimes spoken of these showers as miraculous owing to their red colour. Their colour is simply due, however, to the mingling with the rain of fine particles of solid matter transported by the upper currents of air (i.e., the counter-trade wind). The formation of layers of such dust from the desert through the agency of the run-off of surface water is generally regarded as the origin of a special kind of soil known as *loess.* The name comes from Alsace, where it is applied to a kind of sandy earth with extremely fine grains (from 0.02 to 0.04 millimetres in diameter). It is usually of a yellow colour. When squeezed between one's fingers, it crushes like flour, leaving a stain on one's hand. When dropped into a glass of water, it is dissolved. Being as permeable as sand, it quickly absorbs rainwater. Like limestone, it forms vertical escarpments ; like chalk, it often contains hard lumps. It is usually deepest in hollows, and thus it tends to level up inequalities of the ground.

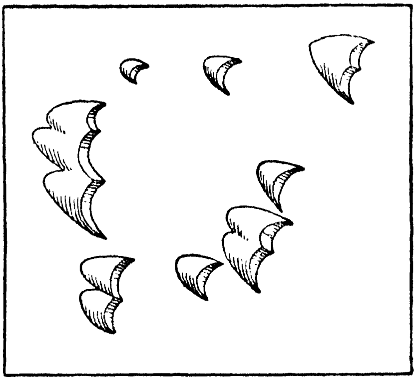

FIG. 80.—A group of *barchanes* in process of forming a line of dunes. (After J. Walter.)

Some of the most fertile regions in Central Europe are of *loess* ; such lands afford the best soil for wheat and beetroot. They form a series of regions stretching from Picardy to Poland.

and have long been cleared of forest and densely peopled. The same kind of soil exists in the prairies of North America and in the pampas of South America, where agriculture and ranching are carried on on a large scale. In Asia, where *loess* covers more than 230,000 square miles of surface, the formation of this deposit can still be seen in progress. The storms of yellow dust which occur in China have convinced all observers who have visited that country that *loess* is of æolian origin. Its depth is often so great (over 330 ft.) that it imposes on the region a true *loess* topography. Gorges are cut through the soil by the agents of erosion and are used as roads in the dry season. Springs often gush out in it. The valley sides move further and further apart when the *loess* contains beds of clay which form natural terraces. The fertility of *loess* soils is proverbial in China. Richthofen has said that their distribution is not without some influence on ethnography, for the northern limit of *loess* almost coincides with that of the Chinese farmer and trader.

Coastal Dunes. Traces of æolian action are found outside desert regions, but only in special localities, and they depend chiefly on the nature of the soil. Certain sandstone cliffs are honeycombed like the rocks in deserts. Dunes are often found along the sea coast and on the shores of great lakes or the banks of rivers. A sandy soil with no vegetation at all is required for the formation of dunes. These conditions may be realised if the ground is periodically flooded and the supply of alluvial sand constantly renewed either by the action of the waves or by deposition during spates in a stream. The wind acts on such sand as it does on the desert sand. *Barchanes* may be seen on the coasts of Brittany and Cornwall. The ridges of shifting dunes are given their direction by the prevailing wind, but the shape of littoral dunes as a whole depends on that of the shore line from which the sand comes. Hence, in deltas dunes mark the former position of the shoreline.

The advance of the dunes to a distance of some miles from the sea, as has occurred in parts of France, is due merely to the carelessness of man in destroying the natural vegetation, which under the existing climatic conditions would have prevented the inland progress of the dunes. It is positively known that the dunes in Gascony began to invade the Landes at the end of the Middle Ages. The successful check placed on their further progress was the work of Bremontier, a French engineer (1738–1809), and the method used by him has also been employed in the dunes of northern France. The sowing of graminaceous plants with running roots prepares the way for plantations of conifers. The blowing in of more sand, which may arrest the growth of young shoots, is prevented by the construction of a dyke along the seashore. A palisade is erected on the dyke to stop the sand, and behind it grasses are planted. Dunes which have been thus fixed in shape and position become a sort of dead topographical feature. Popular language expresses this distinction near Boulogne in the terms *sables blancs*, given to the sand which is still capable of movement, and *sables morts*; and on the shores of the Baltic by the terms "white sand" and "grey sand."

CHAPTER XVII

COASTAL TOPOGRAPHY

Factors of Coastal Topography. An excursion along a fairly broken coastline, like that of Brittany or the West Coast of England, affords an opportunity of recognising the essential characteristics of coastal topography. The first general fact to be noticed is the alternation of cliffs and beaches. If the excursion is followed on the map, the cliffs will be seen to correspond in every case to promontories and the beaches to bays, as is shown in Fig. 81 B. If one walks along parallel to the shore, the constant alternation of up-and-down slopes will remind one that promontories are formed by the high ground on the land and that bays occur at the lower ends of valleys; that, generally speaking, the depth and width of the bay depends on the extent to which the valley itself is hollowed out and on the distance it penetrates inland. From these observations one general conclusion may be drawn, that the outlines of the coast have originally been determined by the relief of the land. The coastline reproduces the windings of the land contours, though it evens up projections and re-entrants. If we observe what is taking place along the ridges which form promontories ending in cliffs, and in the re-entrants which form beach-fringed bays, we shall understand the cause of the straightening out of the curves in the shoreline.

A few hours on the sea cliffs are enough to show how violently they are attacked by marine erosion. Waves never cease to break against them. The water rushes foaming over the reefs and penetrates into the caves with a roar of thunder. The boldest capes are most exposed to the waves. Capes like Pointe du Raz and the Crozon peninsula in Brittany, or the Needles of the Isle of Wight, have obviously been worn down into rocky islets, which prolong into the sea the line of high ground of which they once formed part.

Let us now go down to the beach which fringes the bay. There the swell reaches the shore, but the waves that break regularly on it throw up lines of seaweed mixed with sand or pebbles. Far from encroaching on the land at this point, the sea is always adding to it. After a big storm traces of erosion may be seen in the gentle slope of the beach, but usually the shoreline is gradually advancing owing to the deposition of waste material which is being constantly thrown up by the swell.

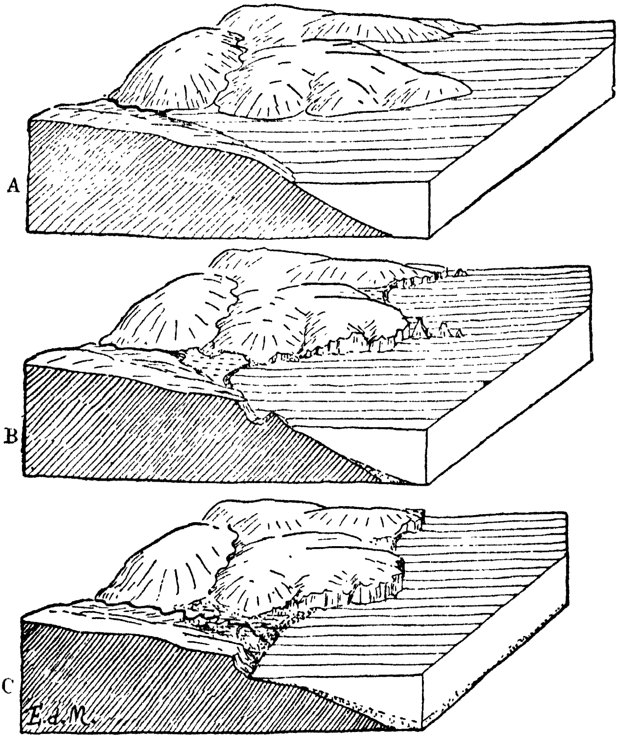

Fig. 81.—Series of models showing the evolution of coastal topography, from youth (A) to middle age (C).

These observations lead to another conclusion, namely, that marine erosion gradually straightens out the irregularities

FORMS OF COASTAL EROSION

A.—THE "CASTLE OF DINANT" IN THE PENINSULA OF CROZON IN BRITTANY

The erosion of a promontory. The natural bridge formed by the junction of caves will crumble down sooner or later

B.—POINTE DE LARCOUEST OPPOSITE BREHAT

Rocky islets which have been rejoined to the mainland by spits

of the coastline by wearing away promontories and by piling up rock waste in bays. Just as fluviatile erosion tends to wear down the high ground of the dry land by levelling the hills and filling up the valleys, so marine erosion wears away all the projections of the coastline; and if the last stage of fluviatile erosion is the peneplain, marine erosion ends into developing almost rectilinear coastlines, as will be seen by a glance at Fig. 81.

Coastal Erosion. Let us observe more closely the work of what is strictly speaking coastal erosion, since it denudes promontories, and also that of accumulation which silts up bays, so that we may come to recognise the more or less temporary topographical forms which they cause at the various stages of development. Coastal erosion is chiefly the work of breakers. The force of storm waves reaches between 8 and 25 tons per square yard. They have been known to destroy piers formed of blocks of stone weighing over 100 tons. To the mighty blows which are dealt at considerable intervals by heavy seas is added the ceaseless work of the surf, which beats against the foot of the cliffs at every high tide and hurls against them the pebbles or the sand which lie along its foot. The average height to which this attack reaches is marked by a groove, which looks like a kind of fluting. Thus undermined, the rock sooner or later crumbles down.

If the rock is heterogeneous, the waves carry away all the disintegrated matter and, penetrating into the cracks, enlarge them and hollow out caves at the base of the cliffs. Capes formed of resistant rock are generally destroyed by the development of caves in this manner. Attacked on both sides, the cliff is soon pierced, leaving a natural bridge, which crumbles down in the end. This is the process by which the capes of Brittany and the west coast of Ireland have been cut up into islands. But the mining operations of the sea are confined to the belt lying between the high and low water marks. The movement imparted to the water by the greatest storms is not felt below a depth of 160 feet. Hence, coastal erosion proceeds only in a narrow belt. The result is that a rocky shelf is formed, which is gently inclined seawards and is submerged to a depth not exceeding that at which the oscillation of waves is felt (see Fig. 81 C). The rock waste swept down from this shelf accumulates just beyond it, forming a slope. The features already described in the littoral topography of lakes occur here also. The coastal shelf of the sea corresponds to the *beine*. Its development tends to restrict the action of the waves, for they die away as they pass over its surface and finally break before having reached the base of the cliff. As soon as

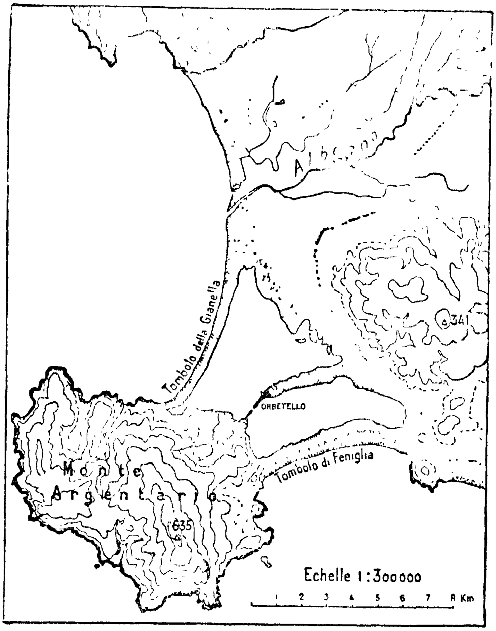

FIG. 82.—Monte Argentario, showing sand spits (*tomboli*) joining the island to the mainland. (From the official map of Italy on a scale of 1 : 100,000)

this stage is reached, the cliff is cut back no further. If the process of erosion is to continue, the mean level of the sea must be raised or the land must sink slowly.

Accumulation of Rock Waste on Coasts. The rock waste which is produced from coastal denudation or which is brought down by rivers in the form of alluvium, is constantly being moved about on the coastal shelf with a fluctuating movement. However, the oscillations result in an advance in the direction of the prevailing wind and the tidal flow. This is proved by the movement of wreckage, which is always in the same direction, and by the drift of pebbles, whose place of origin can often be determined. As it moves along a coast, the rock waste accumulates wherever the rate of movement diminishes, just as alluvium does in a river bed. Accumulation takes place chiefly in bays, where the waves drive the sand and pebbles as far as they can. By this process the gentle slope of the beach is formed. Ridges in the sand mark the highest point reached by the waves each day, the highest ridge corresponding to the reach of waves during storms at flood tide. This ridge is the shoreline.

The gradient of the beach depends on the coarseness of the materials that form it, namely, fine or coarse sand, shingle or pebbles. The shoreline is more or less curved according to the size of the bay, but it always rests on cliffs at each end. When the bay is sufficiently deep, a lagoon is often formed behind the shoreline either by the enclosure of a part of the bay or by the accumulation of drainage water (see Fig. 81 B).

The beach is the most permanent form of accumulation, and coastal waste may be laid down in more exposed places. Reefs forming a submarine prolongation of a headland sometimes cause the deposition of sand or pebbles so as to form a kind of causeway, which soon rises above the level of the water. One of the best known examples is the Sillon de Talbert on the north coast of Brittany. If the causeway is sufficiently lengthened, it may reach an island and turn it into a penisula, as in the case of Chesil Bank and Portland Island. The Quiberon peninsula on the south coast of Brittany has been formed in this way. In Italy Monte Argentario has been joined to the mainland by two causeways, which are covered with dunes and enclose a lagoon (see Fig. 82). A similar formation is seen in the peninsula of Gien in Provence. Deltas are also comparatively unstable forms of accumulation. It has already been said that they are rarely found on the shores of great oceans on account of the tidal movements which scour out the estuaries. But the formation of deltas also depends on the stability of the coast and the abundance of sediment.

The first stage is the silting up of the estuary or gulf into which the river flows. It is usually preceded by the formation of a sandy spit (Germ. *nehrung*) across the mouth of the inlet with a lagoon behind it. The lagoon (Germ. *haff*) is silted up gradually. The German and Polish rivers which flow into the Baltic (e.g., the Oder, Vistula, and Niemen) are at this stage. The Oder has not yet silted up its *haff*; the Niemen is making rapid progress with its *haff* and already has the beginnings of a delta. The Vistula, which is in a more advanced condition, has reduced the area of Frisches Haff, whilst a more complete isolation of the Gulf of Danzig is in progress owing to the formation of another spit, Putziger Nehrung, which has the characteristic hook-like curve at its end (see Fig. 83). It will be noticed that the Elbe and the Weser have kept their estuaries clear, thanks to the tides of the North Sea.

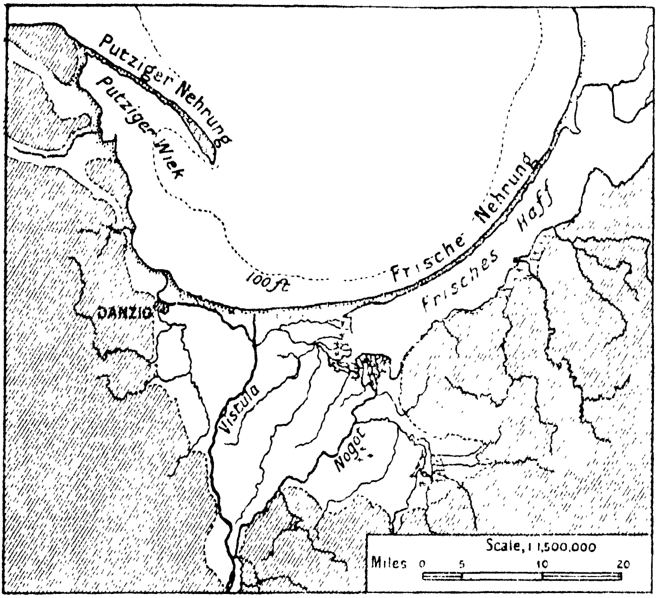

FIG. 83.—Haffs and deltas in North Germany

The continous shaded portion represents the original land area and shows the former coastline. The recent alluvial formations are shown thus: deltaic land, unshaded; swamp, shaded with the conventional sign; sand, stippled.

The presence of islands furthers this form of evolution by giving support to the spits. For instance, the delta of the Nile rests on a line of rocky islets, which have enabled its fringe of bars and lagoons to maintain its arc-like shape. Whether strengthened or not by rocky islets, sandy spits are always covered with dunes, and form the framework of a delta in the making. When sedimentation is active, the river flows directly into the sea as soon as the gulf is entirely silted up. From this moment begins the formation of what is, strictly speaking, the delta. But the process may be delayed or even completely checked by the currents along the coast. Thus, the Rhine has not yet succeeded in building a true delta, for the sediment is carried along the coast, giving it a regular outline. The same is true of all the rivers of Languedoc. They have succeeded in silting up the bays into which they flowed, but they cannot advance their deltas beyond the curve of the coast, which rests on the former islands of Cette, Agde, and Narbonne. Even the Nile delta has been checked in its growth by the currents which run along the shores and sweep the sediment eastwards to the coast of Syria. The same is true of the Hwang-Ho, in spite of the vast quantity of silt which it brings down to the sea. If the river succeeds in overcoming the opposition of the currents, it begins to extend seawards a strip of alluvial land, forming it into an arrow head projection, the point of which is sharp in proportion to the rate of deposition. Examples of this are to be seen at the mouths of the Tiber and Tagliamento in Italy, of the Medjerda in Tunis, in the Rosetta and Damietta mouths of the Nile, and in the Mississippi.

Coral Reefs. The evolution of the coastline is sometimes modified by biological influences. On the shores of tropical lands, sediment is held in place by mangrove roots. The action of coral polyps is even more important. According to Darwin, these animals, which live in colonies along the coasts and in shallow water in tropical seas, are responsible for the formation of circular reefs known as *atolls* and of other reefs, called *barrier reefs*, which are built up round islands and form an almost continuous barrier separated from the shore by a channel.

Darwin's theory has found its way into all the text books and, in spite of the repeated attacks which have been made on it, is still worthy of consideration. The enormous depth of the coral formation, which extends below the limit of existence of the polyps, is explained by the gradual subsidence of the land and the compensating growth of the reef, which is continually built up to the surface by the animals.[1] The shape of atolls

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[1] Instead of the subsidence of the ground, the movement may be due to the rising of the sea level.

and of barrier reefs may easily be deduced from this theory (see Fig. 84).

Effects of Earth Movement. Coral reefs are not the only example of the influence of earth movements on coastlines. In view of disagreement as to what really takes place in the so-called subsidences and uplifts, scientists as a rule merely consider the relative displacement of land and sea and use the expressions *positive movement* to denote an advance of the sea upon the land and *negative movement* to denote a retreat.

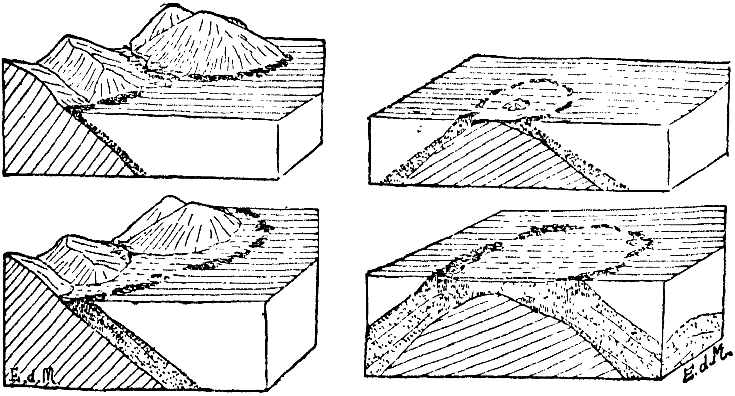

FIG. 84.—Section models illustrating the formation according to the Darwinian theory of barrier reefs (left) and atolls (right) in an area of subsidence.

The effects of positive movement may be seen throughout the coast of Brittany, over a great part of the coast of England and Scotland, on the whole coastline of Norway, and on the shores of the U.S.A. between Cape Cod and Cape Hatteras. Fig. 81 A gives an exact idea of what happens. So long as the movement continues, the coastline becomes more and more irregular and the sea penetrates up the valleys. Wherever a sufficient number of soundings are taken, furrows are discovered in the sea bottom, forming a continuation of river valleys. These are *drowned valleys* (see Fig. 87). Such coasts are most favourable to human occupation, for the establishment of ports or of fishing centres, and they are usually thickly populated.

The effects of a negative movement are exactly the reverse. The coastline becomes more regular, for it is pushed out further on to the continental shelf. On such a coast the deposition of the sediment is difficult; hence, there are no natural harbours and no sites for human occupation. At the end of some time, however, when the negative movement has ceased, the inevitable results of the action of the sea on the coast will begin to appear. The *débris* brought down by rivers and caused by coastal erosion will begin to form accumulations of alluvium. A sandy beach will soon appear, and behind this a coastal strip covered with dunes, on the landside of which the drainage from the hills will mingle with the sea water and form a brackish lagoon (see Fig. 85 A). A series of rapid negative movements with pauses in between results in the formation of tiers of beaches, which are often described as "raised beaches." When the sea retreats beyond the edge of the continental shelf, the latter is exposed and is seen to form a surprisingly regular terrace. On steep coasts such a terrace will form a narrow coast strip (see Fig. 85 B) suitable for human occupation. The coastal terraces in Scotland are an illustration of this.

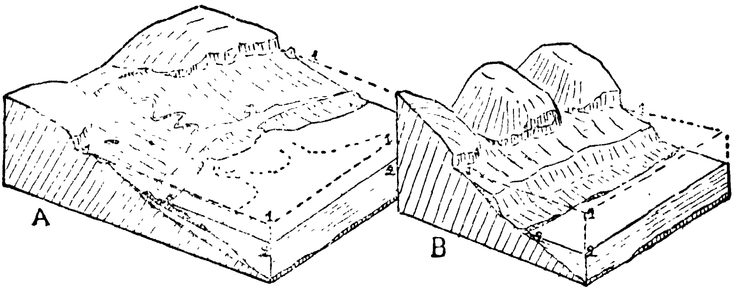

FIG. 85.—Two cases of coastal evolution under the influence of negative movement.

A—slow, continuous negative movement, forming shallow coasts with lagoons. B—rapid negative movement, which is subsequently checked, on a steep coast, resulting in the formation of a raised beach.

Coasts of Low-lying Regions. We can now try to explain the appearance of the most characteristic types of coastline. To do this, we should again start by examining the adjacent land topography. Stable coastal plains offer the simplest type of coast. Sand driven by the waves forms a wide beach with an almost continuous shoreline, broken here and there by narrow channels. Behind this stretches a row of elongated lagoons which are quickly silted up, but which are sometimes flooded by storms that occur at spring tides.

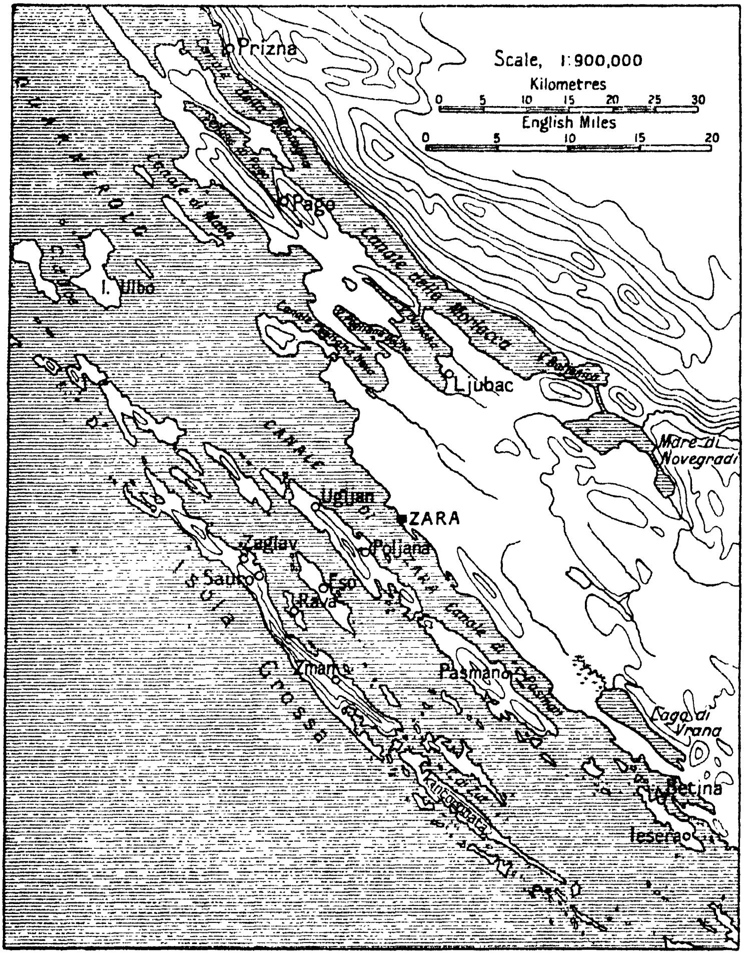

FIG. 86.—The Dalmatian Coast. A typical longitudinal coastline.
Note (1) the long, narrow islands running parallel to the coast, (2) the inlets of the same shape, and (3) the channels between the islands and the mainland.

In Europe, however these inhospitable coasts have been sought after by man, and by draining the lagoons and strengthening the shoreline, the inhabitants have succeeded in adding fertile strips of land to the continent. Flanders, Holland, and the Marschen in Germany are well-known examples. On the Adriatic coast near the delta of the Po, the Italians are at the moment engaged in a similar conquest of the sea. A great deal of the coast of the Gulf of Guinea in Africa affords an instance of a coast in low-lying regions, which is still in its natural state and contains lagoons. So also the shores of the Gulf of Mexico in Texas and Alabama, and even the Atlantic coast of Florida.

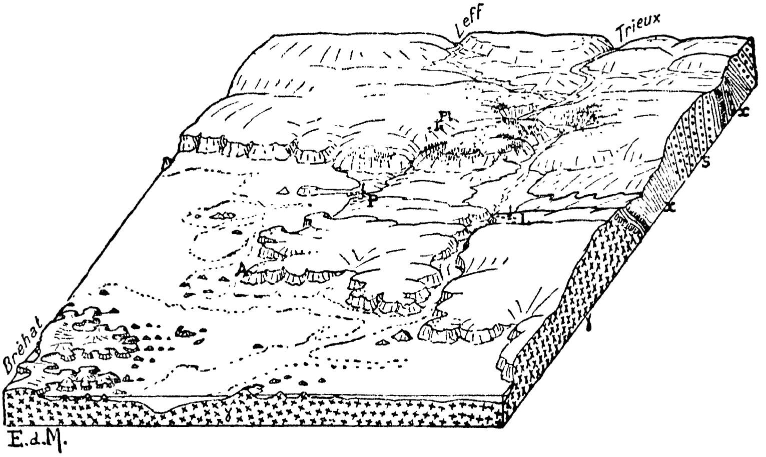

FIG. 87.—A ria coastline. Model of a part of the Breton coast. y = granite. x = schists. s = Armorican sandstone. P = Paimpol. L = Lézardrieux. Pl = Plourivo. The undersea contour outlines the drowned valley, the section of which is shown on the front of the model.

Longitudinal Coastlines. The penetration of the sea into a folded region with moderately strong relief necessarily gives rise to an indented coastline. The longitudinal valleys become gulfs or long, narrow straits, while the ridges which follow the direction of the folds form peninsulas or islands. But the general form of the coast may differ according as the advance of the sea took place in a direction parallel or at right angles to the folds. The Dalmatian coast affords the best example of the first case (see Fig. 86), with its long, narrow islands, its channels (known as *canali*), and its gulfs (called locally *valloni*). The type also occurs in British Columbia.

The advantages of this type of coastline are evident. Navigation is easy in the channels, and ports and towns are always placed where the coast looks towards the mainland.

Ria Coastlines. An old mountain range which has been reduced to the state of a peneplain and subjected to another cycle of erosion contains narrow, steep-sided valleys, carved out in a uniform plateau where the less resistant beds of rock alone form elongated depressions. If the sea invades such a region, narrow gulfs will be formed in the steep-sided valleys and will branch out and widen only in the depressions formed in beds of comparatively soft rock. Gulfs of this kind are called *rias* on the coast of Galicia, and *rivières* or *aber* in Brittany. The granite outcrops which frequently appear on the coast are much disintegrated and cut up into a number of islets, which are characteristic of ria coasts. Excellent examples of the formation are to be seen in the coasts of Kerry in S.W. Ireland and of Trégorrois in Brittany (see Fig. 87).

Coastlines in Glaciated Regions : Fjords and Skjers. The coast of regions where glacial erosion has taken place resemble ria coastlines in their narrow, branching inlets, which are known as *fjords* in Norway. These differ from rias in cross section and in the irregularities in the relief of their floors caused by glacial action. Examination of the floors shows a series of humps and raised sills, which are continued on the one hand over the continental shelf to form a network of submarine valleys, and on the other over the land in a series of lakes rising in tiers. The cutting up of the coastline is still more striking in countries like Finland and South Sweden. Here the coast is further from the highlands from which the great glaciers of the quaternary age descended, and there is a maze of islets and peninsulas formed by the *roches moutonnées*, the *drumlins*, and the *æsars*. This type of coastline is known as *skjer* in Sweden. To reproduce as faithfully as this all the outlines of irregular surface-relief, the coastline must have been formed not long ago by a considerable positive movement. The Baltic coast of Prussia, which has also been formed by moraines, must, on the other hand, have been sufficiently stable for coastal evolution to act on it, for its headlands have been eroded into cliffs, and its bays either turned into lagoons (*haffen*) or silted up (see Fig. 88).

APPENDIX TO PART III

I. SUGGESTIONS FOR FURTHER READING :—

The principles of geology necessary for the study of surface relief may be acquired from any good school text book ; or from LAKE and RASTALL'S *Text Book of Geology* (Arnold, 4th edit. 1927) or A. P. BRIGHAM'S work of the same name (Appleton, 1902). Among French works, A. DE LAPPARENT'S *Traité de Géologie* and E. HAUG'S book of the same name (Paris, 1907) will be found useful, as they deal with general geology and treat a large number of problems of physical geography under the heading of " Present Day Phenomena." Geology can no more do without physical geography than the latter can do without geology.

W. M. DAVIS'S school text, *Elementary Physical Geography* (Boston, 1900), contains a lucid account of modern problems of morphology. The same writer's article, *The Geographical Cycle*, which occurs in a series published under the title of *Geographical Essays* (Boston, 1909), is especially recommended.

Among foreign books on morphology, A. DE LAPPARENT'S *Leçons de Géographie Physique* (Paris, 1925) is a most readable work on the study of relief. It contains a concise description of the various regions of the globe. *Les formes du terrain*, by GENERAL DE LA NOE and EMM. DE MARGERIE, published in 1888, and now out of print, may be read with advantage, though it is difficult reading. W. M. DAVIS'S German work, *Die erklärende Beschreibung der Landformen* (Leipzig, 1912) is more complex than his English works, but the diagrams are extraordinarily suggestive. Finally, the author's *Traité de Géographie Physique*, vol. II (4th edit.), may be found useful.

The student's comprehension of topographical forms will be greatly increased by reading some of the recent works on particular regions. If the reader is fortunate enough to know any of the regions dealt with, he should try to verify the facts mentioned. The following are suggested :—

SIR A. GEIKIE : *Scenery of Scotland* (Macmillan, 3rd edit.).
I. BOWMAN : *Forest Physiography of the U.S.A.*

W. M. DAVIS : *Development of Certain English Rivers. Systematic Description of Land Forms* (G. J., 1909).
J. W. GREGORY : *The Fjords of the Hebrides* (G. J., March, 1927).
J. A. STEERS : *The East Anglian Coast* (G. J., January, 1927).
E. M. WARD : *The Evolution of the Hastings Coastline* (G. J., August, 1920).

(*Note.*—The suggestions given above have been modified to suit the English student, though the books recommended by the author have been retained whenever possible.—Tr.)

II. PRACTICAL EXERCISES :—

The study of surface relief requires more practical work than any other branch of Geography, and most of this work must be done in the field.

(i) *Map reading.* Reading detailed topographical maps should be learnt. This may be done with the help of the following exercises :

(*a*) Compare a contoured topographical map (e.g., 1 in. O.S. Popular map) with a relief map in plaster of Paris (if one can be obtained).

(*b*) Draw hachures on a section of a contoured topographical map. Draw cross sections along a line across the map, using the contours ; repeat the exercise, using hachures ; notice how much more difficult the latter is than the former.

(*c*) Learn to set a map in the open country, either by using a compass or by recognising well-known features of the landscape. In the first case, place the compass on the map with the pivot of the compass on a grid line running from top to bottom, and turn the map and compass together until the needle lies exactly along the grid line and points to the top of the map. In the second case, lay the map out flat and turn it round until your line of sight coincides with a line drawn on the map from your position to a recognised landmark. Identify the villages, roads, hills, streams that are in sight by finding them on the map.

(*d*) Sketch an outline of the horizon, if it is fairly irregular, and find the line on your map. Draw cross sections of the neighbouring hills and verify your results on the ground.

(ii) *Interpretation of the map.* In the course of this work several examples have been given of the interpretation of relief from the map. But many exercises of this kind are necessary. The general procedure is as follows: examine the map as a whole, find the main features, notice where the greatest differences of height exist, follow the streams and see if the gradient is regular. Draw cross sections of the main features. Lastly, if necessary, refer to a geological map and look in it for the causes of features such as steep slopes, cliffs, gorges, etc. Many opportunities will occur of observing the relation between topography or geology and the distribution of woodland, cultivated ground, sites of villages, etc., the path followed by roads, railways, and canals, etc.

(*Note.*—The author gives here a list of sheets of official French maps which illustrate various land forms. The list is omitted with regret, as being useless to English students. An atlas of land forms based on the Ordnance Survey maps has long been overdue. The publication of such an atlas would supply the place of M. de Martonne's list.—Tr.)

III. EXCURSIONS :—

Only general suggestions for excursions can be given here. The interest and character of such excursions naturally depend on whether the relief of the selected area is broken or not. But there is no district in which useful observation is impossible.

A stay at the seaside, though less instructive than a visit to a mountain region, may afford abundant lessons. Apart from coastal forms, opportunities will be presented of studying small scale examples of æolian or other surface erosion. Thus, on a fairly steep beach the run-off will be seen to carve out parallel channels, forming miniature coastal plains ; some of the cliffs will be found to contain niches hollowed out by the wind ; on stormy days the sand will be observed to rise like smoke from the crests of dunes, and the advance of the sand in parallel ridges will be noticed on the windward side of the dunes ; the part played by natural or artificial obstacles will sometimes be very noticeable.

Some of the essential laws of erosion may be seen at work anywhere, at any rate, in miniature. Artificial banks, such as road or railway cuttings, may serve, if no better ground is available, for the study of the run-off of surface water, of the formation of torrents, of the modification of slopes by the development of ravines and by landslides. As they wander through meadows, brooks often afford examples of meanders which are sometimes on the point of being cut off or else have actually been so. Where the streams are half dry, the asymmetry of their beds is clearly seen, and the undercutting of the upstream bank of the convex lobe will probably be evident. Changes may be observed to follow heavy rain; hence, the spasmodic character of erosion will be grasped, together with the fact that denudation concentrates its efforts on certain points, such as changes of gradient on the slopes of valley sides or in the bed of the stream.

In regions where the geological structure is sufficiently varied, and influences the relief, excursions should always be preceded by a study of a topographical map. This map should invariably be compared with a geological map, and one or more cross sections drawn at right angles to the most important features.[1]

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[1] The author concludes this appendix with an account of a model excursion, which has been omitted for obvious reasons. Those who want help in the conduct of excursions will find many examples in *Geography* and in various elementary text books.—Tr

PART IV

BIOGEOGRAPHY

CHAPTER XVIII

VEGETATION AND ITS PHYSICAL SURROUNDINGS

THE physical influences which act on the distribution of plants are recognised by the end of a single day's botanising in the country. The influence of moisture is most easily noticed. Ponds and the margins of lakes, rivers, and canals are the homes of water plants with soft stems and glaucous leaves, many of which float on the water. Cliffs and screes, on the other hand, harbour only plants which are able to resist drought. These are sometimes thorny, hairy, or adapted to keeping a supply of water in their fleshy leaves. The influence of light is nearly as evident. Some plants grow in the shade and are found in clusters amid the undergrowth in forests; others prefer the light and will not grow in the shade. The part played by the soil is no less clear. Certain plants will only grow in limestone soils, others are restricted to silicious earth. On the seashore and in saline soils special types of plants occur, some of which, e.g., glasswort and sea-lavender, are well known. The influence of temperature is seen on climbing a mountain, for the vegetation changes with altitude. Broad leaved trees, like the beech, give way after a time to conifers, and these finally disappear. leaving bare mountain pasture.

If the plants collected during a botanical excursion are classified according to the influence of the foregoing factors instead of according to the usual botanical system, after a time certain plants, though unrelated to each other, will be found again and again growing side by side. The further one's observations are extended, the greater will appear the geographical importance of these *associations*, based on the common needs of the plants belonging to them. For the significance of plant associations to be fully understood, the mechanism of the physical influences whose action is most noticeable on plant life must be explained in detail.

Temperature and Light. As plant life does not generate heat, the conditions of its existence are rigidly determined by temperature. For every species of plant there is a *specific zero,* below which existence is impossible. If the thermometer remains for several days below that zero, the plant is sure to die. There is also an upper limit, beyond which the temperature cannot rise without endangering the life of the plant. Lastly, there is an *optimum temperature,* in which the plant grows most vigorously. The action of cold has no relation to the freezing point, for tropical plants die before the thermometer falls to 32° F., whilst in the polar seas algæ will thrive and multiply in temperatures of 24° or 25° F. To resist the cold, a number of plants have recourse to retarded growth, which consists of the arrest of certain functions and the suppression of the organs that perform them. Reproduction is generally suspended, frequently even respiration and assimilation. Sometimes all the vegetative organs disappear altogether, and the plant completes its cycle of active life during the favourable season and continues its existence by means of a seed which is capable of prolonged resistance to the cold. Thus, besides *perennials,* which live on from year to year, there are a large number of *annuals.* Certain plants relapse into the period of retarded growth without any apparent external change; e.g., most conifers and all the evergreens of the Mediterranean climate.

The duration of the period of growth is not the same for the same plant in different climates. The appearance of leaves takes place earlier and the fall is later in the Mediterranean zone than in the cold temperate belt. The birch completes its seasonal growth in six months at Dresden, in four at Petropavlovsk in Russia, and in three at Yakutsk in Siberia. The rapidity of plant growth in Finland and South Russia is always a cause of astonishment to the Southern European. The same fact is noticed in mountain pastures where snow reduces the length of the period of growth. This rapid progress is largely due to the greater intensity of insolation in the lofty mountains on account of the rarity of the air (see Part I, Chap. V), and to its longer duration during the protracted days of a polar summer.

The action of light differs from that of insolation. The development of branches, leaves, and roots is delayed in most of the phanerogams by intense light. Reproductive developments are favoured by light, and flowers are prevented from opening by being grown in semi-darkness. Hence, plants which grow in the shade are characterised by a relatively greater development of the vegetative organs at the expense of their flowers, whilst light causes thicker leaves and stems, and bigger and more brightly coloured flowers.

Hygrophytes, Xerophytes, and Tropophytes.[1] No plants can do without water entirely. Imbibed from the soil by the roots, water is the basis of the sap which flows through the whole plant, carrying with it mineral substances in solution. It is finally transpired through the leaves, giving rise to a chemical process which prepares the sap for assimilation by the tissues. The readiness with which plants adapt themselves to various conditions of water supply contrasts greatly with their inability to stand changes in temperature. Plants are known to live in sand which is apparently quite dry or on bare rock with an almost unbroken surface, and in air so dry that one's lips are chapped and one's fingernails cracked by it.

Plants which live in water exist under very specialised conditions. The light is subdued and the movements of gases are slow. Hence, the stems and leaf-stalks are unusually long, in order to allow the leaves, which are reduced to thin strips, to reach the surface. The stomata are less developed or altogether absent from the parts below the water, and the tissues are full of holes through which the air circulates directly to the interior of the plants. Several kinds of aquatic plants, notably the water crowfoot, have, in addition to floating leaves which are like the ordinary aerial kind, other leaves which are under water and are reduced to the form of strips. Plants which live in damp soil and in air saturated with water vapour have similar characteristics. The stems are long and are softened by the

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[1] From Gk. ὑγρός = damp; ξερός = dry; τρόπος = change + φυτόν = plant.

reduction of the amount of woody tissue in them, while the leaves develop a greater surface and are relatively more slender. Banana trees are the most remarkable example.

Opposed to these water loving, or *hygrophilous* (Gk. φίλος = friendly), plants are the *xerophytes*, which have adapted themselves to conditions of drought. The roots are very long, in order to obtain water from as great an area of soil as possible ; the stems are shorter and stronger, owing to the development of the woody tissue. These features aim chiefly at reducing transpiration and at increasing the supply of water. The leaves themselves are different : their surface area is smaller, and they are thicker. The stomata are fewer and are grouped together in the folds of the bark. Sometimes they are completely absent from the outer surface. The bark is rendered chemically impervious by a thick cuticle or by a coating of wax. At times the edge of the leaf is woody and thorny. In some cases the leaves and even the branches are replaced by thorns. These characteristics are to be seen in every dry climate. Nearly all the Mediterranean plants show adaptations of the kind ; e.g., the olive, gorse, the cork oak, etc. In certain desert plants the reduction of the transpiratory organs may be carried as far as the complete absence of leaves ; e.g., the *Saxaul* of Turkestan, and the *Raetam* and *Haloxylum* of the Sahara.

But adaptation may proceed in another direction. The plant sometimes accumulates supplies of water by modifying its tissues. The distinction between stem and leaf then disappears, and all the part of the plant exposed to air is turned green by chlorophyll and becomes abnormally thick. Such plants, called fleshy-leaved, are found everywhere in hot deserts and semi-deserts. Their surface is usually covered with prickles. The cactus, the aloe, and the agave are examples known because they are used in ornamental gardens. In hot, dry regions euphorbias also become fleshy-leaved and are often of great size.

In climates which have well marked dry seasons, the vegetation must adapt itself to conditions which are alternately xerophilous and hygrophilous. Hence, most of the trees in normal tropical and monsoon regions drop their leaves in the dry season. The only organs left exposed to the air have as xerophytic a structure as that of desert plants, i.e., woody stems

XEROPHILOUS VEGETATION

A.—COUNTRY NEAR BOU AIECH IN ALGERIA

The pebbly ground is dotted with the spherical growths of the *Anabasis aretioides* and jujube bushes (*Zizyphus Lotus*). Some peanut bushes are seen in the background

B.—STEPPE LAND ON THE BANKS OF THE RIO GRANDE DEL NORTE

Clumps of Ocatilla (*Fouquiera splendens*) appear in the foreground

and branches, and buds covered over with a shiny, wax-coated film of skin. The buds open with the first rains, leaves develop, and the organs of reproduction are formed. Such vegetation may be called *tropophilous*. Plants in the subdivision of the temperate zone with marked winters belong to this class. The cessation of growth during the cold season is chiefly designed to preserve them from the drought.

The rise of the sap does not depend only on the humidity of the air and soil, but also on the temperature. When checked by the cold, it does not bring the necessary nourishment to the plant. Hence, physiologically speaking, winter is a dry season during which the trees and shrubs of the cold temperate belt assume a xerophytic structure, like that of tropical plants, and lose for the time being both their organs of reproduction and their leaves. In winter the aspect of the countryside in the cold temperate zone is like the belt of transition into a desert. But as soon as the temperature allows the circulation of water and nourishment to occur in the plant, the buds open and leaves are developed. Certain trees, e.g., oaks, elms, and especially beeches, have leaves which are clearly hygrophytic in structure. The complete disappearance of the plant, except for roots and embryo shoots, which is observed in herbaceous annuals, is due to the same process of adaption.

Influence of the Soil. The effects of temperature and humidity are modified by the nature of the soil. On rocky ground the soil is composed almost entirely of the rock waste due to disintegration, but in soft ground, composed, for instance, of sand, clay, or alluvium, the soil is quite different. The essential characteristic of the soil is that it is influenced by vegetation, which, after being fed at its expense, must necessarily modify its composition, and also by the climate which regulates the amount of warmth and water that penetrate into it. In the soil there are two classes of elements which have each a different origin, namely, inorganic or mineral elements and organic elements, forming what is known as *humus*. The soil proper is always more or less impregnated with humus. It passes gradually from the surface to a purely mineral layer known as the *subsoil*. The subsoil rests on bed-rock and is renewed at its expense. In its turn it forms new soil. The normal conditions of the soil cease when the infiltration of the humus slackens and a definite line of separation is established between the soil proper and the subsoil. An excess of organic elements on the surface is fatal to vegetation.

The mineral elements, which usually predominate, determine the essential physical and chemical properties of soils, but they are modified to a certain extent by organic elements. Too great permeability is harmful to vegetation and, other things being equal, imparts to it a xerophilous character. A certain proportion of clay is useful, not only to prevent the too rapid infiltration of water, but also to assure a certain degree of cohesion in the soil and to prevent useful mineral or organic substances from being washed away. Clayey soil which rests on a permeable bed is assured good drainage, as may be seen in the silt soils of the limestone plateaux in France. On the other hand, a sandy soil resting on impermeable rock is liable to become saturated with water. This is what occurs in depressions in granite regions and in the peat bogs of Ireland and North Germany.

Nearly all soils contain the necessary mineral elements in sufficient quantities to allow most plants to grow in them. But some elements, such as salt and lime, are harmful to plant life when they are too abundant.

Plants watered with a solution containing 2 or 3 per cent of salt quickly die away. But some plants are capable of standing this treatment, and grow naturally in soils containing a high percentage of salts, either near the sea or on the shores of salt lakes. They are known as *Halophytes* (Gk. ἅλός = salt + φυτόν = plant) or *halophilous plants.* A study of coastal flora shows that the structural character of halophytes is the same as that of xerophytes. The leaves are narrow, thick, and covered with hair, while the stems are fleshy. The difference between the flora in limestone plateaux and in silicious soils early attracted the attention of botanists. Hence, lists of *calcicolous* and *silicolous* plants were made. In reality, carbonate of lime like salt must be considered as harmful to plants on account of its solubility in water. A proportion of over 3 per cent of lime in soil is harmful to most plants. The chestnut especially languishes if cultivated in limestone soil, while in

Southern Europe it is one of the most characteristic trees found in silicious soils. Calcicolous plants often have a xerophilous character for the same reason as the halophytes.

The action of the organic elements in the soil is as much due to their physical as to their chemical properties. The elements themselves arise from the decomposition of dead animals or plants beneath the soil and from their mechanical disintegration by small animals under the surface.

The ordinary humus which is found under average conditions of heat and damp produces a soil in which the organic elements are closely mingled with the mineral elements. Hence, it affords to plants a nourishment which is directly assimilable and, consequently, leads to the development of roots covered with hairs to absorb the food. Moreover, it is constantly liberating carbonic acid, which attacks fragments of mineral and in this manner it contributes to the renewal of the great body of inorganic soil. Its physical influence is no less important than its chemical effect. The capacity to absorb water is increased, especially in coarse-grained soils, like sand, which are naturally too dry. Clayey soils, on the other hand, are made less compact and more permeable.

The influence of climate determines the degree of development of the humus. In tropical countries it is almost absent on account of the heat, which causes extremely rapid decomposition of organic waste matter, and also in deserts, owing to the lack of vegetation. It is often replaced in cold, damp countries by barren ground, which assumes a peaty appearance owing to the imperfect decay of organic matter and to its accumulation on the surface of the earth. A special type of xerophilous flora grows in such infertile soils, viz., heather, furze, sweet gale, etc. In stagnant water and in waterlogged soil in temperate and cold regions peat is formed. Peat bogs are associated with the barren uplands of Scotland and with the plains of Ireland and North Germany.

Soils which have the best arrangement of humus are found in oak forests. In meadows bordering on these forests, the humus accumulates at the surface, but is without the concentration found in peat bogs, and gives a black earth, known in Russia as *tchernoziom*, which when put under the plough forms an excellent soil for cereals. The *tchernoziom* belt is the granary of Europe; and in the United States and Canada it plays the same part.

The Struggle for Space; and Evolution. Even when the various physical influences which are liable to modify the nature of plants and their distribution are known, all the facts necessary for a thorough study of plant geography are not yet at hand. The botanist whose experience is restricted to a limited area may possibly find no further difficulty, since he will always find the same plants in areas in which conditions are the same. But the moment he goes beyond this area, he will probably meet with many surprises. Certain species which in Western Europe are regarded as *calcicolous* thrive in silicious soils in Southern Europe. Pairs of similar species have been observed which are calcicolous and silicolous respectively when struggling against each other for the possession of a district, but which grow indifferently in either kind of soil after the disappearance of the unsuccessful competitor. Such, for instance, are the *Achillea atrata* and the *Achillea moschata*, shown in Fig. 88.

FIG. 88.—Two species of Achillea, one calcicolous (*Achillea atrata*, on the left), the other silicolous (*Achillea moschata*, on the right).

Notice the smaller size of the calcicolous species (here shown on a scale twice as large as the other), its stouter appearance, and its hairy xerophilous adaptations.

Such facts emphasise the complexity of biological geography. Plants are not machines, passively obedient to physical influences, but are living things which react to their surroundings and seek to adapt themselves to them. Like all living things, they are reproductive, and as they multiply they tend to spread.

Every plant tends to occupy an increasingly greater space on the Earth's surface. This is the struggle for existence, and it is also a fight for room. The distribution of vegetable species exhibits a certain instability, for the slightest modification in climate turns to the advantage of one species and to the disadvantage of its rival. The latter is obliged to give way, if incapable of adapting itself by a change in form to the new conditions. The constant evolution of plants must be ever present in the mind of the geographer who wishes to understand fully the character of the vegetation which exists on the Earth's surface.

The origin of the existing flora does not appear to go back much farther than the beginning of the tertiary epoch. At that time the mean temperature of the Earth was higher than at present, and the temperate zone of to-day was still tropical or subtropical in character. Oaks, beeches, and walnut-trees lived in the polar regions. Nor was the distribution of land and water the same as it is to-day, though the continents were already tending to group themselves round the North Pole. This explains the amazing uniformity of the flora in the north temperate belt, the flora being derived from that existing in the polar cap during the tertiary age. Very important changes occurred in the equatorial regions and in the southern hemisphere just when the climate was growing cooler and the present climatic belts were being defined. Australia was once joined to Asia, East Africa to Madagascar and India. This explains certain relationships between the flora of countries which are distant from each other. But the similarities are the exception rather than the rule in the southern hemisphere, and the chief characteristic is the existence of peculiar plant groups in each continent. In identical physical conditions, analogous plant associations are found, but they are composed of very different species. These considerations will come up again and more forcibly in the study of the distribution of animals.

CHAPTER XIX

DISTRIBUTION OF PLANTS

ALTHOUGH the botanist is not yet able to draw up an absolutely complete catalogue of every species of plant represented on the Earth's surface, the geographer can attempt to define the chief features of the mantle of vegetation and to sum them up in plant associations adapted to the same physical conditions. A forest of firs is a type of plant association whose essential element, to which all others are subordinate, is a tree ; an alpine pasturage is a different type, and is characterised by the predominance of grasses. Woodland associations dispute the possession of the soil in every part of the world with grassland associations, and the two types account for differences in the colour of landscapes, and afford different environments for animal life and human activity. Let us see under what conditions each type exists.

Woodland Associations. Bushes, grass, and parasites of various kinds form part of the constitution of a forest, but the tree is the essential element. The tree is the most powerful, but also the most exacting, creature in the vegetable kingdom. The development of transpiratory surfaces in the form of leaves causes the growth of a network of passages through which circulation takes place in the roots and the trunk. The lofty stature demands for its support tissues of considerable strength, forming what is called wood. Trees should certainly be hygrophilous, for a forest of beeches about fifty years old transpires a volume of water equivalent to an annual rainfall of 9.2 inches. Thanks to its powerful spread of roots, the tree can obtain nourishment from soil which is dry on the surface, so long as there is moisture beneath. Consequently, it is less directly sensitive than grass to the absence of rain and can endure a dry period which follows a wet period, if some check is placed on the loss of moisture by evaporation. But hygrophilous forms exist only in the tropics and are characterised by rapid, continuous growth. Hence, the woody elements are reduced and the leaves extremely developed. The characteristic type has huge leaves arranged like a rosette at the end of a single stem or *stipe*. The best known example is the palm.

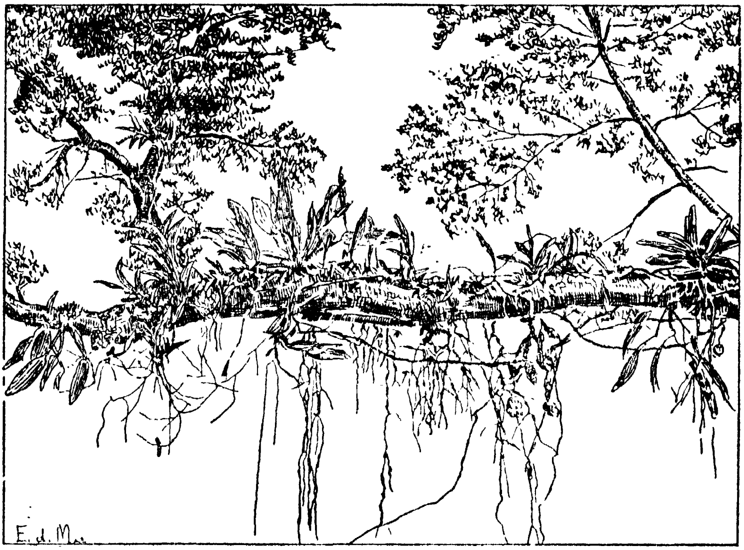

FIG. 89.—A branch covered with epiphytes in the tropical forests of Brazil. (From a photograph by H. Schenck)

Adaptation to drought conditions is achieved by a decrease in height; e.g., the arbutus and other shrubs and bushes; by transformation and reduction in size of the respiratory organs, as in leaves with a coating of wax and in elongated needle-shaped leaves; by the development of the woody parts and the substitution of thorns for leaves, or, on the contrary, by the growth of soft tissues in which water can be stored up, as in succulent plants of the *Cereus* type. There are many tropophilous types of trees. The xerophilous features which occur during the period when growth is arrested are well marked in the hot belt, and two chief types are observed: one short and squat with enormous trunk and branches, e.g., the baobab; the other slender and prickly, like the acacia.

With forest trees are often associated *lianas*, which are rope-like plants which entwine themselves round the trunks and branches. Their rapid growth demands a high temperature. Hence they are excluded from cold climates and are characteristic of tropical forests.

Epiphytes[1] are also more common in forests in the hot belt. Orchids are a well known example. They generally grow on a branch and spread their roots among the cracks and roughnesses of the bark, striving to overcome the inconveniences of such an unfavourable position by adapting themselves to xerophilous conditions or by developing hanging roots which absorb the slightest amount of moisture that occurs (see Fig. 89). *Saprophytes* (Gk. σαπρός = decayed + φυτόν = plant) also belong to the woods and live on decaying matter. The mushroom is the best known example. *Parasites* are plants which, strictly speaking, live by feeding on the sap of the tree on which they grow, using suckers to obtain it. They are of more frequent occurrence in forests than anywhere else. There are parasitic lianas, e.g., the dodder, as well as epiphytic lianas.

Grassland Associations. The essential element in the grassland association is grass, but shrubs, bushes, and sometimes even isolated trees occur. Owing to its low stature, grass escapes the drying effect of air and wind more than trees do, but its short roots make it more immediately sensitive to variations in humidity in the surface layer of soil and consequently to variations in rainfall. It cannot endure prolonged drought during the period of growth. Most herbaceous plants are either xerophilous or tropophilous. Adaptation to xerophilous conditions is achieved in several ways: by a reduction in size and a change in form of the leaves, together with the development of woody tissue, as in heather, or with the appearance of prickles, as in furze or thistles; by the development of matted hair on the surface of leaves, as in mullein; or by the invasion of the whole

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[1] Gk ἐπί + φυτόν = plant which lives on another, without roots in the soil, like lianas, and without feeding at the expense of the trees on which they grow, as parasites do.

PLATE VIII

EQUATORIAL VEGETATION

A VIRGIN FOREST ON THE LOWER AMAZON, SHOWING THE VARIETY OF THE UNDERGROWTH

In the centre is a Mumbaca palm

plant by green tissues, as in broom or the stonecrop. The tropophilous types are widespread. They take the form of perennials, with hibernating shoots, or plants with bulbs or stoles, like the garlic, onion, and iris.

Herbaceous plants also resort to dying down during the winter or during the dry season after completing their growth in a single season. Such plants are annuals, and are very widespread in the temperate belt. The climatic conditions favourable to herbaceous vegetation are usually the reverse of those which suit arborescent vegetation. During the period of growth at least, the latter requires constant and even great heat, a soil which is damp at any rate beneath the surface, and an atmosphere whose relative humidity must not fall below 70 per cent. Herbaceous vegetation is better adapted to a moderate temperature, and requires soil which is damp on the surface, but endures a considerable dryness of air.

African Forests and Savanas. Africa was chosen to illustrate the connexion between the different types of hot climate (see pp. 64-66); the same continent will now serve to describe the mantle of vegetation corresponding to the various climatic types of that belt. At whatever point a traveller disembarks on the Guinea coast between the Ogowe and the Gambia, he finds himself at the end of a few hours' march plunged into the depths of an equatorial forest. A deep sense of the exuberance of life around him and a feeling of oppression, which has been remarked upon many a time by explorers, is cast over him by the foliage, which is penetrated by an opaque light and which shoots up and intertwines in an indescribable tangle in an atmosphere of damp heat, impregnated through and through with fever-breeding miasmas. An observer who tries to analyse this chaotic mass of vegetation is struck by the abundance of palms, of tree ferns, of lianas, and of epiphytes with hanging roots. Besides herbaceous plants which are as big as a tree (e.g., the banana), there are trees like those in temperate forests; but these have comparatively few branches and their boles are often almost smooth, resembling those of the plane-tree rather than those of the oak. Sometimes bunches of flowers grow straight from the bole. If, as is rarely possible, an elevated point can be reached, from which the forest can be overlooked, the variety of tints in the foliage and the unequal height of the trees become striking. The equatorial forest is an indescribable mixture of lofty giants rising to more than 170 feet, of smaller trees, and of tree-like herbaceous plants, the whole being bound together by a tangle of lianas and epiphytes, which endeavour to reach the highest branches in order to open their flowers to the light above.

What is most astonishing is that this aspect never varies. The forest is as impenetrable, its gloom is as deep, at one season as at another. This is not due to the fact that there is no fall of leaves or that every plant is constantly growing, but to the fact that the high temperature and great humidity, which give rise to this luxuriant vegetation, never fall sufficiently to impose an interval of rest on all the trees alike. Only hygrophilous types occur in these forests, which are consequently always green.

The same conditions exist, with but little modification, wherever the equatorial, or Amazonian, climate prevails. But the aspect gradually changes as one leaves the shores of the Gulf of Guinea and travels northwards, or as one ascends from the centre of the Congo basin towards the Uele or the Shari. At first, the forest becomes less dense, the average height of the trees decreases, the woody parts become more noticeable, the bark thickens, and the branches are more numerous. The leaves become smaller, as in the baobab; sometimes, as in the acacia, prickles appear. Certain palms, indeed, have adapted themselves to conditions of drought. Lianas and epiphytes still occur, but they are woody, and often covered with thorns, e.g., the rattan. This makes the forests impenetrable, except along the paths forced by elephants. But the most important change is the general fall of leaves during the dry season. This season is soon appreciable and grows longer and longer as one leaves the equator, and trees are obliged to adapt themselves to xerophilous or tropophilous conditions.

But high temperatures cause vegetation to feel the drought to such a degree that even these adaptations are insufficient, and the forest soon gives way to a grassland association, forming the *tropical savana*. This is a discontinuous carpet of grasses which grow in tufts at greater or less intervals, springing up rapidly during the rainy season and in a few months reaching a height of 6 or 9 feet, but soon drying up so completely that it often catches fire spontaneously, when it is not deliberately burnt by the natives to draw the big game in it or to prepare the ground for cultivation. Clumps of trees, baobabs or acacias, are usually dotted about on savanas, giving them a park-like appearance. Thorny bushes and fleshy plants, like the *Euphorbia candelabra* and the *Cereus*, appear here and there, especially in dry places.

Relief and the nature of the soil give rise to a variety of aspects. Forest lines the bottoms of damp valleys and its foliage often appears over the edges of plateaux where the savana prevails. In the Sudan such remnants of forest are known as gallery forests or savana forests. Wherever there is limestone or laterite, there are xerophilous forms, and grass sometimes gives way almost entirely to thorny bushes. As one approaches the tropic or the plateaux of East Africa, the lines of gallery forest shrink, clumps of trees become rarer, and bushes and fleshy plants prevail over the grasses. In the end they gain the upper hand completely, and the ground is bare in great patches. This is the edge of the desert.

Variety of the Flora in the Hot Belt. This rapid analysis leads to the conclusion that in Africa the equatorial climate gives an evergreen virgin forest formed of trees and hygrophilous arborescent plants. The climate of the Sudan gives, according to the nature of the ground, either the savana or the tropical forest with its xerophilous or tropophilous adaptations and with its fall of leaves in the dry season. The Senegalese climate, with its long dry season, is a zone of transition to desert conditions, and under it the gallery forests diminish and thorny bushes are developed at the expense of the herbaceous vegetation of the savana. These conclusions may be extended to the whole of the hot belt. But the combinations of species are naturally different, since the continents are completely separated in this belt and the separation dates from an early age.

The greatest extent of equatorial virgin forest is found in South America in the vast, abundantly watered plain of the

Amazon. Here palms are as characteristic as in Africa, but they belong to different genera. The tropical forest with its fall of leaves during certain months appears, as a rule, as soon as one goes any distance from the rivers. They are succeeded by the savanas known as *campos* or *llanos* (pronounced *lyanos*). Thorny bushes, or *catinga*, present curious forms of fleshy plants in Brazil or Venezuela.

In India and Malaya the equatorial virgin forest prevails in the dampest regions with a luxuriance and exuberance in no way inferior to its Amazonian counterpart. But most of the monsoon region is covered with tropical forests or savanas. Here the bamboo is characteristic. Palms are numerous, and in India the species seem to be closely related to those of Africa. Malaya, on the other hand, shows some connexion with Australia, in the north of which there is a tropical flora with species closely related to those of New Guinea and Celébes.

Flora of the Mediterranean and Chinese Regions. The variety of aspect exhibited by vegetation and the relation of the various aspects to geographical influences in the subtropical belt may be illustrated by the comparison of two widely separated and apparently quite different countries, namely, Southern China and Provence or Italy.

The nature of vegetation in the Mediterranean region is that of a comparatively dry area, which has a bright sky, hot summers, and winters which, though mild, are yet sufficiently well marked to be felt by plants. Forests are definitely xerophilous in character. They are composed of conifers (pines), of trees with gnarled trunks, thick bark (e.g., the cork oak), and small wax-coated leaves (e.g., the evergreen oak), associated with evergreen shrubs, like the arbutus and laurel, and thorny bushes like the broom. In silicious soils the vegetation is more vigorous, and tangled bushes form the *maquis*. In calcareous soils, often nothing but a little stunted evergreen oak, like the Kermes (*Quercus coccifera*), is found. This is the *garrigue*. Herbaceous plants are rare. Where they occur, they form a *steppe* with their widely separated tufts, which are completely dried up in summer and in winter. The dry heat and the cold impose on the vegetation two periods of rest during the year. Bulbous plants which store up supplies of water beneath the surface are almost the only ones which can adapt themselves to this life and are always ready to shoot up with the first signs of spring and to develop blossoms of amazing brilliance and spontaneity.

The flora of Southern China is far richer than that of the Mediterranean. Although the conditions of temperature are the same, there is no dry season. Woodland vegetation is strikingly vigorous and extraordinarily varied. Along with conifers with their needle-shaped leaves (e.g., the pine), there are others of totally different types, like the *Araucarias* and the *Ginkgo.* To the evergreen oaks and laurels are added plants with wax-coated leaves and large, brilliant flowers, like the magnolia and tulip. Even tropical types occur, e.g., palms, tree-ferns and bamboos. Lianas, which are very rare in the Mediterranean, grow vigorously, and often make the forest nearly as impenetrable as those of the hot belt.

The differences between the flora of the Chinese region and that of the Mediterranean are less surprising, however, than their similarities. In both there are conifers, a family which is unknown to the hot belt, shrubs like the laurel, with spreading, green leaves, and evergreen oaks. The fact that with the help of irrigation Chinese cultivated plants like the orange and the citron have been introduced into the Mediterranean region is not without significance. The similarities are due to the fact that China and the Mediterranean region belong to the subtropical belt, where in the tertiary epoch uniform climatic conditions probably like those of China at the present day prevailed everywhere. The uplifting of the great mountain ranges of Asia, the desiccation of the continental interiors, and the extension of the deserts have separated them, and xerophilous adaptations, which are particularly marked in the Mediterranean region, were developed later.

The contrasts between the Chinese and Mediterranean floras (corresponding to climatic differences) are also found in all the other continents, but so also are some of the similarities just mentioned. In North America deserts and steppes separate California from the Atlantic regions of Georgia and the Carolinas in the same way as the deserts and steppes of Asia separate Southern China from the Mediterranean.

On the Pacific side there is a Mediterranean flora with a sort of *maquis* known locally as *chaparral* and forests of a special type of conifer, the *Sequoia*. On the Atlantic side are pines, palms, magnolias, and oaks, which give the landscape an appearance similar to that of Southern China. The same contrasts and similarities are seen in South Africa to exist between the flora of Cape Colony and that of Natal, and in South America between the flora of Southern Chile and Paraguay; but the species and genera are naturally quite different.

The Temperate Belt. The temperate belt presents far more uniform aspects. The only difficulty encountered in explaining them is due to the fact that man's concentration in these regions seems to have produced far-reaching changes in the primitive aspect. Botanists generally admit that most of this zone was formerly occupied by forest. In Europe two chief *facies* are recognised: the *deciduous forest*, in which the oak predominates in the south and the beech in the north, and the *coniferous forest*, which extends over the northern regions and mountainous districts. In each case there is a period when growth is arrested in the winter. Conifers readily resume their growth at the first sign of spring, which appears late in their habitat. To the differences due to the predominant trees are added those of the undergrowth. This is far more luxuriant in deciduous forests, which do not cast their shade over the ground throughout the year, and especially in oak forests, since the leaves of these trees appear late. Moreover, deciduous forests are usually less compact. An oak grove is often broken by natural glades. In these clearings man first entered the wood and began his destruction of the forests. Huge primeval glades probably stretched through the driest regions, either on account of their soil (which is *loess* or limestone) or their climate, when they lay in depressions surrounded by mountains. Towards the East they gradually became wider. The grass plains of Southern Russia, which pass gradually into steppes and salt marshes on the shores of the Caspian, are certainly due to natural conditions.

A grass plain, formed by tufts of grass close enough together to cover the whole surface and mingled with bulbous and leguminous plants, is a plant association characteristic of temperate continental climates. The nearly even distribution of humidity throughout the year is favourable to its development. A covering of snow which lasts for some time is a handicap to the growth of trees, but protects the grass from extreme cold, and the violent, dry winds are not felt by the grass which lies close to the ground. Here again there are forests along the streams, and here and there stand clumps of trees which give the region a park-like appearance. Abounding in game and fertile, these lands have been sought after by man from early times, and were probably the starting-point of the great migrations which peopled Central and Western Europe.

The same conditions occur also in the New World. From north to south and from the coast into the interior, both in Canada and the United States, there is a succession of forests of conifers, of forests of oaks and beeches, of grass plain and of steppe. Not only is the general aspect the same, but also the plant genera, namely, *Abies*, *Larix*, *Pinus*, *Epicea*, *Quercus*, *Fagus*, etc. The reason is that the trees have come from the north, as has been said before, and that in this direction there have always been close relations between the Old and New Worlds. In the southern hemisphere, on the contrary, the temperate belt is reduced in area, and the trees are of different genera in Chile and southern Australia.

The Deserts. In all the belts of vegetation the desert seems to be the goal towards which the gradual impoverishment of plant life is tending. Like the garrigues and steppes of the Mediterranean region, tropical scrubland shades off into the Sahara. The grass plains of Russia shade off into the saline steppes and trans-caspian deserts. In deserts vegetation is no more absent than water, but it occurs only in local patches, and is liable to disappear not only for a season, but even for several years. A casual spate in a ravine in the Sahara brings up with extraordinary rapidity a carpet of grass and other herbaceous plants, but this disappears in a little while, and for perhaps another fifty years will not be seen by passing travellers. Apart from these plants with a short period of growth, only xerophytes can exist. Nearly every plant tends to develop underground or on the level of the ground. The network of

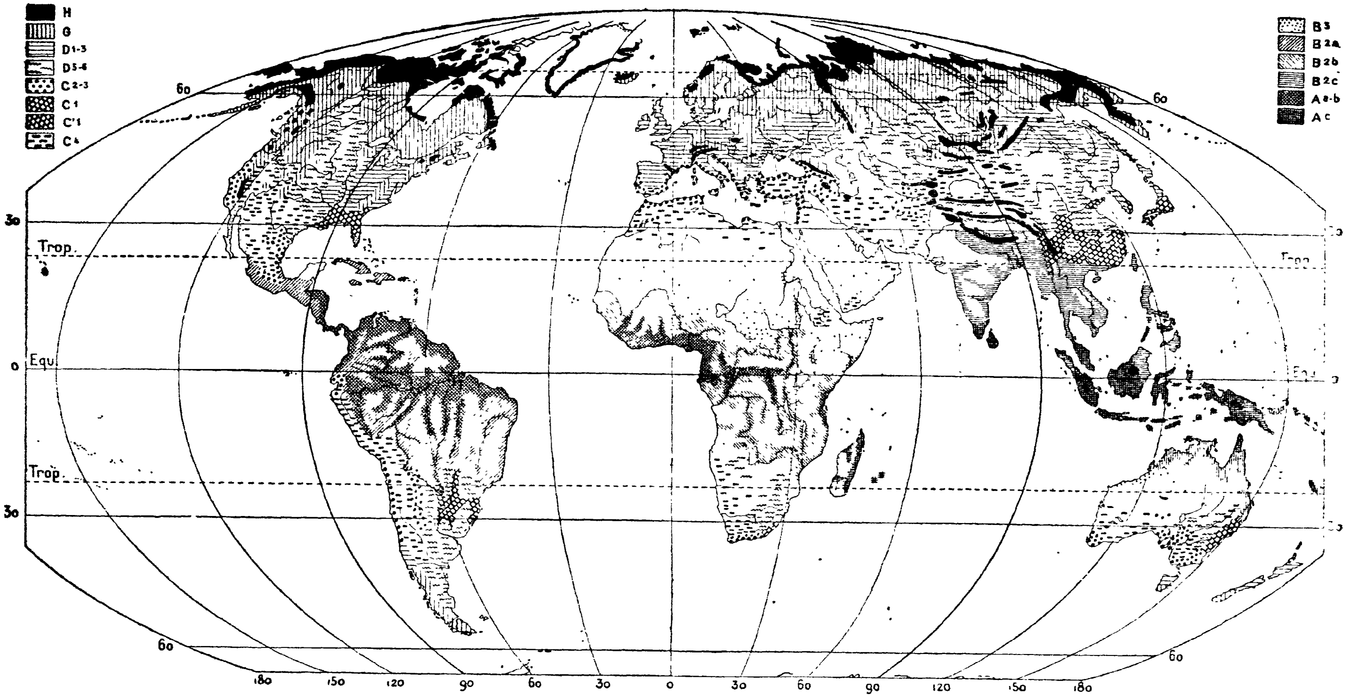

FIG. 90.—World distribution of types of vegetation.

H = Polar tundras and Alpine vegetation.

G and D1–3 = Temperate forest belt (G = Areas in which conifers predominate; D1–3 = Areas in which the oak is the typical tree).

D5–6 = Steppe-land (temperate grass-land).

C2–3 = Plant associations of the *maquis* type (chiefly xerophilous shrubs with traces of coniferous forests and evergreen oaks).

C1 and C'1 = Subtropical forest of the Chinese climate. (The slight difference in shading distinguishes regions which are quite distinct from a systemmatic point of view; the Chino-Japanese, the Florida, the Uruguayan, the South African, and the Australian regions.)

C4 = Subtropical semi-deserts.

B3 = Tropical savanas.

B2 = Tropical forests (the difference in shading is intended to bring out the individuality of the several regions; B2a is the South American region; B2b the African: and B2c the Eastern).

A = Equatorial forest (with distinctions as for B).

N.B.—(1) Gallery forest is indicated by the extension of shading for forests along streams running through savanas.

(2) Deserts are marked by the gradual thinning out of the shading denoting the types of vegetation which passes step by step into desert land.

roots is enormous, the stem diminutive, the leaves are often invisible and are turned into prickly spicules.

The deserts of the tropics are the best developed and are probably the oldest; hence the variety of xerophilous forms found in them. Fleshy plants are numerous, e.g., Euphorbias and Aloes in Africa, Yucca and Cereus in Mexico. The deserts of the subtropical and temperate belts are less rich. Thorny shrubs are characteristic in them. In the deserts of Asia, in Persia, Turkestan, and Gobi, the *Saxaul* is everywhere seen growing in the driest sand and looking like a pollard willow, which is for ever without leaves, but it sometimes forms real forests in the valleys.

Polar Tundras. Excessive cold, like drought, tends to give plants the characteristics of desert vegetation. In polar climates where summer is unknown, diminutive woody plants or herbaceous plants with a xerophilous constitution are found, as in waterless regions. The snow which covers the ground for the greater part of the year, the dryness of the air at the coldest period, the freezing of the soil, all prevent the growth of plants both under the surface of the ground and above it. The few trees that exist keep low down against the ground (pines and birches). But the characteristic aspect is the *tundra,* a kind of scrubland covered with evergreen bushes, like the heather and the bilberry, and broken by convex peat-bogs which form mounds 9 or 12 feet high and 70 to 100 feet in diameter, from which water oozes.

Alpine Vegetation. Alpine vegetation is closely related to its Arctic counterpart, and the character of plants which live near the region of eternal snows sometimes resembles that of tundra vegetation. But mountain climate differs in certain respects from polar climate; it has a real summer, when the soil is completely thawed and insolation is very great. Hence the brilliant display of flowers and the activity of assimilative functions, which enables plants to make up for time lost during the winter. As in the polar regions, the parts of plants which are exposed to the air are liable to damage from the snow which remains unmelted for long, from the wind, and from the cold.

Hence the absence of trees. But nothing prevents the development of roots or tubercles, and the mountain pastures of the Alps are often covered with grass or with bushes. In either case the xerophilous structure of the plants is remarkable. Evergreen bushes predominate: conifers, like the mountain pine (*Pinus montana*), and the dwarf juniper (*Juniperus nana*), or shrubs with thick leaves, like the rhododendron. Herbaceous plants keep their leaves and flowers compactly together, often forming a sort of pad which at a distance looks like moss ; e.g., the *Silene acaulis* of the Alps.

The lower limit of the Alpine zone coincides with the upper limit of the forest belt. Its height depends on climate and surface relief, and it conforms with the variations in the snow-line, being naturally highest in warm regions. Thus, its upper limit reaches to 16,000 feet in the Himalayas, while in the Alps it hardly goes beyond 7,000 feet. In the same mountain range or in a valley, it may be over 300 feet higher on the slope looking towards the equator. An abundant rainfall always lowers its elevation. This is probably the chief reason why it is always remarkably lower in the Pre-Alps than in the Central Alps. Thus, at Säntis it rises to 5,100 feet, in Valais to 7,100 feet; in Grande-Chartreuse to 5,250 feet, but in Tarentaise to 7,000 feet.

CHAPTER XX

DISTRIBUTION OF ANIMALS

Contrast with the Distribution of Plants. Like plants, animals are dependent on their natural environment, and in fauna as well as flora associations of species may be observed which are adapted to a life in common under fixed physical conditions. It is difficult, however, to explain the causes of these associations and to understand the reasons for their distribution. Animals are, even less than plants, not passively obedient to external influences, and they react vigorously against anything that threatens their existence. Animal life produces heat, and mammals keep their bodies at a constant temperature. Hence, the geographical distribution of warm-blooded animals has but little connexion with conditions of temperature. Even cold-blooded animals, e.g., reptiles and batrachians, do not wholly regulate the temperature of their bodies by that of their surroundings.

A very large number of animals are gifted with the power of moving more or less rapidly from one place to another, and this makes them less directly sensitive than plants to changes of climate. Animals with the greatest capacity for travelling cannot be restricted to a limited region. Many of them are migratory and change their habitat with the seasons of the year. Such, for instance, are a great number of birds which are observed according to the season either in the north of Europe or in the Mediterranean and even in tropical regions; certain ruminants, like the reindeer of the tundras and northern forests and the antelopes of the steppes and the tropical and sub-tropical savanas; lastly, many fishes, certain species of which (e.g., eels and salmon) actually leave the sea and ascend streams.

The facts to be dealt with in the distribution of animals are, therefore, far more complex than in the vegetable kingdom. The associations cannot be as directly related to their environment, except in the case of less mobile, inferior organisms. Animals do not depend only on the physical conditions of soil and climate, but still more on biological conditions. The vegetable kingdom furnishes their food, either directly, as in the case of herbivores, or indirectly, as in the case of carnivores. But other animals dispute the food with them, others form their prey, and others prey upon them. The struggle for existence and for room obviously dominates the whole system of the animal kingdom far more than it does the vegetable kingdom. Hence, the character of existing fauna can only be understood with reference to the past, to the evolution of species, and to variations in the distribution of land and water.

But too much generalisation must be avoided. Animal life is far more varied in its forms and is more widely distributed than vegetable life. Unlike plants, animals have no imperative need of light. Hence, they can live under the surface of the earth and even in the greatest depths of the ocean. No mention has been made above of aquatic flora ; but aquatic fauna could not be neglected save at the risk of incurring the charge of omitting half of the subject in hand. But conditions of life are completely different in water and on dry land, and the two elements are, indeed, two distinct worlds whose animal life requires separate study.

I. AQUATIC FAUNA

Aquatic Life. Nothing illustrates the special conditions of life in the water better than the adaptations undergone by sea mammals. Whales, for instance, are well known. Their bodies have assumed a shape similar to that of most fish. The trunk has become longer, slimmer, and more pointed, so as to overcome the resistance of the water more easily. The hind limbs are completely atrophied, while the fore limbs have been changed into fins by an increase in the number of bone-joints. The bones have become comparatively light and spongy to enable the animal to float more easily. The head is enormous. The external parts of the ears have disappeared, and the nostrils have shifted their position to the back in order to allow respiration to take place while the animal is swimming on the surface. A very thick skin covers a deep layer of blubber which keeps out the cold ; in fact, though there is little variation in the temperature of the water, the body of the mammal is usually a good deal warmer than the water.

Most aquatic animals, however, are cold-blooded and are able to vary the temperature of their bodies to suit the variations in the temperature of the water, provided the latter are not too sudden. They should not be considered as adapted to a certain temperature, but to a certain mean range of temperature. Thus, a goldfish has been known to live in water which was heated slowly to a temperature of 102.2° F., while it died immediately on being transferred to a jar the temperature of which differed from that of its previous water by only 9° F.

In fine, aquatic life assumes the possibility of enduring very great pressure and of overcoming it for the purpose of movement, special arrangements for breathing, a relatively low specific gravity, and lastly adaptability to a temperature which varies little, yet may be very low.

Aquatic animals do not all move by spontaneous action, and the relations between those which can move of their own free will and their natural surroundings are not the same as those of others which have not the power of free movement. Naturalists have universally accepted the distinction between the *Nekton* (Gk. νηχτός = able to swim), i.e. mobile animals, including most fish, a large number of crustaceans, and the mammals ; those which are fixed to the bottom, such as coral polyps, starfish, etc., and form the *Benthos* (Gk. βένθος = bottom) ; and lastly those which drift along without any power of movement in themselves and are termed *Plankton* (Gk. πλαγχτός = wandering).

Plankton consists chiefly of minute organisms of rudimentary structure, which sometimes occupies a doubtful position on the borderline of the animal and vegetable kingdoms (Peridinians), of silicious algae (Diatom), of Protozoa (e.g., Globigerinae, Radiolariae, Noctilucae) and little crustaceans (Copepods), and of the larvae and eggs of fish or crustaceans. Its study is of great geographical importance, because its distribution depends directly on physical conditions of temperature, salinity, light, and ocean currents, to which it is so sensitive that it undergoes seasonal or even daily displacements. Moreover, a great number of fish feed on plankton, so that their distribution and the possibilities of fishing depend on its abundance and its fluctuations.

Marine Fauna. There are two main divisions of aquatic life, the sea and fresh water. The first is by far the more important. It has two essential characteristics, continuity and salinity. The continuity of the waters of the ocean gives its fauna almost boundless possibilities of dispersion, and the struggle for existence and for room functions without any other restrictions save those imposed by the physical environment. The salinity of the great oceans is constant, and prevents fresh water fauna from mingling with that of the sea. When suddenly transferred to sea water, most river fish immediately die of dessication. Conversely, sea animals swell to bursting point when placed in fresh water. There are exceptions, such as eels, which have a mucilaginous skin, and dolphins, which have a thick, leathery skin. As the change from salt water to fresh water surroundings is made by sea creatures only, it is the accepted theory that fresh water fauna has been derived from marine fauna by a slow process of adaptation. A movement in the opposite direction would seem almost impossible. Above all else, the nature of marine fauna depends on the depth of the water in which the animals live.

Abyssal Fauna. Abyssal fauna, which lives in the depths of ocean below the 2,500 fathom line, has only lately become known and affords some of the most peculiar and ancient forms of life in the animal kingdom. Uniformity of physical conditions is the essential factor in their lives. The same extremely low (see Part II., Chap. VI) and strictly invariable temperatures prevail throughout their habitat, the pressure is enormous, nor does the sun's light reach them. Animals adapted to such surroundings are incapable of existing elsewhere and die as soon as they are brought to the surface.

The absence of light causes the disappearance of the eyes in most of these animals, though in some, on the contrary, it leads to a hypertrophy of the organs of sight, causing them to assume the form of a sort of telescope (see Fig. 91 A). The light which these exaggerated eyes seize is emitted by the animals themselves, e.g., the *Calliteuthis*, a cephalopod which is covered with luminous corpuscles (see Fig. 91 B). Other animals replace the power of sight by developing that of touch. For instance, certain shrimps have legs and feelers which are four or five times as long as their bodies. One fish, the *Stomias* (see Fig. 91 C), is provided with a sort of tactile barbel.

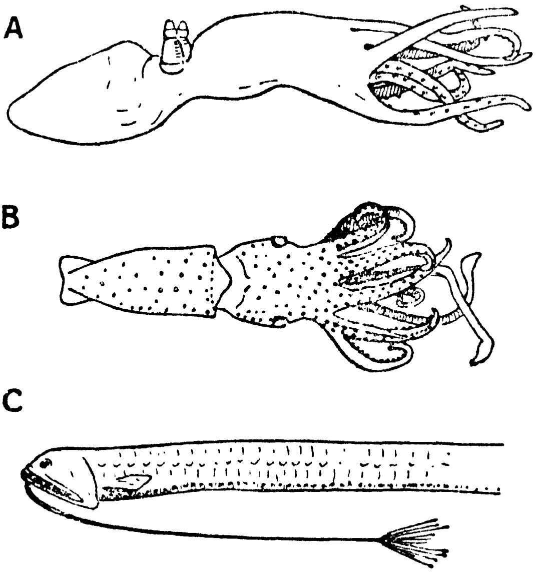

FIG. 91.—Types of abyssal fauna.

A = cephalopod with telescopic eyes; B = cephalopod with luminous corpuscles; C = fish with a long feeler.

The distribution of abyssal fauna is remarkably uniform. The number of species which are closely related to some that lived near the surface in former geological ages is striking. The even temperature of the ocean deeps made it a place of refuge for such animals as were unable to adapt themselves to the greater variations in temperature which accompanied the general cooling of the Earth's surface.

Pelagic Fauna. The surface layers of the sea are far richer in fauna. Light penetrates down to 200 fathoms, thus permitting the development of vegetable organisms, which together with larvae and protozoa form plankton. The plankton is different in hot and cold regions, and hence the mobile animals (nekton), which feed on it or on each other, are also different. Whales, for instance, are most common in the cold zones because they feed on the plankton of those regions. Very slight variations in temperature and density are enough to cause the plankton to sink or to rise to the surface, since they float by simple hydrostatic equilibrium. This is the explanation of the seeming disappearance of shoals of fish, when the latter go to greater depths in pursuit of their food. When warm and cold currents come in contact with each other, the polar plankton becomes mingled with the equatorial. Such an occurrence causes the presence off Newfoundland of the schools of cod which attract fishermen from the coasts of Europe. A great number of the pelagic (Gk. πελαγος = ocean) nekton may live temporarily in shore waters.

Coastal Fauna. The fauna of coastal waters is the most varied on account of the differences in surroundings which are seen at every step and of the variations in temperature and salinity which occur in any given place. This variety is particularly striking in marginal and continental seas, where the continental shelf is often very broad and where, as has been seen above (Part II, Chap. VII), many anomalies occur in the system of temperature. The plankton is very sensitive to seasonal variations, and animals which feed on it follow it in its movements. Organisms which are fixed to the bottom (benthos) are unable to avoid the changes in temperature and salinity. Moreover, they cannot escape from their carnivorous foes, and must be able to endure the action of the waves. Lastly, they find very great differences in the sea bottom. In one place there is soft mud, in another sand ; in a third, pebbles or rock. From all these causes arise a host of curious adaptations which may be seen on exploring the strip between high and low water mark. Another fact increases the variety of coastal fauna, namely, its lack of continuity ; and the character of the animals now existing would be far more different in the several continents if a large number of them did not have larvae which spend a phase of their existence among the plankton of the ocean.

On the whole, the essential difference to be noticed lies between the fauna of the hot belt and that of the cold regions. The former is characterised by a number of specialised fishes, by the coral polyp, whose work in building up atolls and fringing reefs has been noticed (Part III, Ch. XVII), and by the pelagic mammals which frequent deltas and even penetrate into rivers. The similarities between the two cold zones is amazing. To explain them, one must assume great changes in the distribution of land and a greater uniformity of climate during former geological ages.

Fresh Water Fauna. The passage of certain marine species into fresh water streams indicates the process by which rivers and lakes must have received their fauna. It is on this assumption that zoologists explain the fact that, in spite of an infinite variety in the different environments, the fresh water fauna is not radically different in the two hemispheres or in the New and Old Worlds.

From the biological point of view, lakes must be considered apart from rivers. In lakes of any considerable extent, three regions may be distinguished on the analogy of the classification of ocean fauna: a shallow water belt, where a multitude of larvae of aquatic and terrestrial creatures are to be found and where fish come in search of food and shelter among the reeds; a deep water belt, with an abundance of plankton consisting of vegetable (Algae and the spores of terrestrial plants) as well as animal organisms (Crustaceans and Rotatories), fish, and, in certain deep lakes, even Medusae (e.g., in Tanganyika and Lake Victoria) or seals (e.g., in Lake Baikal and the Aral Sea); lastly, a bottom water zone, which is comparatively poor, but contains worms, blind crustaceans, and a few predatory species of fish.

In rivers the aquatic domain is restricted to a long, narrow, branching zone. In it variations in temperature are relatively great, and the movement of the water is more or less perceptible according to the size of the river and the gradient of its bed.

Fish and molluscs differ according as they live in rivers which flow across plains or in mountain streams, in rivers of countries with an abundant rainfall, which vary little, or in those of the steppes, which lay bare long stretches of sandy bottom in the dry season. As a precaution against drought, some fish bury themselves in the mud and remain hidden there in a state of suspended animation until the following wet season ; e.g., the African mud-fish. Some molluscs adopt the same method on the banks of great rivers flowing through plains, e.g., the Nile, Congo, and Danube.

II. LAND FAUNA

Restricted Dispersion. The continuity of the surroundings of marine fauna is in contrast to the discontinuity of continental areas, and the relatively even temperatures of the sea water with the greater variations in the temperature of air and earth. The spread of animals over the land surface is checked by impassable barriers in the form of various arms of the sea, while climatic differences due to altitude and relief also hinder migrations to distant regions. The homogeneous nature of the fauna in cold and temperate regions in the northern hemisphere is due to the wide expanse of the continents and to their proximity on the Arctic Circle. In the southern hemisphere, on the other hand, each continent has its special types of animals. The related species occurring in India, South Africa, Madagascar, and Australia postulate the existence of a continent which formerly united these countries, but which has been broken up since the secondary age. The isolation of Madagascar and Australia has enabled them to preserve archaic forms which have elsewhere been ousted by types that are more highly developed and are better adapted to the existing climate. In small islands the old types have died out without being replaced, and the larger mammals, especially the herbivores, which require a good deal of space, are entirely absent, unless the islands were recently joined to the mainland. With them disappear the carnivores which prey on them. Isolation in an island always leads in the end to impoverishment of the fauna.

Influence of Variations in Temperature. Land animals adapt themselves to the greatest variations in temperature. Warm-blooded animals, which maintain a constant body temperature, succeed in living in the coldest climates after achieving some interesting adaptations. Their bodies become covered with hair, which is long in proportion to the severity of the winter, and this process of adaptation is observed in ruminants, like the Tibetan yak (see Fig. 92), as well as in carnivores like the Manchurian tiger. Even birds grow a thicker plumage and change their appearance according to the season; as, for instance, the Alpine ptarmigan, which assumes at one time the appearance of the partridge and at another of the willow grouse (see Fig. 93). But no form of adaptation can resist the scarcity of food which results from the disappearance of the vegetation and the lower species of animals. To escape its effects, certain mammals adopt hibernation. In the marmot, for example, this takes the form of slowing down the circulation

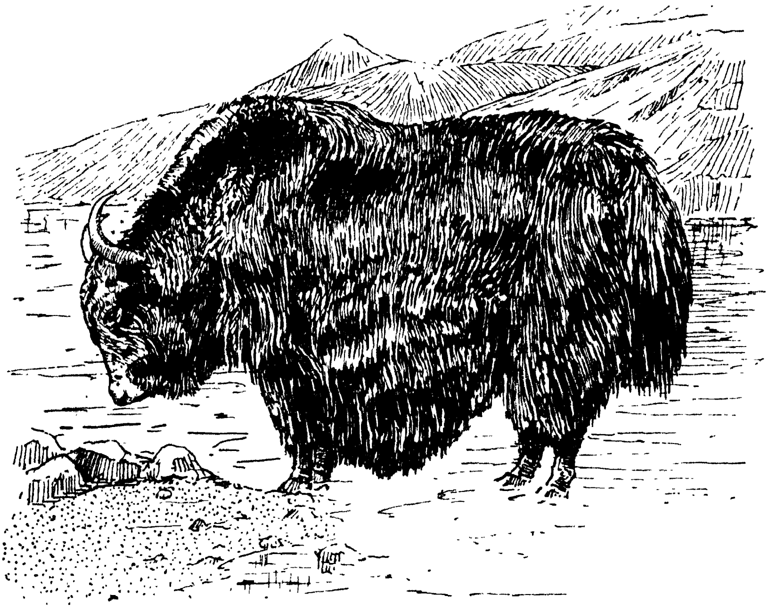

FIG. 92.—A Tibetan yak.

and breathing, so that the body temperature falls to 50° F. Hibernation causes the animal to become so lean that on awakening from its torpor it is obliged to make up for its long period of fasting by eating continuously for several days. Another means of protection is migration, which is extensively practised by birds and certain herbivores. Cold-blooded animals, particularly reptiles, are almost all given to hibernating, and during the period of torpor they assume more or less the same temperature as their environment. The same is true of many moths and insects. A number of invertebrates disappear completely during the winter, preserving their species in the same way as annual plants do, by eggs or cysts.

FIG. 93.—The Alpine ptarmigan (*Lagopus mutus*), which changes its plumage with the season.

Influence of Soil, Water, and Trees. The readiness shown by land fauna in adapting itself to its environment leads to the distinction of biological types, similar to those already described among marine fauna. But the mobility of animals does not allow them to be classified as living in only one set of surroundings. All that can be said is that certain species have a more or less marked predilection for life in the soil (*terricolae*), or by the water side (*aquicolae*), or in trees (*arboricolae*), etc. Such predilections are quite enough to cause important adaptations. Terricolous fauna consists chiefly of invertebrates, i.e., insects and worms, which provide food for rodents that also frequently live beneath the surface. In hot countries, where the conditions beneath the soil are extraordinary, amphibians are found which have assumed the shape of worms, e.g., the Brazilian Cecilia.

Terricolous rodents have very special characteristics. The fore-paws have become specially adapted for rapid digging, and the hind-paws for throwing up the earth behind them. Their tail is short and sometimes rudimentary. Their head is almost conical, and their incisors are very strong and point forward. Life underground causes the eyes to degenerate, and in the American *Geomydae* they have become very small, in the *Spalax typhlus* they are reduced to black points, while in the mole they are covered over with skin. Most burrowing animals are nocturnal and often hibernating in their habits. Some, like the beaver and otter, have adapted themselves to a semi-aquatic life. Conditions of life in caves produce equally curious results. Animals which live in caves have some characteristics in common with marine animals, for the darkness of their environment causes the eyes to be atrophied or to disappear, tactile appendages to be developed (see Fig. 94), and sometimes the skin to be deprived of colour, as in the blind Proteus.

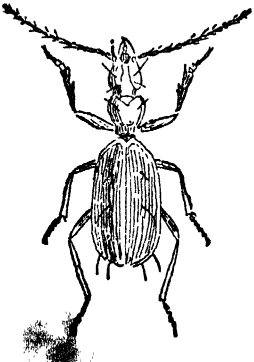

Fig. [illegible].—A typical cavernicolous insect.

Note the development of the feelers.

Special adaptations are also caused by the frequenting of water. Apart from amphibians, birds and mammals are attracted by the abundance of food in the shore waters of lakes and at the sides of rivers.

The beaks of birds are modified according to whether their food consists of fish, worms, or larvae and insects that live in the mud. There is the long bill of the crane and stork, the blade-shaped beak of the white spoonbill, the curved bill of the avocet, and the cormorant's chin-bag, which enables the bird to store up temporarily fish that has been swallowed rapidly. The legs are sometimes lengthened, as in the flamingo, the heron, the crane, and the stork, to enable the bird to wade further out in the water; or else a membrane connecting the toes makes the feet capable of being used as paddles. Such birds are web-footed or palmiped. Mammals which live in water are for the most part insectivores or rodents. They all have very thick fur which keeps water out. Their feet are more or less adapted for swimming, according as the animal's habits are more or less strictly aquatic. In the musk-rat and the beaver the hind feet are webbed like those of the water-fowl. Only one ungulate, the hippopotamus, is adapted to an aquatic life. Its hide is impenetrable to water, and its head is modified somewhat after the manner of marine mammals, i.e., with small external parts to the ears, and with eyes and nostrils moved to the upper part of the skull.

Arboreal habits also produce in mammals modifications which enable them to climb, run quickly along branches, hang from boughs, and jump from one tree to another.

The toes are long, with an opposable great toe or thumb. The tail itself becomes prehensile in platyrhine monkeys and in Lemuridæ. The limbs, and especially the forearm, are lengthened (see Fig. 95). Certain animals, like the flying squirrel and flying lemur (*Galeopithecus*, see Fig. 96), have a membrane stretching across from the forearm to the trunk, which forms a sort of parachute and holds up the animal as it leaps from one bough to the other.

FIG. 95.—The orang-utan. A typical arboreal ape.

Note the length of the arms, the use of the foot for grasping, and the opposable thumbs.

The air may also be regarded as a biological environment. Bats are mammals adapted to flight by the development of membranes between the trunk and the feet, the digits of which are elongated. But the real inhabitants of the air are the birds, with their light bones, their prominent breast-bone, and their powerful flight, which enables them to maintain a speed of sixty miles an hour for a whole day. Freed by this power from the ocean barriers which restrict the expansion of land species, they play a special part in animal life, appearing successively in the most widely separated climatic regions. Yet there are some birds which are not migratory. Some have lost the power of flight and have undeveloped wings; e.g., the ostrich, cassowary, and Apteryx.

To sum up, it is possible to distinguish very marked biological types in land fauna; and the grouping of types determines the character of the main zoological regions which are closely connected with the vegetation—itself depending on climate—and with the distribution of land and water.

The Fauna of the Forest and Steppe in Africa. Let us turn once more to Africa to study an example of associations of animals in the hot belt. All zoologists notice the contrast between the fauna of the forest and that of treeless regions such as savanas, steppes, and deserts. In the equatorial virgin forest, and even in tropical forests, food is always plentiful. The branches and foliage are inhabited by numbers of insects, while the warm, damp earth swarms with life. The shores of lakes, the borders of marshes, and the banks of great rivers are equally rich in insects, worms, and various kinds of larvae. Hence, food is assured at every season throughout the region and there is no need for migration. Besides, movement is difficult on the ground. This is what gives the traveller in the virgin forest the impression of death-like stillness, for no bird sings and none of the herbivorous animals which animate the treeless regions are to be seen.

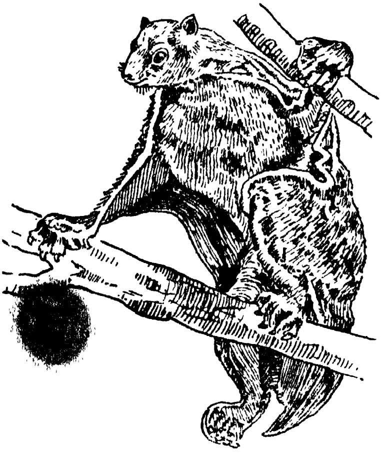

FIG. 96.—Galeopitheca: a typical arboreal lemurian.

The zoologist notices the absence of antelopes and of the cervine family in general, and the amazing abundance of arboreal forms of life, such as anthropoid apes like the gorilla and chimpanzee, special types of Lemuridae like the *Pterodictus*, flying squirrels (*Anomalurus*), fruit-eating birds (*Musophagidae*), and large parrots with scarlet crests like the *Psittacus erythaceus*). Snakes and even amphibians (e.g., *Hylumbatis*) sometimes adapt themselves to arboreal life. The waters are frequented by a special group of large fisher birds (e.g., *Baloeniceps*), of snakes, and tortoises, and there is an insectivorous animal with the habits of the otter and a very strong tail used in swimming (*Potamogale ferox*). Finally, a huge pachyderm—the hippopatomus—lives constantly in the water.

The fauna of the treeless regions is quite different. In the dry season, the grass, the leaves of trees, and a great number of the worms and insects, all disappear. But nomadic habits are easily developed by animals capable of rapid movement in search of food. Hence, on the borders of the forest where the arboreal fauna disappears and the number of animals living in or near water diminishes, there come into existence a multitude of swift herbivores, with slender, sinewy legs and an elongated neck and skull, like the antelope and the giraffe. These animals are all the swifter because they are obliged to depend on their speed to escape from the dreaded beasts of prey, of which the lion and the hyena are examples.

There are also insectivores, like the scaly ant-eater, for the hot, rainy season breeds a swarm of creatures on the ground, on the plants, and in the air. There are also rodents which live underground and sally forth at night so as to escape the beasts of prey. They progress by rapid bounds, thanks to the strength of their hindlegs (e.g., the *Hilamys*). Apart from the birds of passage which come from the temperate belt in winter, the feathered species live on the ground and feed on lizards and snakes, as the secretary-bird does, on insects or even on small rodents. After a time they lose the habit of flight. The ostrich has strong legs and undeveloped wings.

A certain number of animals live more particularly in the zone of transition between the forest and the savana. Such, for instance, are the elephant, which penetrates some distance into the virgin forest, the giraffe, and the big cats. Others, on the contrary, prefer the dryer regions, as, for example, the antelopes. Some, like the camel, are specially adapted to desert life. In fine, the distinction between the forest and the open country is a striking fact in African fauna. In the forest, animals are arboreal and aquatic and almost tied to one small area; in the plains, they are specialised to their environment and are migratory. Monkeys are the characteristic type in the former, antelopes in the later. Nevertheless, the two associations have some features in common, owing to the similarity of the conditions of temperature, viz., abundance of life in the earth and of reptiles, and the presence among mammals of giant forms, such as elephants, hippotami, and giraffes, which are unknown in the temperate belt and call to mind the fauna of bygone geological ages, of which they are survivals.

Variety of Fauna in Hot Climates. The same characteristics are also found in other continents, but in a modified form when these lands have long been isolated or when they are less extensive.

In South America, where the forest is more extensive than in Africa, the fauna of the forest is far richer in species. Monkeys are plentiful, but they belong to a different group, showing differences in the nose, in their prehensile tail, and, generally speaking, in their smaller size (e.g., the sapajou and the marmoset). Lemuridae are absent; but there is an amazing variety of brilliantly coloured birds, like the humming bird, and others which live on insects, like the fly-catcher. Innumerable ants swarm on the ground and in the trees, forming the food of arboreal edentates, like the ant-eater, which has a long, rough-en[illegible]ngue and powerful claws.

[illegible]a is another region where forest life contains some most peculiar species. There are large apes, like the Orang-utan of Borneo (see Fig. 95), flying Lemuridae (see Fig. 96), flying frogs, like the *Rhacophora* of New Guinea, whose interdigital membranes form a sort of parachute. Australia, which has been isolated since the cretaceous period, has preserved families of mammals, marsupials and monotremes, which up to that time had inhabited the Old World. The best known of these is a giant leaper, the kangaroo. Madagascar and New Zealand have a still poorer and more archaic fauna. In the first there are Lemuridae and arboreal insectivores, which have survived owing to the absence of monkeys and great beasts of prey; and in the second wingless birds like the kiwi or Apteryx, which still survives, and the *Dinornis*, or moa, and the *Miornis*, which have only recently become extinct.

Fauna of the Forest and Steppe in the Temperate Belt. The same methods of study may be applied to the temperate belt. Generally speaking, there is less distinction between the forest—which is here less dense than in the hot belt—and the open country. Herbivores like the stag and the buck, as well as carnivores like the wolf and the fox, frequent the woodland glades. Many birds nest in the woods, but seek their food elsewhere. The strictly arboreal fauna comprises hardly more than insectivorous birds like the woodpecker, fruit-eaters, and rodents, like the squirrel, which are sometimes adapted for flight (e.g., the *Pteromys*). Other arboreals are the wild cat and other little carnivorous bird-hunters like the marten and the pole-cat, and finally the bear, which is generally herbivorous, but is occasionally carnivorous. Aquatic fauna abounds in the form of birds like the heron, crane, and stork, and even of fishing mammals like the otter, and of rodents like the beaver.

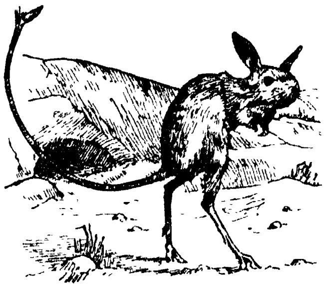

FIG. 97.—The Jerboa (*Dipus gerboa*), a burrowing rodent of the steppes of the Old World.

The fauna of the steppes is comparatively richer. Drought is not the only danger, for there is also the cold of winter, which causes the vegetation to disappear and with it the little invertebrates, and which forces the mammals either to migrate or to hibernate. Burrowing rodents, it is true, find a fairly plentiful food supply in plant bulbs. Their burrows pierce the surface of plains and steppes. The characteristics of the burrower and of the leaper are best observed in the ground squirrel and the jerboa of the steppes of Russia and Asia. Even birds take to the ground, nesting there and assuming its colour, as the partridge does. They feed on insects, especially beetles, and pursue their victims on their well-developed legs. Herbivorous mammals which live in herds are less varied and less numerous than in tropical grasslands. The common features which differentiate this association from that of the hot belt are the absence or scarcity of monkeys, the presence of bears, which are unknown in Africa and are rare elsewhere, the universal habit of hibernation or migration, and, finally, the poverty of types and in particular the absence of giant forms.

Most of this fauna must have come into existence to the north of the region it now occupies and at a time when the mean temperature was higher than at present, for the relative uniformity of temperate fauna is to be explained by its passing from continent to continent at the points where the land masses are close together. Man's influence has increased this uniformity still more by the diffusion of domestic animals, like the horse, the ox, the sheep, and the pig. The spread of cultivation has given rise to a host of fruit and grain-eating birds which plunder orchards and fields, and of rodents, like the rat, the mouse, and the vole, which haunt fields and houses.

The Arctic Region. The uniformity of the frigid zone, where the continents all touch each other round the North Pole, is even greater. The soil is frozen over a great part of the year, and the temperature is below 32° F. for nine, ten or even eleven months. Cold-blooded animals, i.e., amphibians and reptiles, are therefore strictly excluded. Short-lived invertebrates multiply to an extreme degree during the mild season; for instant, 402 species of butterfly are known in Iceland. Mosquitoes make the interior of Labrador quite uninhabitable, and their swarms on the forest limit help to drive the Samoyedes of Siberia northwards in summer with their reindeer. Warm-blooded animals do not hibernate, because the cold is too great; but they are covered with thick fur which, in the small animals, is very fine and close growing, but is coarse in the larger types, like the muskox. During the mild season, herbivores like the muskox and reindeer, which live in herds and migrate according to the season, frequently accumulate a store of fat for use during the winter. Rodents like the lemming, on the other hand, form densely populated colonies in underground warrens, from which the surplus population is sometimes obliged to emigrate in large bands to new burrows in the forest zone. They naturally form the prey of the carnivores, the ermine, the fox, and the Artic hare,[1] whose existence indeed depends entirely on them. Certain birds, such as the Arctic owl (*Stryx nyctea*), prey on them also. All these animals and birds have assumed the white colouring of their surroundings.

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[1] The Arctic hare is not regarded by zoologists generally as carnivorous. But there is still some uncertainty on the subject.

Islands and coastal districts also have special associations. There are no herbivores or rodents or the natural enemies of these. The polar bear, which avoids the mainland and lives by fishing, advances across the ice to the extreme northern limit of life. But the characteristic feature is the extreme abundance of birds, chief among which are sea-birds, whether fishers, swimmers, or plungers, such as the eider duck, the gull, the barnacle goose, etc. A large number of birds of passage also come to these remote areas to seek shelter for breeding purposes. The cliffs are sometimes literally covered with nesting birds. On the shore, flocks of penguins afford a striking spectacle to travellers. Polar fauna is, therefore, far from being as poor as might be expected from the severity of the climate, but it is remarkably uniform.

CHAPTER XXI

MAN AND NATURE

Influence of Environment. More than once in the course of this work the influence of various phenomena of physical geography on human life has been pointed out The influence of climate is one of those most frequently mentioned. It has been shown that the most densely populated regions lie within the temperate belt and in certain areas which have a monsoon climate; that the hottest and the coldest regions are more or less given up to desert; and that the highest forms of civilisation and the centres of economic development are becoming more and more localised in the subdivision of the temperate belt which has a definite winter, i.e., Europe and the United States. Certain races are restricted to certain climates. Thus, the European cannot really become acclimatised in the hot belt, for he feels the want of a cold season. Moreover, certain physical or psychic characteristics in races seem to have some connexion with certain peculiarities in the temperature or rainfall of the districts in which they live. Drought, for instance, seems to act as a tonic on the nervous system, making the people of the steppes and of the deserts always more active and enterprising than those of the damp equatorial regions. Through its influence on vegetation, climate controls economic life. Variations in rainfall from one year to another have an effect on the returns of cereal crops in the United States and Eastern Europe and hence on the quantity of goods which can be imported from other countries, while an attempt has been made to formulate the connexion between rainfall and the value of the cane-sugar crops in the West Indies.

Winds also play a part in human life, as is clearly shown by the local names given to them in various places. No one can imagine Provence without the mistral, Dalmatia without the bora, or Italy without the sirocco. In the Alps the föhn, like the chinook in the Rockies, melts the snow and adds several weeks to the summer, to the great benefit of crops and pasture lands. The monsoon enabled a precocious development of trade to take place on the coasts of the Indian Ocean, and bore the Arabs and Hovas as far south as Madagascar.

The sea is not less important to human life. Bound to the land by his physical nature, man nevertheless felt the influence of the ocean long before he succeeded in venturing upon it or in crossing it. Warm currents have made the eastern shores of the oceans habitable right up to the Arctic Circle. The Gulf Stream has created Norway. By keeping estuaries free from silt, tides have caused the growth of the ports of London, Liverpool, Glasgow, Hamburg, Bremen and Bordeaux, at points where tidal effect can be felt. Even on dry land man remains a slave to water. In regions of drought, whether desert or steppe, his habitations are restricted to such places as contain springs or to areas where the underground water supply is near enough to the surface to be tapped. Even in the damp temperate zone, the position of villages is often determined by the lines of springs on the hillsides, as is the case in the Paris district. There is no need to labour the part played by rivers, those " moving roads," or the advantages they afford—more or less according to their systems—for transport and irrigation. The Mississippi has had great influence in the development of the United States, just as " little mother Volga " has had in Russia, while Egypt has been said to be the gift of the Nile.

The influence of relief is one of the most striking. It has been touched on in the discussion of local areas and in the interpretation of topographical maps. Nowhere is it more evident, more predominant, or more varied than in lofty mountain regions. If one ascends a great Alpine valley to its head, preferably on the ground or, if this is impossible, on a good map, one notices a whole series of topographical positions which attract human habitation and others which seem to repel it. All the details of glacial topography which we have learnt to recognise are reflected in the position of hamlets and cultivated areas. The steep sides of a glacial trough, the gorges which cut through the ridge dividing basins in a glacial bed or the terraces formed at a confluence, and the sites of great rock falls are avoided. The shoulders which occur above the glacial trough, the many level stretches found on the slopes of large valleys, and the edges of the terraces of hanging valleys are sought after. So also are alluvial fans, each of which, as we have seen in Valais, has a more or less important village according to the size of the catchment basin of its torrent. Terraces and moraines, especially those of the previous ice age, are densely inhabited on the fringes of a mountain region. Generally speaking, man seems to prefer comparatively gentle slopes on which he can more easily construct his dwelling, cultivate his fields and meadows, and build his roads, while he appears to avoid steep slopes which are liable to contain gullies and are exposed to falls of rock. But in mountainous districts he sometimes prefers a slope to the level ground, when the slope has a good aspect and when it rises above the zone of mist and cold in the valley bottom.

Even away from mountain regions, the influence of relief is always felt. In hilly districts, we have seen how outliers and projecting spurs of plateau borders, which have been denuded, are crowned with castles or ancient churches ; we have noticed the villages which line the foot of the escarpment, as in the classic instance of Lorraine, and the attraction of subsequent valleys. Volcanic areas abound in attractive sites, and mansions and churches forming a nucleus for a village are perched on necks or on the remains of lava streams. Recent volcanoes like Vesuvius are encircled with villages (see Fig. 56). The rich nomenclature of coastal features existing in the language of maritime nations like the Scandinavians or the English proves how important coastal topography is to man. We have already noticed the advantages afforded as a whole by youthful coastlines, which are more indented and contain a greater number of natural harbours than older ones. Ria and fjord coasts are among the most thickly populated.

The influence of the plants and animals is still more evident than any other. From them man gets his food, clothes, tools, and some of his means of transport. The relations noted above between climate and the distribution of the human race cannot be wholly explained without the help of botanical geography. The almost complete absence of man from the coldest and the hottest, the driest and the wettest, regions is largely due to the lack of facilities for securing food and for moving about.

Human Geography in its Relation to Biogeography. In dealing with this subject we are faced with complex relations which require complete analysis in order to be understood. If we are to derive any real benefit from our observations of the relation between physical and human geography, we must endeavour to form a clear idea of the value of this relation. When the unfailing nature and the almost inevitable character of some of the relations are considered, we are led to regard human geography as a chapter of biogeography. Let us take this instructive point of view and see where it leads us.

Like all other animals, the human species is endowed with a power of dispersion which is opposed not only by the unfavourable circumstances of the physical environment, but also by the struggle for existence with other species. Moreover, this power varies with race, though every race is subject to the same physical laws. Man also forms associations whose characteristics are more or less strictly adapted to physical and biological conditions. The great difference between man and other animals lies in his intelligence, which enables him to react more quickly to the influence of his surroundings and to discover a thousand ways of adapting himself to the most unfavourable circumstances. The best way of illustrating this is to describe shortly a few instances of human life in extremely different circumstances. There are fixed limits to man's power of dispersion, and these are determined by the distribution of land and water, of climate, and of vegetation. Though he has acquired the power of crossing the widest oceans, man is none the less tied to the dry land. The seas, lakes, and marshes are complete deserts. So also are the regions of eternal snow in mountains and near the poles. Vast forests are almost uninhabited, and the equatorial *silvas* are as hostile to man as the deserts under the tropics. Yet a few men dwell on the frozen coasts of North America and Greenland, while others manage to exist in the depths of the virgin forests of the Congo basin, and even in the Sahara.

Human Life in the Arctic. The Eskimos inhabit the western coast of Greenland as far north as Lat. 78°. In these parts the mean annual temperature is as low as 14° F., and the mean July temperature hardly reaches 41° F. In summer the sun is pale and remains above the horizon for many days together, while in winter the land is plunged into night for more than a month. The soil is frozen almost throughout the year and is covered with snow for eight or nine months. A few kinds of mosses and a greeny-grey lichen appear in summer. Vast glaciers which descend to the sea leave uncovered only a narrow fringe of coast. The shores are steep and bounded by a sea which is frozen nearly all the year or dotted with floating ice.

The Eskimos who live in this region of difficulty are as perfectly adapted to it as is possible. As a protection against the cold they wear fur garments, which are so suitable that explorers have found nothing better for the purpose. In winter they live together in large huts made of stones, wood, or whalebone, and covered over first with skins, then with snow. The interior is partly underground and is reached through a long, narrow passage. In summer, on the other hand, each family lives separately in a conical tent formed of skins stretched over poles and held in place by large stones. The difficulties caused by environment are due less to the cold than to the scarcity of food. The vegetation provides little or nothing, and the Eskimo lives by hunting and fishing. He is forced to eat large quantities and to assimilate a great deal of fat in order to resist the cold. His favourite quarry is the seal, and his dwelling places are restricted to localities where that animal occurs. Other causes hold him to the coast. The sea casts up the driftwood with which he builds his tent and perhaps his winter house, fashions his bow and his sledge, his javelin and his harpoon. From the same element comes the whalebone with which he builds or strengthens his sledge and sometimes his bow. In fact, his whole equipment, to the very arrow-heads of fishbone, are derived from the sea. His clothes are often of sealskin, his waterproof hood being made of gut obtained from the same animal. Sealskin also covers his fragile *kayak*, which is a sort of canoe in which the hunter dares to face even whales, and the *uniak*, or larger boat, which bears the whole family and its tent to its summer quarters.

In spite of their wonderful ingenuity, the Eskimos are barely able to support life. Their number, reckoned from the eastern extremity of Asia eastwards to Labrador and Greenland, has been calculated at 600,000 at the very most. Traces of abandoned settlements in the north show that they have retreated south. Violent deaths from accidents either in the course of hunting or during risky fishing expeditions account for 10 per cent of the death-rate. Children often die in infancy, and old people are rare. A late or too sudden thaw causes a famine, and decimates the population which had increased during a short series of good years. After being isolated for centuries from the rest of humanity, the Eskimo is at last feeling the effects of the approach of European civilisation. The appearance of whalers has thinned out his hunting grounds and made his existence even more precarious. The rifle has made hunting easier for him, but the advantages thus gained are perhaps counterbalanced by the ravages due to the introduction of alcohol.

This description of the Eskimo shows that man, like other mammals, is checked less by cold than by the difficulty of procuring food. In regions of the greatest difficulty, the social group makes existence possible by means of a strict adaptation of its mode of life. Isolation helps to preserve scattered groups, while the progress of civilisation threatens their existence.

Life in the Equatorial Forest. Heat, no less than cold, is man's enemy, whether when in combination with great humidity it gives rise to luxuriant vegetation or whether, when allied with drought, it causes the evaporation of all water from the surface. Life in the equatorial forests of Africa is difficult and full of hardships. Damp, oppressive heat constantly prevails, and torrents of rain fall every afternoon during most of the year. The sky is for ever veiled with mist or cloud, and it can indeed rarely be seen. From the tops of the lofty trees, which rise to 130 or 160 feet, right down to the ground the vegetation forms a solid mass cemented together by the lianas which pass from tree to tree. Nor is there any change in its appearance, or a season in which the leaves fall. The view is always shut in on every side, and it is difficult to move about. The ground swarms with noxious insects, which devour one's clothes and other belongings. Numbers of them attack man, some of them lodging under his skin and producing swellings. Mosquitoes spread sleeping sickness, while big animals, like elephants and hippopotami, and monkeys are dreaded on account of the ravages they commit on growing crops.

Man lives in little groups which are completely isolated from each other. The negritoes or pygmies belong to a race which is greatly different from all others. They are of short stature, varying between 4 feet 5 inches and 4 feet 11 inches in height, and have short legs, powerful bodies, and fairly long arms. Armed with bows and poisoned arrows, they seek their food by hunting, and have no knowledge of domesticated animals or of agriculture. Completely naked, they sleep in the open air and take shelter only from the torrential rains in small, low huts made of palm leaves. Their camps, which are placed in clearings formed naturally by the fall of some old trees, are frequently changed. Savage and distrustful, they scatter like a flight of birds at the least alarm.

A few negroes who are not so different from the other native races of Africa have penetrated into the forest. They also live in small, scattered groups, usually on the banks of a river where the stream enables them to move about, and build their villages on the bank of sand which separates the main channel of the stream from the belt of flood plain. Their quadrangular huts are made of leaves placed on a framework of palm stalks. The banana tree affords easily procurable food, and to this are added a few roots and some beans cultivated by the women. The number of domestic utensils is extremely small and are all derived from the vegetable kingdom. So also are their weapons, even their bowstring being a plant-fibre. Stock-breeding is unknown, the only domestic animals being dogs, a few goats and some fowls.

In this forest region the most widespread ideas of the human race are unknown. There is no measurement of time, no calculation of seasons or years, since the sky is always hidden by the green foliage or the mist, and even the phases of the moon have escaped notice. The main idea is to eat, and cannibalism is sometimes caused by the need of food. Amidst an amazing luxuriance of life, the negro is always hungry, for his wretched crops are threatened by voracious insects and not only by the caprices of monkeys, elephants, or hippopotami, but also by torrential rains. The mortality is enormous, and the population, far from increasing, can barely hold its own. The percentage of survivors is nothing like 50, except among those between the ages of 20 and 30. It is almost unheard of for anyone to pass the age of 50, for the aged, as well as delicate children, are often put to death.

Life in the equatorial forest, then, is not unlike the conditions in the far north. Man exists with difficulty in surroundings not made for him, and, oppressed by the hot, damp climate, he shows less ingenuity in taking advantage of the resources which are at his disposal.

Life in the Sahara. The conditions of life in the Sahara are better known, and a few words will suffice to sum them up. Nomadism is the most important feature. Water is found at a few places only and the stock of it is soon exhausted. An occasional shower may bring up some vegetation in a wadi and may even make some cultivation possible. Hence, men flock from afar to take advantage of this windfall, which will not occur again for some time. For the most part, however, the desert dweller's food is exclusively animal. Goats and sheep provide milk, and sometimes meat, but the most valuable domestic animal is the camel, which gives milk and serves as a beast of burden. Thanks to it, the Bedouin can cross the *erg* or the *hamada*, carrying stores of water, tents and domestic utensils—which last are few, however. Whatever is missing from the food supply is obtained, usually by force, from the settled inhabitants of the oases. The nomad is naturally warlike and is more or less of a brigand.

The mobility imposed upon him by his surroundings develops in him initiative and a sense of independence. Just as the equatorial forest is an isolated world, so the desert is open to commerce, to ideas, and to inventions. The rifle has found its way into every corner of the Sahara and helps to maintain the ascendancy of the nomad, who pillages oases and caravans. The Tuaregs of the Western Sahara are the most perfect type of the nomad of the hot deserts. Their strong, delicate features and their chivalrous spirit of adventure have often been described. But they number very few, and the tribes which centre about Muidir Ahnet do not contain 300 families.

The desert is somewhat like the sea in that they are both spaces which can be crossed, but in which man can only dwell on the oases or islands.

Distribution and Differentiation of the Human Race. The cases just considered enable certain conclusions to be drawn with respect to the absolute and relative limits within which the human race is confined geographically. The absolute limits are fixed by the great expanses of water, whether oceans, seas, or lakes, and by the areas of eternal snow either at the poles or on lofty mountain regions. Man can subsist everywhere else; but, in spite of marvellous efforts of ingenuity and a ready adaptation of life to the environment he can barely exist in sporadic groups on the polar tundras, in hot deserts, and in equatorial forests. In fact, more than half the earth is nearly or wholly devoid of inhabitants.

A map showing density of population throughout the world (see Fig. 98) indicates the discontinuity of man's habitat. The densely peopled areas are merely spots appearing here and there, and separated by areas which are relatively sparsely inhabited, and which correspond to the mountainous regions, the deserts, and great forests. The position of these densely peopled areas is not without significance. Although man is able to subsist on a meat diet in areas from which vegetation is absent, he can form compact societies only in such places as afford abundant food; and such plenty is only afforded by grasslands, either directly through the cultivation of cereals or indirectly through stock-rearing. The inhabited areas lie in parts where the forest, though not entirely absent, does not take entire possession of the ground; that is, in the savanas and parklands under a normal tropical or monsoon climate, where millet and rice grow freely, and in the Mediterranean region and its adjacent zone, where the oak grows more or less abundantly and where wheat and maize will thrive.

This discontinuity in the areas of dense population lies at the bottom of the formation of races. Intercommunication between the areas has always existed, but was formerly far more rare than it is to-day. The improvement of transport by land and sea has now united the human race into a single unit, and the result is that communities which have hitherto been isolated in regions of difficulty and consequently have survived, such as the Eskimos of the polar regions and the negritoes of the equatorial, are now threatened with extermination owing to contact with what we call civilisation. So also are the natives of the Pacific Islands. And a similar fate threatens animal species which have hitherto been preserved in islands and sheltered from the struggle for the survival of the fittest.

There has been much discussion over the question of whether the human species has sprung from a single stock. Whatever view is taken of this probably insoluble problem, the relations between the human population and physical geography show that groups of men have been practically isolated for ages. The mingling of races has resulted from migration along zones which have nearly the same physical conditions and relative density of population, i.e., the grasslands of the temperate and tropical belts. Certain climatic features continue to present impassable barriers to the mingling of certain races. The white man cannot become acclimatised in lands south of the tropical deserts, nor has he, until recently, crossed these deserts for thousands of centuries. The black man, when transplanted to the north of the same zone, which he would probably never have crossed if left to himself, can only hold his ground in a few of the big towns in the United States, where the losses due to disease are replaced by immigration due to the allurement of high wages.

Characteristics of Social Groups. We have also seen in the cases we have examined above how man, even in regions of the greatest difficulty, forms communities which adapt their mode of life to the natural conditions. The characteristics of these

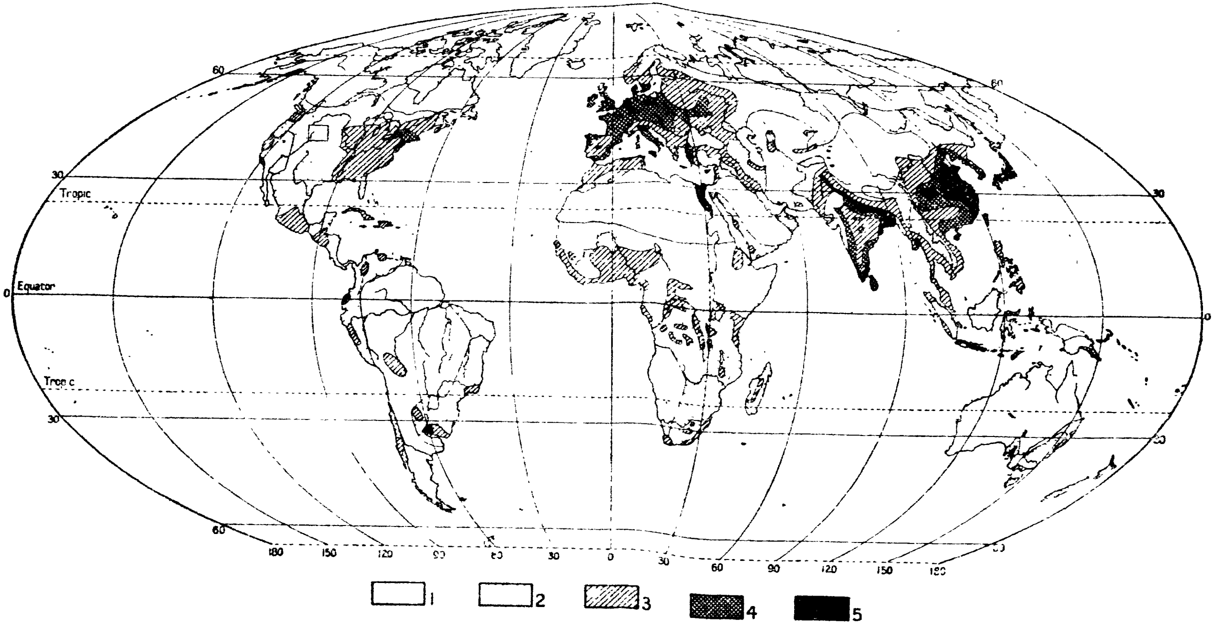

Fig 98.—Density of population. (After Vidal de la Blache, *Principes de géographie humaine*, pt. I.)

1 = less than 1 person to the square kilometre; 2 = between 1 and 10 persons to the square kilometre; 3 = between 10 and 50 persons; 4 = between 50 and 100 persons; 5 = more than 100 persons to the square kilometre.

social groups are not all directly due to physical geography. One of the most important is *density*. We have just considered this feature in its relation to vegetation. Its study is one of the most interesting parts of human geography, when good maps and reliable statistics are available, and shows more clearly than any other the influence of physical geography. But one has merely to think of the over-populated industrial areas in England and in the North of France and of the fertile plains in the French province of Beauce and in some parts of England where the population is decreasing, to realise that one must pay even more attention to the social and economic position, which is liable to rapid changes during certain historical periods.

The *method of grouping* and the *form of habitation* are also an important feature in the appearance of social groups. The countryside in parts of Wales, in Ireland, and in Brittany *with its scattered homesteads, has an utterly different appearance* from the countryside of East Anglia or Lorraine, where the houses cluster in villages. The system of scattered homesteads is favoured by the abundance of springs in a region of impermeable soil, but is difficult where the soil is permeable. But other considerations intervene to fix the limits of these two types of human habitation, among which are racial and social conditions. The form of habitation often shows in its materials and internal arrangement a definite dependence on the physical environment. We have already mentioned the use of palm leaves for building huts in equatorial forests, of skins for tents among nomadic tribes, and the partly subterranean dwelling of the Eskimo. Geography abounds in similar examples. Even in Europe, the presence or absence of stone, the abundance or scarcity of wood, have an influence on architecture in country villages. But social or economic changes, involving the extensive use of bricks, of zinc roofing, etc., are daily modifying the influence of primary factors.

Race is another important characteristic in the formation of social groups. Racial purity is found only in the scattered groups living in isolation in the almost uninhabited wastes like those which we have considered above. In the areas of dense population there is usually a great mixture of races, and this is true of Europe as well as of China or India. Hence, in most cases the environment does not mould the race. Racial admixture, of which certain traces can at times be found, has occurred almost everywhere.

Mode of life is generally closely connected with climate and biological environment. Methods of obtaining food influence the social and material condition of the communities in a variety of ways. We have seen how the Eskimo succeeds in living by hunting or fishing, how the negrito can do without agriculture and domestic animals, how the nomad of the desert gets his food from the animal he rides, eking it out with the produce of the chase and, if need be, with plunder. It is important that this part of the subject should be dwelt on further, for the relations between human and physical geography are more evident here than elsewhere. Let us extend our field of observation a little and describe by way of example two great regions which present extremely different conditions, equatorial and tropical Africa on the one hand and Central Europe on the other.

Mode of Life in Tropical and Equatorial Africa. We already have some ideas about social grouping in the equatorial forest. The density of population and the characteristics of the people change in the region of forest galleries. Pygmies do not appear out of the dense forest. Negroes who also live within its bounds have a less primitive civilisation, more varied forms of cultivation, and some domestic animals, like the dog, goat, and fowl. But still theirs is a forest community. If we plot on the map the area in which bow, shield, clothes, and other useful belongings are made of vegetable matter, and the limits within which are found the square hut evolved from the palm leaf shanty and the food supply obtained by collection, we shall mark more or less accurately the area over which this type of civilisation prevails (see Fig. 99), and we shall see that the civilisation belongs to a climatic region rather than to a racial group.

This first civilisation differs from that of the great open spaces of savana and steppe-land which stretch over the Senegalese and Sudanese climatic belts, both north and south of the equator, and over the East African plateau which, thanks to the configuration of the continent, joins the two belts in the region of the Great Lakes. In this area the needs of human life are supplied chiefly from the animal kingdom. Skins are used as clothes wherever the cotton stuffs imported by Arab trade have not penetrated. The bowstring is made of gut, the shield is covered with leather or raw hide. Cereals become the basis of agriculture, and real cultivation takes the place of mere collection or of unsystematic planting. The greater production of food enables the density of the population to be greater. But the area under cultivation is restricted to the most fertile and most easily worked soil, for the plough is unknown and the earth is only slightly scratched with a hoe. The number of domestic animals is far greater, and ruminants, which naturally dwell in the region, are added to the goats and fowls. Numerous herds of horned cattle and sheep satisfy nearly all human wants by yielding milk, and occasionally meat for food, and their hides for use as clothing or for the manufacture of weapons and other articles.

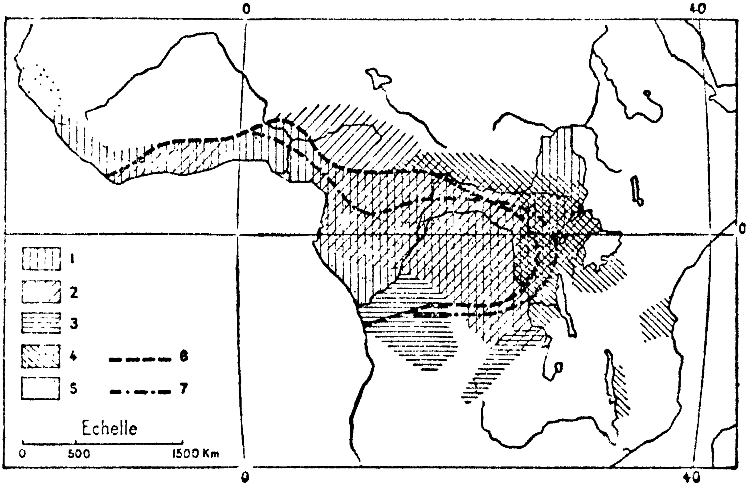

FIG. 99.—Traces of forest civilisation in Africa. (After Frobenius.)

1, area in which use is made of the bow with a string of vegetable matter ; 2, of the shield made of reeds ; 3, of garments of palm fibres ; 4, of bark clothing ; 5, of tatooing ; 6, limits of the square hut ; 7, limits of the area within which the banana is the main article of food.

Thus, in the open spaces two opposing modes of life are developed and sometimes combined. The agriculturist who produces cereals leads a sedentary life and tends to live in villages of some size. His house is comparatively roomy, and each village contains its communal edifice of great size, which is used for assemblies. There is a rudimentary social life, but its bonds do not extend beyond the limits of the village. Stock-breeding is always associated with agriculture. But when it is the chief or almost the sole means of subsistence, the communities are smaller and more mobile. Thus, in the Kir district near the confluence of the Bahr-el-Ghazal and the Nile, the Dinkas migrate according to the season from the plains above down to the edge of the marshy country. More extensive migrations occur on the plain of the Shari. The herdsman is usually better armed and more warlike than the agriculturist. He is induced to obtain what he lacks, either by trade or by force, from the sedentary tribes. Among his mobile clans arise the chiefs who succeed in extending their authority over comparatively numerous masses of people and in founding veritable empires by subjugating the agricultural tribes. The whole history of the Sudan is one of the repeated rise and fall of such primitive states, owing to pressure which always comes from the east or north-east.

Just as the forest region is one of life in a restricted area, so this region of savanas is one of movement and intermixture. Here the races become mixed in the ceaseless swirl of migration, and in attempting to classify them no less attention should be paid to migrations which are known to have occurred than to anthropological or social features. We have already described the life in the desert. One new fact, however, is the appearance of the plough in the cultivated spots in the oases of the Northern Sahara. This instrument brings about a revolution in the value of land. Drawn by the ox, it breaks up the earth and allows the growth of nutritive plants or textiles over vast areas. Though first used in grasslands, it has spread over the temperate zone, giving agriculture a new character and complicating the mode of life more and more.

Mode of Life in Central Europe. Such are the various climatic influences which affect the mode of life in Africa indirectly through the vegetation. In Central Europe the climate is governed by the marked relief. The Alps, the Carpathians, and the block mountains of the Hercynian region form the boundaries of warm, dry plains, whilst their own slopes are colder and damper. Forests and grasslands form, not zones, but disconnected areas. We know that man has increased the area free from trees, especially at the expense of deciduous species, and we are informed by Roman historians of the circumstances existing at a time not more than twenty centuries ago when the human grouping and the mode of life differed profoundly from what they are to-day. The forests were of greater extent, especially in Germany, and agriculture was a primitive affair. Political groups were scarcely more important than they are in tropical Africa, and were defined by the limits of spaces which were naturally open, though perhaps somewhat widened by man. The cultivation of cereals on a considerable scale did not go beyond the Mediterranean coasts, and consequently urban life, areas of dense population, and the higher forms of social and political life were restricted to that margin. The invasions which marked the beginning of the Christian era brought about a great mixture of races, close contact between groups which had different modes of life, and the foundation of empires extending over wide areas and spreading both the ideas and the material benefits of civilisation. Here one is faced with such complex reactions that it seems difficult to discover the influence of environment, which is‘ nevertheless, at work (see Fig. 100).

In Central Europe cereals form the basis of diet. The soil is turned up by the plough, which has been so greatly improved that it enables extremely barren ground to be tilled with the aid of natural or chemical manures. But agriculture on a large scale is restricted to certain types of soil and particularly to areas of silt and *loess*. In such areas the population dwells in villages which lie close together and which for centuries have been practising the same rotation of crops, following a regular routine that binds all members of the community. Such a mode of life is found in Alsace and Lorraine as well as in Saxony and Wurtemberg, etc.

Throughout Central Europe there are numerous herds of

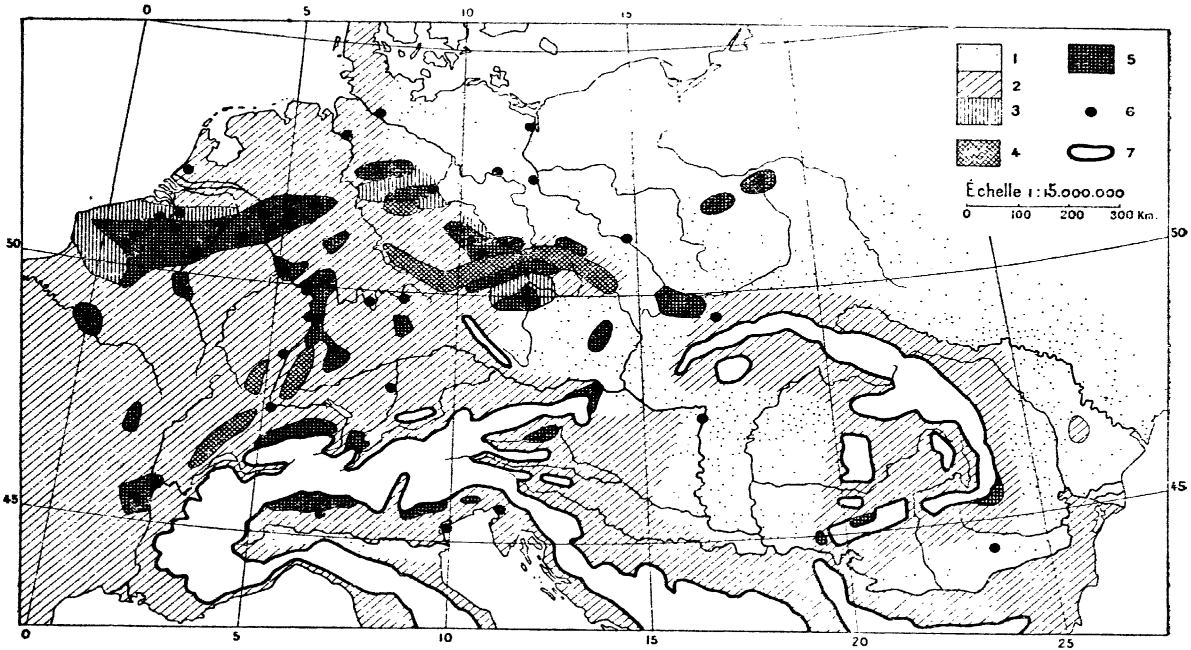

FIG. 100.—Types of life in Central Europe.

1, agricultural areas in which land holdings are extensive, mixed farming is carried on, and population is thin; 2, agricultural areas in which farms are small, cereals the prevailing crop, and in which the population is moderately dense; 3, agricultural areas with small holdings producing crops suitable to industrial areas and with the densest population among the agricultural areas; 4, densely peopled sloping country in which agriculture and industry are mingled; 5, great industrial areas with very dense populations; 6, great towns; 7, mountain regions with pastoral occupations.

domestic animals, horned cattle, sheep, pigs, goats, etc. But cattle-breeding is preferred in damp, broken areas where the population is usually more scattered and where it often happens that the type of scattered homestead prevails, each family retaining its freedom to exploit at will the fields, the meadows and the woods. Property is generally less subdivided in these regions than in those in which cereals are grown. In mountainous districts, especially in the Alps, stock-breeding becomes the principal occupation, and very peculiar types of pastoral life are developed. The herds and flocks, together with all or part of the population, migrate to the hill pastures of the Alps, or back to the plains according to the alternation of the seasons. Even the flocks of sheep are brought down from the mountains in winter to feed on the grass in the valleys below. This practice, known as *transhumance* in the French Alps, is adopted in all mountainous districts bordering on the Mediterranean.

The Danubian plains, which are sufficiently extensive and dry always to have been treeless, have for centuries been largely occupied by steppes or natural grasslands on which insecurity of life and property, no less than climate, seems to have prevented the formation of agricultural communities and which have been ranged over by tribes of herdsmen. Through them have passed various waves of invasion, some of which have remained to settle. The last of these were the Magyars, who settled round the middle Danube. Agricultural life, however, gradually takes possession of these plains, and the cultivation of cereals on a large scale is associated with the breeding of horned cattle to the increasing exclusion of sheep. The villages are large, some growing into veritable country towns with several thousand inhabitants. This mode of life is quite different from that of Lorraine, for instance, where the villages are small, with a few hundred people, and are ancient growths resulting from a long process of evolution. On the one hand there are extensive domains and the exploitation of huge areas by a simple landowner; on the other, small properties and a system of subdivision.

The modes of life found in Europe owe most of their complication to the development of towns and industry. The great city is a complex growth which influences its neighbourhood and causes a modification in the agricultural system to meet the needs of its inhabitants Modern industry which has sprung from the use of coal causes agglomerations of extraordinary density. Its localisation depends on the geological structure. It is established on coalfields, which all lie within the region of the Hercynian block mountains (i.e., the coalfields of Northern France, of Belgium and Westphalia, which are situated on the edge of the schistous *massif* of the Rhine, and those of Saxony and Silesia on the edge of the Bohemian *massif*), or else it springs up near the metalliferous deposits in the same zone. Formerly, industrial conditions were quite different, the work being decentralised and often associated with agriculture. Spinning and weaving were carried on in the ancient villages during the winter periods of leisure, whilst forges were usually established in the neighbourhood of forests whence they drew their fuel. But industry has not yet entirely freed itself from the old connexions. The presence of local skill in manufacture still maintains a number of local centres of industry in Wurtemberg and Thuringia. In certain Alpine cantons (Vorarlberg and Saint-Gall) weaving combined with stock-rearing produces a special mode of life. The use of water power seems on the point of causing an extension of industry in mountainous districts.

collection with a mass

Evolution of Social Groups. The foregoing description will suffice to show to what an extent the mode of life, even in the most advanced societies, reflects the conditions of the environment. If to explain associations of plants and animals it was necessary to take evolution into account, in human geography the historical point of view must necessarily play a greater part. Social groups undergo changes. Their numerical importance, as well as their characteristics, have changed sufficiently during the few centuries of which we have any knowledge to enable us to suspect still greater changes during the prehistoric ages. Consequently, environment does not explain everything. Before its discovery by Europeans, the New World had the same climates, the same belts of vegetation as now. The native population, always small in number, has almost completely disappeared in North America and has been driven out or cross-bred with the invaders in Central and South America. More than 100 million Europeans have settled on the other side of the Atlantic, where they have adopted European modes of life with certain modifications, the significance of which to the world is only now beginning to be understood.

In the Old World, the focus of economic power has moved from the Mediterranean region, when it lay before the Christian era, towards the forest belt containing clearings which have been extended by man. In places where the Romans found only primitive tribes now stand forests of factory chimneys. The transformation of agricultural and rural Germany into an industrial and urban country has been the work of less than a century. Still more amazing are the changes due to the colonisation of remote lands in the southern hemisphere, such as Australia and New Zealand. Moreover, evolution is quickening its step. It proceeds ten times as fast as it did in the first centuries of history and a hundred times as fast as in prehistoric times. The improvement of transport is making the human race into a single unit.

Nevertheless, local differences survive ; indeed, some appear ineffaceable. Such, for instance, are those which have been most deeply imprinted by isolation and which for long centuries in the past were found in almost all social groups and even to-day in some of the communities dwelling in the uttermost bounds of the habitable earth, whether in polar lands or in equatorial forests. Such, too, are those due to veritable paradoxes in the physical characteristics of the environment. Real acclimatisation of the European in equatorial regions seems impossible, except in elevated districts, and the forests of the Amazon and Congo will always remain unfavourable to the growth of population. Cultivation by means of the hoe is likely to persist in the tropics, for in the hot belt the possibilities of agriculture on a large scale are restricted to the savanas, where the most various, the most mobile, and the most advanced social groups are always found. The deserts will always remain deserts from the human point of view, for in them only limited area round the oases can be developed by irrigation. Apparently, the temperate belt will retain the privilege of fostering the centres of population and of the most energetic economic life. The focus may once again shift within the belt, but only within it.

The necessity for studying physical geography in order to understand human geography will now be understood. It is no less necessary than a study of geology is for the interpretation of relief and of meteorology for the comprehension of climatic conditions.

APPENDIX TO PART IV

I. SUGGESTIONS FOR FURTHER READING :—

Throughout this part a knowledge of the elementary principles of the classification and physiology of plants and animals has been assumed. These principles may be learnt from any school text on the subject.

The only general work on plant geography that exists is SCHIMPER'S *Pflanzengeographie auf physiologischer Grundlage* (Jena, 1898, good English translation, Oxford, 1903), but one is in preparation for the Standing Committee for Geography in the Public Schools. Purely regional studies are: TANSLAY: *Types of British Vegetation* (Cambridge, 1912); FLAHAULT: *Projet de carte botanique et forestière de France* (*Annales de Géog. VI*, 1896, page 289); SORRE: *Les Pyrénées Méditerranéennes* (Paris, 1913); CHRIST: *La flore de la Suisse et ses origines* (French translation, Lyon, 1907); and CHUDEAU: *Sahara soudanais* (Paris, 1909).

For zoological geography, DR. M. I. NEWBIGIN'S recent *Animal Geography* (Oxford, 1913) is recommended. A. R. WALLACE'S *Geographical Distribution of Animals* may still be read with profit. For general ideas, see EMM. DE MARTONNE'S *Traité de Géog. Physique*, Part V. (vol. III. of 4th edit.)

Among the numerous works devoted to human geography, J. BRUNHES' *Géographie Humaine* (Paris, 1912), stresses the influence of physical conditions on the material elements of civilisation. DENIKER'S *Races of Man* (Contemporary Science Series, 1900) attempts to take into account more than physical environment. VIDAL DE LA BLACHE'S posthumous work, *Principes de Géog. Humaine* (1922 ; English translation published by Constable, 1926), is a most penetrating study of the subject.

II. PRACTICAL WORK : EXCURSIONS.

In order to verify by personal observation the laws of biogeography a certain amount of knowledge of botany and zoology is necessary. Opportunity for observation will occur during excursions into the country or during a visit to botanical or zoological gardens. The assistance of a naturalist on such occasions will be of great use. In any district, a well chosen walk will bring one to a wood, a field, a meadow, a river, or a lake. These will be enough to enable the different biological characteristics to be seen. In a wood, for instance, find plants which grow in the shade and have very small flowers, like the sanicle (*Sanicula europea*); notice the poverty of the undergrowth in beech woods and the appearance of bracken only where the sun's rays reach the ground through an opening in the foliage above; find some plants that thrive in arid soil, like cow-wheat; observe the trees and shrubs and their associations and note the growth of shrubs with bright flowers on the edge of oakwoods and in glades; e.g., the wild briar, the elder, wild cherry, etc.

In fields and meadows, note the length and brilliance of flowers. Collect a series of plants peculiar to the meadows, e.g., buttercup, pilewort, cardamine, iris, etc., and notice the absence of xerophilous adaptations such as are found in certain plants that grow in fields and by the roadside (e.g., the hairy leaves of the mullein, the leaves and stems of the bugloss, which are covered with prickly hair, and the prickly leaves and stems of the thistle, etc.), and the hygrophilous features, such as soft stems and thin leaves. By the side of a river or lake, many plants that grow on the banks or in the water may be observed. Find the water crowfoot with its two kinds of leaves, one spread out on the surface and one like streamers under water; note the flexibility and fibrous stems of the reeds, sedges and marsh marigolds (*Caltha palustris*).

Do not miss an opportunity of observing the influence of soil. In some places furze, broom, heather, and purple foxglove are strictly limited to silicious sand; in others there are plants which only grow on limestone. Sandy wastes, such as are found here and there near the Cornish coast, afford opportunities of noting xerophilous characteristics due to the aridity of the soil; e.g., the smallness of leaf seen in heather, furze, broom, and the development of thorns, etc. The seaside enables one to make numerous interesting observations. The dunes have a special flora with easily recognisable xerophilous characteristics, such as the leathery, prickly leaves of the thistles, the smallness of leaf in shrubs like the tamarisk, the great development of roots. The xerophilous character of plants growing on saline marsh or on spray-swept cliffs will also be seen; e.g., the fleshy leaves and stem of the glasswort, sea-lavender, and marsh samphire (*Crithmum maritimum*), etc.

To botanical as well as to physical geography mountains offer numerous opportunities for observation. Verify what has been said about aspect, the limit of the forest belt and the characteristics of alpine flora (i.e., reduction of stem, development of flowers, great spread of roots, leaves clinging to the ground, pad-like appearance). A visit to a botanical garden enables one to extend one's observations to exotic regions. Study the fleshy plants of dry regions, the palms, bamboos, and lianas of the tropics, etc.

The seaside will provide the best opportunities for observations in zoological geography. Take advantage of the spring tides to walk along the cliffs and on the broad stretches of uncovered beach. A zoologist who knows the neighbourhood can show you many adaptations to life in sand, in mud, among rocks sheltered or beaten by the waves, beds of seaweed, etc.

A visit to a zoological garden will illustrate the characteristic adaptations due to climate and the geographical distribution of the species. Specimens of the fauna of tropical savanas (antelopes and giraffes), of the deserts (camel), of forest regions (monkeys, hippopotami, parrots) will be seen. Our description of forest life and of the characteristics of animals living on trees, by the waterside, and underground can be verified by looking for the animals mentioned in Chapter XX.

The relation between human and physical geography can be verified during any excursion. The most obvious are the situation of villages in places where a change of slope occurs and where springs rise; the position of various types of crops; and the track followed by roads, railways, canals, etc.

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