which is 21·547. The map of North America so found (fig. 25) shows small portions of country in strictly correct forms; but the areas are slightly too great at the extreme latitudes and too small in the centre. At any part of the map a degree of latitude may be used as the true scale in any direction.

Fig. 25.

The value $h=\frac{1}{3}$, as suggested by Sir John Herschel, is admirably suited for a map of the world. The representation is fan-shaped, with remarkably little distortion (fig. 26).

It follows from what has been said above that the condition that the scale is true at the equator is $hk=a$, which determines k when h is given. The radius of the parallel whose co-latitude is u being ρ, let r be the distance of that parallel from the equator; then, keeping to the condition that the scale is true at the equator,

$$\rho=\frac{a}{h}\tan^h\frac{u}{2},$$

$$r=\frac{a}{h}\left(1-\tan^h\frac{u}{2}\right).$$

When h is very small, the angles between the meridian lines in the representation are very small; and proceeding to the limit, when h is zero the meridians are parallel, that is, the vertex of the cone has removed to infinity. And at the limit when h is zero we have

$$r=a\log_e\cot\frac{u}{2},$$

which is the characteristic equation of

Mercator's Projection.

From the manner in which we have arrived at this projection it is clear that it retains the characteristic property of Gauss's projection,—namely, similarity of representation

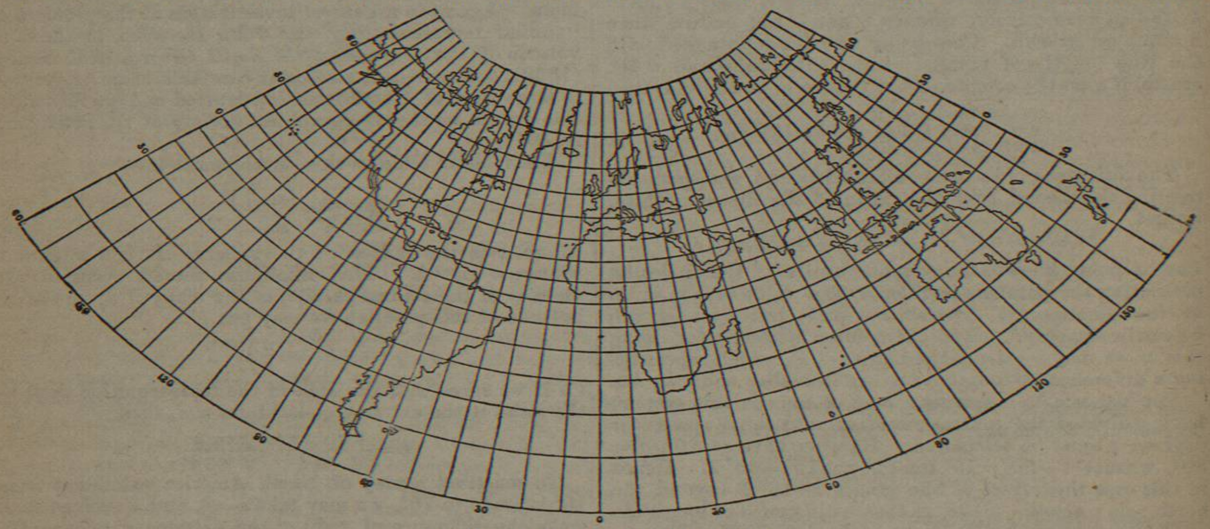

FIG. 26.—Fan-shaped Map of the World.

of small parts of the surface. In Mercator's chart the equator is represented by a straight line, which is crossed at right angles by a system of parallel and equidistant straight lines representing the meridians. The parallels are straight lines parallel to the equator, and the distance of the parallel of latitude ϕ from the equator is, as we have seen above, $r=a\log_e\tan(45°+\frac{1}{2}\phi)$. In the vicinity of the equator, or indeed within 30° of latitude of the equator, the representation is very accurate, but as we proceed northwards or southwards the exaggeration of area becomes larger, and eventually excessive,—the poles being at infinity. This distance of the parallels may be expressed in the form $r=a(\sin\phi+\frac{1}{3}\sin^3\phi+\frac{1}{5}\sin^5\phi+\ldots)$, showing that near the equator r is nearly proportional to the latitude. As a consequence of the similar representation of small parts, a curve drawn on the sphere cutting all meridians at the same angle—the loxodromic curve—is projected into a straight line, and it is this property which renders Mercator's chart so valuable to seamen. For instance: join by a straight line on the chart Land's End and Bermuda, and measure the angle of intersection of this line with the meridian. We get thus the bearing which a ship has to retain during its course between these ports. This is not great-circle sailing, and the ship so navigated does not take the shortest path. The projection of a great circle (being neither a meridian nor the equator) is a curve which cannot be represented by a simple algebraic equation.

If we apply Mercator's system of projection *along a meridian*, as proposed by Lambert, we have the representation of all possible great circles. The diagram (fig. 27) gives the projection. The two vertical bounding lines are the equator—crossed at right angles by the initial meridian passing through one of the poles. From the form of the representations of parallels round the pole it is clear that the distortion up to a distance of 30° or 40° from the initial meridian is not at all great. The representation extends to infinity upwards and downwards, and the left and right half are interchangeable; if interchanged the representation is on a meridian extending from pole to pole.

The meridian Mercator drawn as described in the last paragraph—with the meridians and parallels rather close—

may be made to serve the important purpose of enabling one to trace on the ordinary Mercator's chart the track of a great circle joining any two places, and of indicating at the same time the distance of the two places. For this

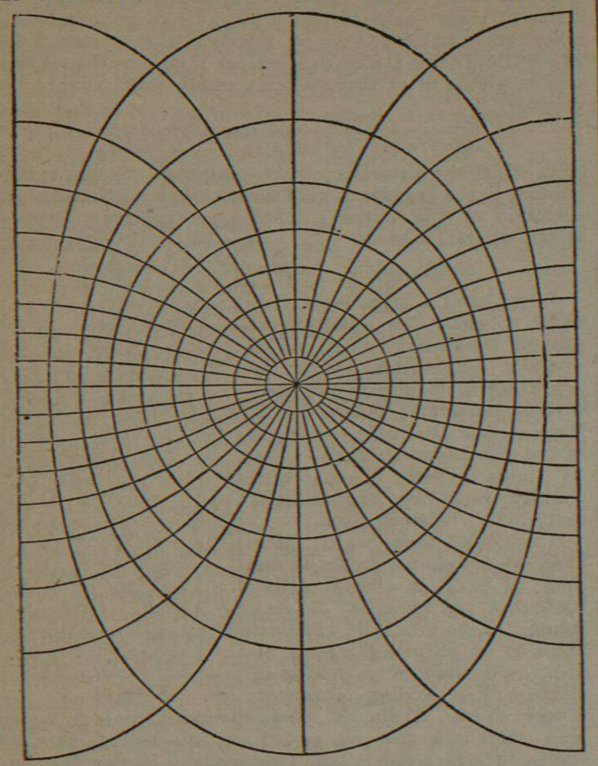

Fig. 27.

purpose the two charts must be on the same scale, one of them being on tracing paper or tracing linen. The transparent chart being placed over the other, the equator in the ordinary chart must coincide with the initial meridian in the meridian Mercator. Retaining this relative position, let the upper chart be moved until the two points (the projection of the great circle joining which is required) on the ordinary Mercator are found to lie on a great circle of the meridian Mercator.

The curvatures of the meridians and parallels in the meridian Mercator are expressed by very simple formulæ. Let x, y be the coordinates, measured from the pole along and perpendicular to the initial meridian, of any point S of the representation,—x corresponding to an arc of the sphere $=x$, and y to an arc η which is on the sphere the distance of S from the initial meridian. Then if x', y' be the centre of curvature of the parallel at S, x'', y'' the centre of curvature of the meridian at S,

$$x'=x-\tan x,\quad x''=x+\frac{1}{\tan x},$$

$$y'=y-\sin\eta,\quad y''=y-\frac{1}{\sin\eta}.$$

The corresponding radii of curvature are $\sin\beta\div\cos x$, where β is the spherical radius of the small circle, and $1\div\sin x\sin\gamma$, where γ is the longitude of the great circle, counted from the initial meridian.

Polyconic Development.

Imagine a hollow globe formed of a mere surface of paper, to be cut by a system of parallel planes along equidistant parallels of latitude; let also one meridian be cut through, from north pole to south pole, 180°. In this state let the whole be opened out into a plane from the meridian exactly opposite to the one cut through, and the previously spherical surface is converted into a number of strips of paper, each of which is part of a circular belt, with the exception of the equator, which will be straight. All points which lay on the parallel whose co-latitude is u now lie on an arc of a circle whose radius is $\tan u$ and length $2\pi\sin u$; moreover, the centres of these arcs lie in the same straight line, which is the central meridian produced. The parallels being now defined, we must define meridians. These may be formed by laying off on each parallel the degrees of longitude according to their true lengths, which is the system adopted in the maps of the United States Coast Survey. Or we may take for meridians that system of lines which cuts the parallels at right angles, forming the rectangular polyconic system.

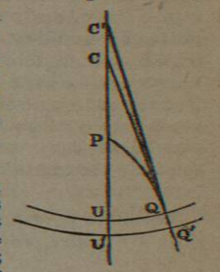

Fig. 28.

In this case, let P (fig. 28) be the north pole, CPU the central meridian, U, U′ points in that meridian whose co-latitudes are u and $u+du$, so that $UU'=du$. Make $PU=u$, $UC=\tan u$, $U'C'=\tan(u+du)$; and with CC′ as centres describe the arcs UQ, U′Q′, which represent the parallels of co-latitude u and $u+du$. Let PQQ′ be part of a meridian curve cutting the parallels at right angles. Join CQ, C′Q′; these being perpendicular to the circles will be tangents to the curve. Let $UCQ=2\phi$, $UC'Q'=2(\phi+d\phi)$, then the small angle CQC′, or the angle between the tangents at QQ′, will $=2d\phi$. Now

$$CC'=C'U'-CU-UU'=\tan(u+du)-\tan u-du=\tan^2u\,du;$$

and in the triangle CC′Q the perpendicular from C on C′Q′ is equal to either side of the equation

$$\tan^2u\,du\sin2\phi=-\tan u\,d\phi.$$

$$-\tan u\,du=\frac{2d\phi}{\sin2\phi},$$

which is the differential equation of the meridian: the integral is $\tan\phi=\omega\cos u$, where ω, a constant, determines a particular meridian curve. The distance of Q from the central meridian, $\tan u\sin2\phi$, is equal to

$$\frac{2\tan u\tan\phi}{1+\tan^2\phi}=\frac{2\omega\sin u}{1+\omega^2\cos^2u}$$

At the equator this becomes simply 2ω. Let any equatorial point whose actual longitude is 2ω be represented by a point on the developed equator at the distance 2ω from the central meridian, then we have the following very simple construction (due to Mr O'Farrell of the Ordnance Survey Office) Let P (fig. 29) be the pole, U any point in the central meridian, QUQ′ the represented parallel whose radius $CU=\tan u$. Draw SUS′ perpendicular to the meridian through U; then to determine the point Q, whose longitude is, say, 3°, lay off US equal to half the true length of the arc of parallel on the sphere, *i.e.*, 1° 30′ to radius $\sin u$, and with the centre S and radius SU describe a circular arc, which will intersect the parallel in the required point Q. For if we suppose 2ω to be the longitude of the required point Q, US is by construction $=\omega\sin u$, and the angle subtended by SU at C is

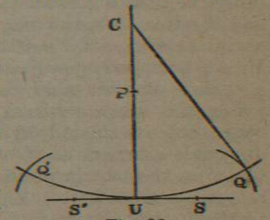

Fig. 29.

$$\tan^{-1}\left(\frac{\omega\sin u}{\tan u}\right)=\tan^{-1}(\omega\cos u)=\phi,$$

and therefore $UCQ=2\phi$, as it should be. The advantages of this method are that with a remarkably simple and convenient mode of construction we have a map in which the parallels and meridians intersect at right angles.

The following table contains the lengths of the radii for describing parallels, and also the lengths of degrees of longitude for every 5° of latitude,—the radius of the sphere being 57·296.

Lat.	Radius for Parallel.	Degree of Longitude.	Lat.	Radius for Parallel.	Degree of Longitude.
0°	∞	1·0000	45°	57·30	·7071
5	654·89	·9962	50	48·08	·6428
10	324·94	·9848	55	40·12	·5736
15	213·83	·9659	60	33·08	·5000
20	157·42	·9397	65	26·72	·4226
25	122·87	·9063	70	20·85	·3420
30	99·24	·8660	75	15·35	·2588
35	81·83	·8191	80	10·10	·1736
40	68·28	·7660	85	5·01	·0872

With regard to the distortion involved in this system of development, consider a small square described on the surface of the sphere, its sides being parallel to and perpendicular to the meridian. Let u and 2ω define its position, and let i be the length of its side. If we differentiate the equation $\tan\phi = \omega\cos u$, u being constant, $\sec^2\phi\, d\phi = \cos u\, d\omega$. But the representation of $2d\omega$ is $2\tan u\, d\phi$, which is equal to $\sin u \cos^2\phi\, d.2\omega$; hence that side of the square which is parallel to the equator is represented by $i\cos^2\phi$. And similarly the meridional side is represented by

$$i\cos^2\phi(1+\omega^2+\omega^2\sin^2 u).$$

Therefore the square is represented by a rectangle whose sides are in the proportion of

$$1 : 1+\omega^2+\omega^2\sin^2 u,$$

and its area is increased in the proportion of

$$1+\omega^2+\omega^2\sin^2 u : (1+\omega^2\cos^2 u)^2.$$

Fig. 30 is a representation on this system of the continents of Europe and Africa, for which it is well suited. For Asia this system would not do, as in the northern latitudes, say along the parallel of 70°, the representation is much cramped.

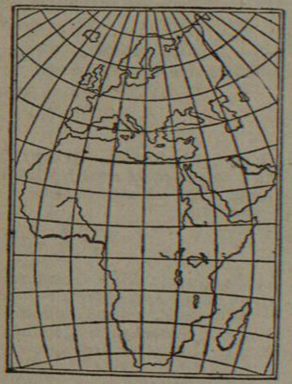

Fig. 30.

With regard to the distortion in the map of Africa as thus constructed, consider a small square in latitude 40° and in 40° longitude east or west of the central meridian, the square being so placed as to be transformed into a rectangle. The sides, originally unity, become 0·95 and 1·13, and the area 1·08, the diagonals intersecting at 90° ± 9° 56′. In the perspective projection a square of unit side occupying the same position, when transformed to a rectangle, has its sides 1·02 and 1·15, its area 1·17, and its diagonals intersect at 90° ± 7° 6′. The latter projection is therefore the best in point of "similarity," but the former represents areas best This applies, however, only to a particular part of the map; along the equator towards 30° or 40° longitude, the polyconic is certainly inferior, while along the meridian it is better than the perspective—except, of course, near the centre. Upon the whole, the more even distribution of distortion gives the advantage to the perspective system. The system of lines ordinarily used for the map of Africa is objectionable, and has scarcely the excuse of facility of construction, since the perspective coordinates given above are so easily computed.

Ordnance Survey Maps.

The method of development used in the Ordnance Survey maps of England on the scale of one inch to a mile, as also in the county maps of England, Scotland, and Ireland, on the 6-inch scale is this. A central meridian having been selected. let a perpendicular arc be drawn from any trigonometrical station p to the meridian, meeting it in q. S being a point of reference selected in the central meridian, make $Sq=y$, $pq=x$. Then in the development, a straight line drawn to represent the central meridian is the axis of y, and a line at right angles to this is the axis of x. The point whose coordinates are $x=pq$, $y=Sq$ is the representation of p. Supposing the earth spherical, if ϕ, ω be the latitude and longitude of p, then, ω being small, that is, only a few degrees,

$$dx = -x\tan\phi\, d\phi + \cos\phi(1-\tfrac{1}{2}x^2\tan^2\phi)d\omega,$$
$$dy = (1+\tfrac{1}{2}x^2-\tfrac{1}{2}x^2\tan^2\phi)d\phi + x\sin\phi\, d\omega,$$

from which the distortion can be computed. It principally consists in the exaggeration of the scale in a north-and-south direction at the extreme longitudes, where $\sigma = \sec x$.

Contours.

In maps of a large scale, it is usual to show the relief of the ground by contour lines, which are the intersections with the actual surface of a system of equidistant horizontal planes. Contours indicate not only the height of the ground but its slope. Fig. 31 shows a piece of contoured country, including two summits and a "col" between them.

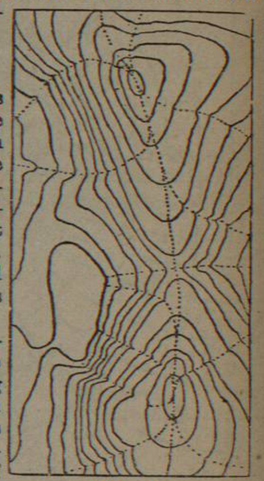

Fig. 31.

The dotted lines, which, however, are not shown in maps, are lines of greatest slope, cutting contours at right angles. At each summit, supposing the contours there to be ellipses (Dupin's indicatrices), there is an infinity of steepest lines having a common tangent there. At the col, where the indicatrix is an hyperbola, there are two steepest lines intersecting at right angles, of which one is the "water-shed" joining the summits.

(A. R. C.)

III. Physical Geography.

This term in its ordinary acceptation means a description of the physical features of the earth. It includes an account of the phenomena of the atmosphere; of the composition, distribution, and movements of the sea; of the forms of the land, with its water circulation, earthquakes, and volcanoes; of the distribution of plant and animal life. Its object, however, is not to present a mere bald enumeration of facts, but to group the facts together in such a way as to bring before the mind a luminous picture of the whole structure and working of the earth as a habitable planet. Physical geography is not so much a science or branch of science as a collection of the data ascertained, and probable conclusions arrived at, by different sciences, in so far as these bear upon its own subject. Accordingly, it culls from all departments of inquiry whatever helps to give additional distinctness and vividness to that broad conception of the daily economy of the globe which it is its aim to form and develop.

So vast a subject, if treated in its entirety, would demand a very large allotment of space for its adequate discussion. Some of its branches have, during the last few years, received so much development that in the present edition of this work it has been considered more expedient to make them the subject of special articles; and here, therefore, to avoid the repetition which a general article on physical geography would involve, there will be given, instead of a formal essay, a mere outline or synopsis of the branches of knowledge embraced in the subject, with references to the other parts of the work where detailed

information may be looked for. In the first three parts of the article Geology, a large section of what is usually included under physical geography will be found.

1. *The Earth in its Cosmical Relations.*—From astronomy we learn the shape and size of the earth, its motions of rotation round its axis and of revolution in an elliptical orbit round the sun, the origin of day and night, and of the seasons. Speculating on the original condition of the whole solar system, we may regard it as having been in the condition of a nebula, gradually contracting, condensing, and leaving behind successive rings, which on disruption and reaggregation formed planets. Hence the primitive condition of our globe as a separate mass must have been gaseous or fluid. Since that time the earth has been cooling and contracting, but still retains a high residual temperature in its interior. This original condition, and the internal heat of the earth, must be constantly kept in view as an explanation of many of the features of its outer surface. See Geology, part i.; Astronomy, chapter i.; Geography (Mathematical); Geodesy.

2. *The Atmosphere or Gaseous Envelope of the Earth.*—The solid planet is covered by two envelopes, one of gas which completely surrounds it, and one of water, which occupies about three-fourths of its surface. In studying the atmosphere we have to consider its height, its composition, its temperature, its moisture, and its pressure (see Atmosphere, Meteorology). Its height must be at least 40 or 50 miles. This deep gaseous ocean consists of a mixture of the two gases, oxygen (21 parts by weight) and nitrogen (79 parts), with a minute proportion of carbonic acid (·004) and of aqueous vapour. The physical geographer takes note of the manifold importance of oxygen, not only in supporting animal life, but in the general oxidation of the earth's outer crust. He recognizes the atmospheric carbonic acid as the source of the carbon built up into the structure of plants He cannot contemplate without ever-increasing wonder and delight the coming and going of the water-vapour in the air, as it rises incessantly from every sea and land, and after condensation into visible form courses over the land as rain, brooks, rivers, and glaciers (see Geology, part iii.). The consideration of the temperature of the atmosphere elicits the facts that temperature falls as we rise above the sea-level, and as we recede from the equator to the poles, and that it is profoundly affected by the relative positions of sea and land. The want of strict dependence upon latitude in this distribution of temperature is strikingly brought out by the contrast between the mean temperature of Labrador and Ireland on the same parallels (see Climate, Isotherms). In dealing with the moisture of the air we have to consider the phenomena of evaporation and condensation, the formation of dew, clouds, rain, snow, and hail, the distribution of rain, the position of the snow-line, the occurrence of deserts, &c. (see Meteorology). The study of the pressure of the atmosphere, which appears to vary with variations in temperature and amount of vapour, brings before us the cause of the constant aerial movements. The law has now been well established that air always flows out from tracts where the barometric pressure is high into those where it is low. A knowledge of the distribution of pressure over the globe furnishes the key to the great movements of the atmospheric circulation. The trade winds, for example, blow constantly from a belt of high pressure towards the equator, where the pressure remains low. Periodic winds, like the monsoons and land and sea breezes, shift with the changes in atmospheric pressure. Thus Asia during winter is a vast region of high pressure; the winds round its margin therefore flow out towards the sea. In summer, on the other hand, it becomes a region of low pressure, and the winds consequently blow inland from the sea. Sudden and violent atmospheric movements, such as tempests and hurricanes, are illustrations of the same law, the force of the wind being always proportional to the shortness of the space between great extremes of pressure (see Atmosphere).

3. *The Ocean or Water-Envelope of the Earth*, from the point of view of physical geography, presents for consideration the form of the basins in which it is contained, the shape and nature of their bottom, their submarine ridges and islands, the density and composition of the water, the distribution of marine temperature, the ice of the sea, and the movements of the ocean due to cosmical causes as in the tides, to the effects of winds as in surface drifts, currents, and waves, and to differences of temperature. The largest additions in recent years to our knowledge of the earth have been made in the ocean, notably by the different expeditions and cruises equipped for the purpose by the British Government. The climates of the sea have been systematically determined, and the extraordinary fact has been brought to light that the great mass of the ocean water is cold, or below 40° Fahr. Even in the equatorial parts of the Atlantic and Pacific Oceans (*q.v.*), though the upper layers of water partake in the heat of the intertropical latitudes, a temperature of 40° is found within 300 fathoms of the surface, while at the bottom, at depths of 2500 or 3000 fathoms, the temperature (32°·4 to 33° Fahr.) is very little above that of the freezing-point of fresh water. It has been proved that the bottom temperature of every ocean in free communication with the poles has a temperature little different from that of the water in polar latitudes. Between Scotland and the Faroe Islands a sounding was obtained giving even a temperature of 29°·6, or 2·4 degrees below the freezing-point of fresh water, and very little above that of salt water. These observations warrant the conclusion that a vast system of circulation takes place in the ocean. The cold heavy polar water creeps slowly towards the equator under the upper lighter water, which moves away towards the poles.

4. *The Land.*—We have to consider the distribution of the land over the face of the globe, the grouping of the continents, the forms and trend of the great terrestrial ridges, the relation of coast-line to superficial area, the contours of the land, as mountains, table-lands, valleys, and plains, the relation of the continents to each other as regards general mass (see Geology, part ii.; Africa, America, Asia, Europe). Over this framework of land there is a ceaseless circulation of water. The vapour raised by the sun's heat from every ocean and surface of water on the land, after being condensed into clouds and rain, falls in large measure upon the land, and courses over its surface from mountain to shore in brooks and rivers, which again have their own distinguishing phenomena, such as the formation of terraces, deltas, &c. Part of the water performs an underground circulation and returns to the surface in springs. Another portion falls as snow upon the mountains and descends into valleys in the form of glaciers. In this ceaseless flow of water from the summits to the sea we must recognize one of the great agencies by which the present contour of the land has been moulded (see Geology, part iii., section ii.).

The physical geographer collects, moreover, data which show the reaction of the earth's interior upon its surface,—proofs from bores and mines of a progressive increase of temperature downwards, the evidence of hot springs, and of earthquakes and volcanoes. He finds proofs of oscillations in the level of the land, some regions having been raised and others depressed within the times of human history. From the geologist he learns that such instability has characterized the outer crust of the planet from very ancient times, and that indeed it is to the results of terrestrial movements that we owe the existence of mountain ranges and even the dry land itself (see Geology, part iii., section i., and part vii.). He perceives that the present area of land on the earth's surface is the result of the balance of two antagonistic processes—the destruction caused by superficial agents on every portion of land exposed to their influence, and the periodic elevation, by subterranean action, of the land so wasted, or of new land from beneath the sea.

5. *Distribution of Animal and Vegetable Life.*—It is usual to include in treatises on physical geography an outline of the distribution of plants and animals, with an account of the great regions or provinces into which zoologists and botanists have divided the continents. The question naturally arises why the distribution should be as it is. Two answers obviously suggest themselves—1st, climate, and 2d, the power possessed by plants and animals of diffusing themselves. Yet climate only explains a part of this problem, and it is evident that migration cannot possibly account for the diffusion of innumerable organisms. There is a large residuum of unexplained phenomena on which much light is thrown by geological inquiry. Thus, for example, the presence of living Arctic forms of vegetation on the mountains of central Europe can be connected with the occurrence of the remains of Arctic animals in the superficial deposits of that region, and with other facts which make it clear that at no very distant date an Arctic climate prevailed over most of Europe, that at that time a northern vegetation spread southwards and covered the plains and heights of Europe even as far south as the Alps and Pyrenees, and that as the climate gradually ameliorated the northern vegetation was extirpated from the low grounds by the advance of plants better suited to the milder temperature, but continued to maintain its ground amid the congenial frosts and snows of the mountains, where to this day it still flourishes (see DISTRIBUTION). (A. GE.)

GEOLOGY

GEOLOGY is the science which investigates the history of the earth. Its object is to trace the progress of our planet from the earliest beginnings of its separate existence, through its various stages of growth, down to the present condition of things. It seeks to determine the manner in which the evolution of the earth's great surface features has been effected. It unravels the complicated processes by which each continent has been built up. It follows, even into detail, the varied sculpture of mountain and valley, crag and ravine. Nor does it confine itself merely to changes in the inorganic world. Geology shows that the present races of plants and animals are the descendants of other and very different races which once peopled the earth. It teaches that there has been a progress of the inhabitants, as well as one of the globe on which they dwelt; that each successive period in the earth's history, since the introduction of living things, has been marked by characteristic types of the animal and vegetable kingdoms; and that, however imperfectly they have been preserved or may be deciphered, materials exist for a history of life upon the planet. The geographical distribution of existing faunas and floras is often made clear and intelligible by geological evidence; and in the same way light is thrown upon some of the remoter phases in the history of man himself. A subject so comprehensive as this must require a wide and varied basis of evidence. It is one of the characteristics of geology to gather evidence from sources which at first sight seem far removed from its scope, and to seek aid from almost every other leading branch of science. Thus, in dealing with the earliest conditions of the planet, the geologist must fully avail himself of the labours of the astronomer. Whatever is ascertainable by telescope, spectroscope, or chemical analysis, regarding the constitution of other heavenly bodies, has a geological bearing. The experiments of the physicist, undertaken to determine conditions of matter and of energy, may sometimes be taken as the starting-points of geological investigation. The work of the chemical laboratory forms the foundation of a vast and increasing mass of geological inquiry. To the botanist, the zoologist, even to the unscientific, if observant, traveller by land or sea, the geologist turns for information and assistance.

But while thus culling freely from the dominions of other sciences, geology claims as its peculiar territory the rocky framework of the globe. In the materials composing that framework, their composition and arrangement, the processes of their formation, the changes which they have undergone, and the terrestrial revolutions to which they bear witness, lie the main data of geological history. It is the task of the geologist to group these elements in such a way that they may be made to yield up their evidence as to the march of events in the evolution of the planet. He finds that they have in large measure arranged themselves in chronological sequence,—the oldest lying at the bottom and the newest at the top. Relics of an ancient sea-floor are overlaid by traces of a vanished land-surface; these are in turn covered by the deposits of a former lake, above which once more appear proofs of the return of the sea. Among these rocky records lie the lavas and ashes of long-extinct volcanoes. The ripple left upon the shore, the cracks formed by the sun's heat upon the muddy bottom of a dried-up pool, the very imprint of the drops of a passing rain-shower, have all been accurately preserved, and yield their evidence as to geographical conditions widely different from those which exist where such markings are now found.

But it is mainly by the remains of plants and animals imbedded in the rocks that the geologist is guided in unravelling the chronological succession of geological changes. He has found that a certain order of appearance characterizes these organic remains, that each great group of rocks is marked by its own special types of life, and that these types can be recognized, and the rocks in which they occur can be correlated even in distant countries, and where no other means of comparison would be possible. At one moment he has to deal with the bones of some large mammal scattered through a deposit of superficial gravel, at another time with the minute foraminifers and ostracods of an upraised sea-bottom. Corals and crinoids crowded and crushed into a massive limestone where they lived and died, ferns and terrestrial plants matted together into a bed of coal where they originally grew, the scattered shells of a submarine sand-bank, the snails and lizards which lived and died within a hollow tree, the insects which have been imprisoned within the exuding resin of old forests, the footprints of birds and quadrupeds, the trails of worms left upon former shores—these, and innumerable other pieces of evidence, enable the geologist to realize in some measure what the faunas and floras of successive periods have been, and what geographical changes the site of every land has undergone.

It is evident that to deal successfully with these varied materials, a considerable acquaintance with different branches of science is needful. Especially necessary is a tolerably wide knowledge of the processes now at work in changing the surface of the earth, and of at least those forms of plant and animal life whose remains are apt to be preserved in geological deposits, or which in their structure

and habitat enable us to realize what their forerunners were. It has often been insisted upon that the present is the key to the past; and in a wide sense this assertion is eminently true. Only in proportion as we understand the present, where everything is open on all sides to the fullest investigation, can we expect to decipher the past, where so much is obscure, imperfectly preserved, or not preserved at all. A study of the existing economy of nature ought thus to be the foundation of the geologist's training.

While, however, the present condition of things is thus employed, we must obviously be on our guard against the danger of unconsciously assuming that the phase of nature's operations which we now witness has been the same in all past time, that geological changes have taken place in former ages in the manner and on the scale which we behold to-day, and that at the present time all the great geological processes, which have produced changes in the past eras of the earth's history, are still existent and active. Of course we may assume this uniformity of action, and use the assumption as a working hypothesis. But it ought not to be allowed any firmer footing, nor on any account be suffered to blind us to the obvious truth that the few centuries wherein man has been observing nature form much too brief an interval, by which to measure the intensity of geological action in all past time. For aught we can tell the present is an era of quietude and slow change, compared with some of the eras which have preceded it. Nor can we be sure that, when we have explored every geological process now in progress, we have exhausted all the causes of change which, even in comparatively recent times, have been at work.

In dealing with the Geological Record, as the accessible solid part of the globe is called, we cannot too vividly realize that at the best it forms but an imperfect chronicle. Geological history cannot be compiled from a full and continuous series of documents. From the very nature of its origin the record is necessarily fragmentary, and it has been further mutilated and obscured by the revolutions of successive ages. And even where the chronicle of events is continuous, it is of very unequal value in different places. In one case, for example, it may present us with an unbroken succession of deposits many thousands of feet in thickness, from which, however, only a few meagre facts as to geological history can be gleaned. In another instance it brings before us, within the compass of a few yards, the evidence of a most varied and complicated series of changes in physical geography, as well as an abundant and interesting suite of organic remains. These and other characteristics of the geological record will become more apparent and intelligible as we proceed in the study of the science.

In the systematic treatment of the subject the following arrangement will here be followed:—

1. *The Cosmical Aspects of Geology.*—Under this head we may consider the evidence supplied by astronomy and physics regarding the form and motions of the earth, the composition of the sun and planets, and the probable history of the solar system.

2. *Geognosy,—an Inquiry into the Materials of the Earth's Substance.*—In this division we deal with the parts of the earth, its envelopes of air and water, its solid crust, and the probable condition of its interior. Especially, we have to study the more important minerals of the crust, and the chief rocks of which that crust is built up. In this way we lay a foundation of knowledge regarding the nature of the materials constituting the mass of the globe, and may next proceed to investigate the processes by which these materials are produced and altered.

3. *Dynamical Geology* embraces an investigation of the various agencies whereby the rocks of the earth's crust are formed and metamorphosed, and by which changes are effected upon the distribution of sea and land, and upon the forms of terrestrial surfaces. Such an inquiry necessitates a careful study of the existing geological economy of nature, and forms a fitting introduction to the investigation of the geological changes of former periods. This and the previous section include most of what is embraced under Physical Geography; and for the reason stated under that heading the subject will here be treated more in detail than is usual in geological treatises.

4. *Structural Geology, or the Architecture of the Earth.*—We now advance to consider how the various materials composing the crust of the earth have been arranged. We learn that some have been formed in beds or strata on the floor of the sea, that others have been built up by the slow aggregation of organic forms, that others have been poured out in a molten condition or in showers of loose dust from subterranean sources. We further find that, though originally laid down in almost horizontal beds, the rocks have subsequently been crumpled, contorted, and dislocated, that they have been incessantly worn down, and have often been depressed and buried beneath later accumulations.

5. *Palæontological Geology.*—This branch of the subject deals with the organic forms which are found preserved in the crust of the earth. It includes such questions as the relations between extinct and living types, the laws which appear to have governed the distribution of life in time and in space, the relative importance of different genera of animals in geological inquiry, the nature and use of the evidence from organic remains regarding former conditions of physical geography. This subject will be more properly discussed in the article PALÆONTOLOGY, and will therefore be only cursorily treated in the following pages.

6. *Stratigraphical Geology.*—This section might be called geological history. It works out the chronological succession of the great formations of the earth's crust, and endeavours to trace the sequence of events of which they contain the record. More particularly it determines the order of succession of the various plants and animals which in past time have peopled the earth, and thus ascertains what has been the grand march of life upon the planet.

7. *Physiographical Geology*, starting from the basis of fact laid down by stratigraphical geology regarding former geographical changes, embraces an inquiry into the origin and history of the features of the earth's surface—continental ridges and ocean basins, plains, valleys, and mountains. It explains the causes on which local differences of scenery depend, and shows under what very different circumstances, and at what widely separated intervals, the hills and mountains, even of a single country, have been produced.

PART I.—COSMICAL ASPECTS OF GEOLOGY.

Before geology had attained to the position of an inductive science, it was customary to begin all investigations into the history of the earth by propounding or adopting some more or less fanciful hypothesis in explanation of the origin of our planet, or even of the universe. Such preliminary notions were looked upon as essential to a right understanding of the manner in which the materials of the globe had been put together. To the illustrious James Hutton (1785) geologists are indebted for strenuously upholding the doctrine that it is no part of the province of geology to discuss the origin of things. He taught them that in the materials from which geological evidence is to be compiled there can be found "no traces of a beginning, no prospect of an end." In England, mainly to the influence of the school which he founded, and to the subsequent rise of the Geological Society (1807), which resolved to collect facts instead of fighting over hypotheses, is due